



NRC Publications Archive Archives des publications du CNRC

Moisture transport through glass-fibre insulation in the presence of a thermal gradient

Kumaran, M. K.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Journal of Thermal Insulation, 10, Apr, pp. 243-255, 1987-04

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=e653517f-9488-4d30-8282-bd280b963a62>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=e653517f-9488-4d30-8282-bd280b963a62>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.



National Research
Council Canada

Conseil national de
recherches Canada

Canada

Ser
THL
N21d
no. 14877
c. 2
BLDG

**National Research
Council Canada**

Institute for
Research in
Construction

**Conseil national
de recherches Canada**

Institut de
recherche en
construction

Moisture Transport through Glass-Fibre Insulation in the Presence of a Thermal Gradient

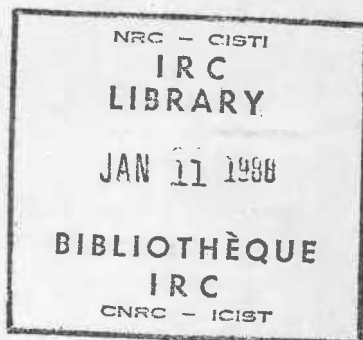
by M.K. Kumaran

ANALYZED

Reprinted from
Journal of Thermal Insulation
Vol. 10, April 1987
p. 243-255
(IRC Paper No. 1487)

Price \$4.00

NRCC 28451



Canada

7773703

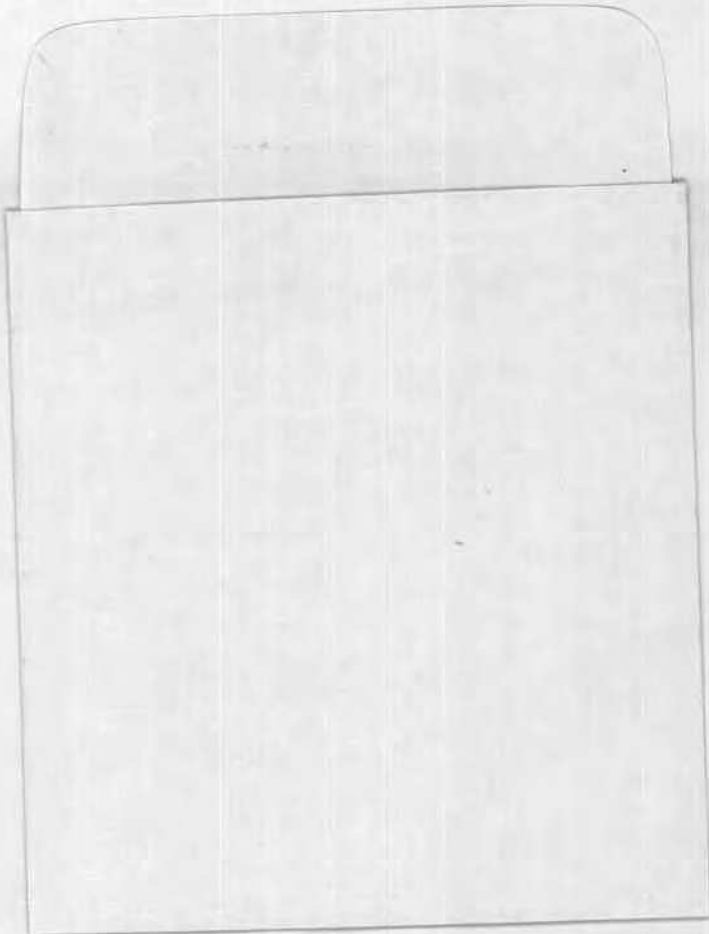
RÉSUMÉ

On a utilisé un thermofluxmètre pour mesurer le flux thermique dans une éprouvette humide d'isolant en fibre de verre à faible densité. Les résultats ont révélé que la pénétration de l'humidité dans l'éprouvette se fait essentiellement par diffusion de vapeur d'eau. On propose un modèle thermodynamique représentant ce processus de pénétration. Ce modèle permet d'obtenir deux coefficients de pénétration de l'humidité qui sont caractéristiques de l'éprouvette.

CISTI/ICIST



3 1809 00210 6729



Moisture Transport Through Glass-Fibre Insulation in the Presence of a Thermal Gradient

M. K. KUMARAN

Building Services Section

Institute for Research in Construction

National Research Council of Canada

Ottawa, Ontario, Canada, K1A 0R6

ABSTRACT

A heat flow meter apparatus is used to monitor the heat flux across a moist specimen of a low density glass-fibre insulation. The results indicate that moisture is transported through the specimen predominately by vapour diffusion. A thermodynamic model is suggested to represent the transport process. This model leads to two moisture transport coefficients characteristic of the specimen.

KEY WORDS

Thermal insulation, moisture, heat flux, vapour pressure, enthalpy, enthalpy of vaporization, diffusion, thermal diffusion.

INTRODUCTION

THEORETICAL MODELS FOR the calculation of heat transfer through a moist building material require accurate knowledge of the heat and moisture transport characteristics of the material. A survey of literature reveals a current lack of this knowledge. This paper aims at a quantitative understanding of the moisture transport characteristics of one of the most widely used thermal insulations, namely glass-fibre. For this purpose, a set of experiments were carried out systematically on a specimen of low density glass-fibre insulation. Although some of these experiments are similar to those reported by Langlais [1], the experimental results from the present in-

vestigation are used to calculate two moisture transport coefficients, which are characteristic of the specimen. These calculations use equations from classical thermodynamics.

EXPERIMENTAL METHODS AND RESULTS

A sample of low density glass-fibre insulation with a bulk density of $17 \text{ kg}\cdot\text{m}^{-3}$ that had been exposed to laboratory conditions for two to three years was chosen for the experiments. A specimen was prepared from this sample having an area of $58 \times 58 \text{ cm}$ and an average thickness of 8.55 cm . The initial mass of the specimen was 493 g . This specimen was dried in an oven at 378 K for approximately 100 h . This resulted in a specimen mass loss of 5 g , which is attributed to the moisture adsorbed during its exposure to laboratory conditions. Six different sets of experiments were done on the specimen. The principal measurement was that of heat flux through the specimen as a function of time for selected pairs of hot and cold temperatures on the surfaces. This was done in a horizontal "24 inch heat flow meter (HFM) apparatus" [2] with a metering area of $30.5 \times 30.5 \text{ cm}$. The direction of the heat flux was always upwards. Heat fluxes were recorded at both surfaces of the specimen. The six different sets of experiments conducted are summarized below:

Experiment No. 1

The dry specimen was sealed in a polyethylene bag and placed in the HFM apparatus with the hot surface temperature at $(312.5 \pm 0.1) \text{ K}$ and the cold

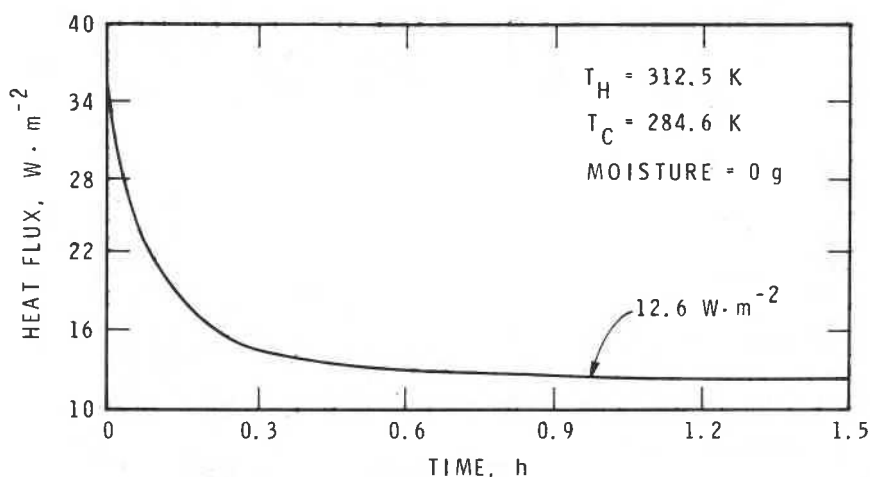


FIGURE 1(a). Heat flux through specimen as a function of time, Experiment No. 1.

surface temperature at (284.6 ± 0.1) K. The history of the mean heat flux as monitored in 2 min intervals is shown in Figure 1(a). The specimen attained the steady state in 45 min and the steady state heat flux was (12.6 ± 0.2) $\text{W}\cdot\text{m}^{-2}$.

Experiment No. 2

Next the specimen was removed from the polyethylene bag, placed in a plexiglass chamber and exposed to a stream of moist air with an RH of 75% at 296 K for 24 h, and then weighed. The increase in mass was 6 g. It was immediately sealed in the polyethylene bag and placed in the HFM apparatus. The surface temperatures were the same as in experiment no. 1. The specimen again attained the steady state in 45 min. The heat flux monitored was identical to that shown in Figure 1(a). The steady state heat flux was once again (12.6 ± 0.2) $\text{W}\cdot\text{m}^{-2}$.

Experiment No. 3

The specimen was once again removed from the polyethylene bag and exposed to an air stream of RH 90% at 296 K for 24 h. It gained only 1 g of moisture at this stage. An increase of the RH to approximately 93% had no noticeable effect on the adsorption. So in order to introduce more moisture, the specimen was laid flat and at each of 25 evenly distributed points 2 cm^3 of water was injected into the specimen with a hypodermic syringe. The total moisture content was thus increased to 57 g. It was then sealed in the bag and placed in the HFM apparatus with the surface on which the water was injected closer to the hot surface. The heat flux was monitored for 30 h

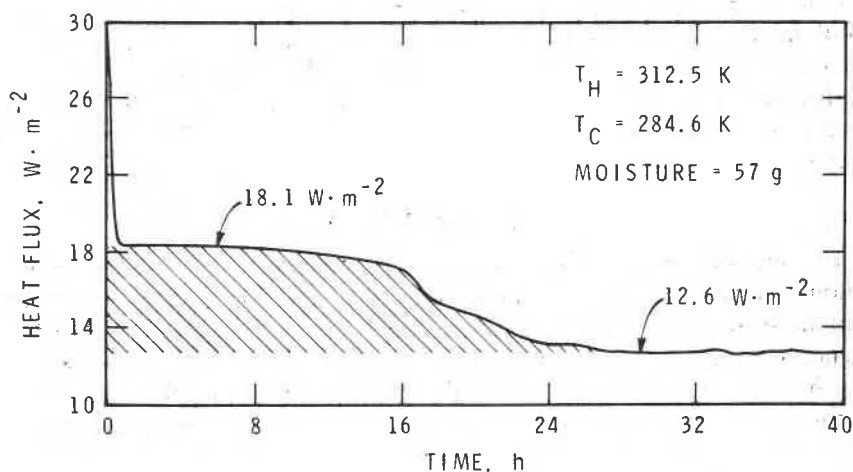


FIGURE 1(b). Heat flux through specimen as a function of time, Experiment No. 3.

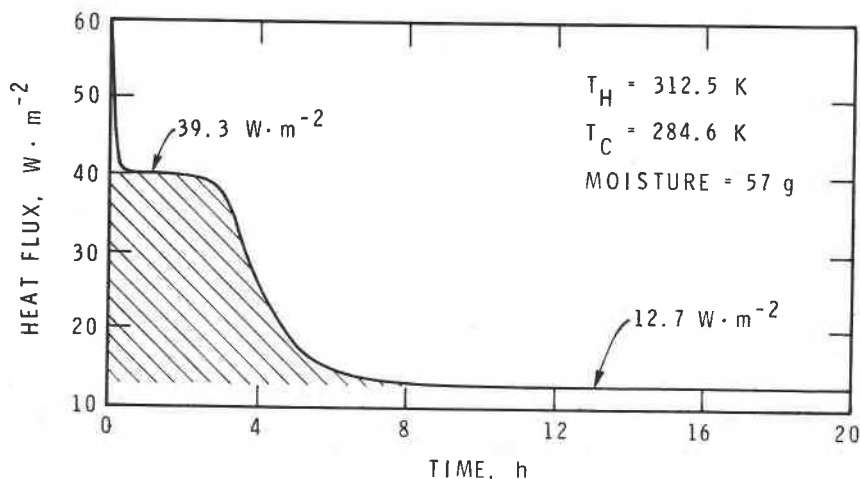


FIGURE 1(c). Heat flux through specimen as a function of time, Experiment No. 4.

for the same pair of surface temperatures as in experiment no. 1. The history of the mean heat flux is shown in Figure 1(b). Within one hour, the specimen attained an initial steady state, which lasted for approximately 14 h. Then it moved on to the final steady state. The heat flux for the initial steady state was $(18.1 \pm 0.2) \text{ W}\cdot\text{m}^{-2}$ and the final value was once again $(12.6 \pm 0.2) \text{ W}\cdot\text{m}^{-2}$.

Experiment No. 4

The specimen from the final steady state of experiment no. 3 was turned upside down in the HFM apparatus and the heat flux once again monitored until the steady state was reached. The history of this is shown in Figure 1(c). Again the system went through a well defined initial steady state but with a higher heat flux of $(39.3 \pm 0.4) \text{ W}\cdot\text{m}^{-2}$, which lasted for about 3 h. The final steady state was again characterized by a constant heat flux of $(12.7 \pm 0.2) \text{ W}\cdot\text{m}^{-2}$.

Experiment No. 5

The specimen was removed from the bag once again and an additional amount of water was injected at the colder surface of the specimen. The total amount of water was thus increased to 91 g. It was put back in the polyethylene bag and placed in the HFM apparatus with the surface on which water was injected closer to the hot plate. The surface temperatures were the same as those in the previous experiments. The heat flux was recorded as a function of time and is shown in Figure 1(d). The specimen went through an initial steady state as in experiment no. 4 and then through an intermediate

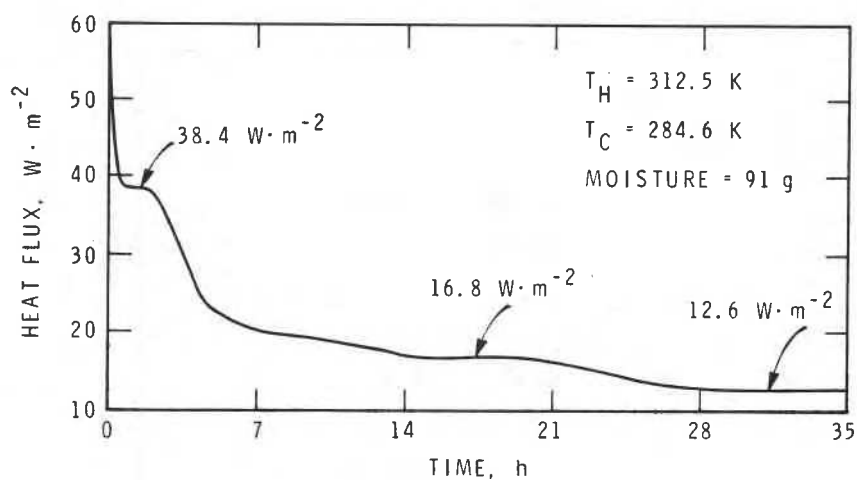


FIGURE 1(d). Heat flux through specimen as a function of time, Experiment No. 5, injected side up.

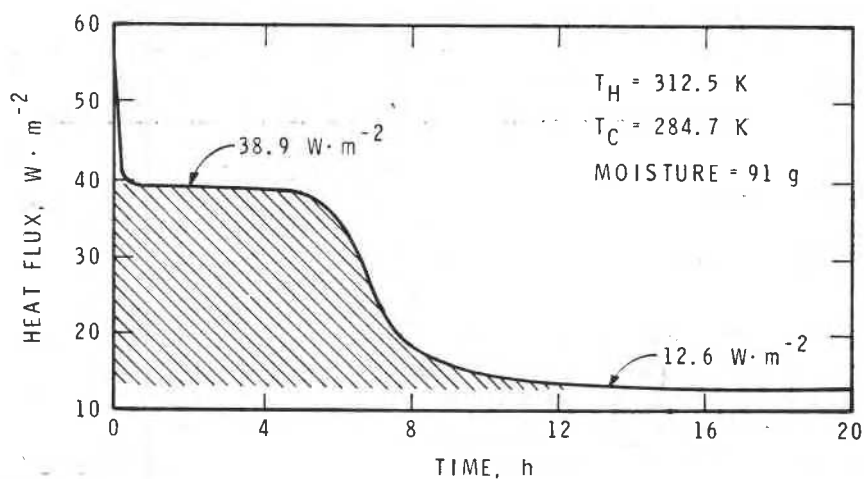


FIGURE 1(e). Heat flux through specimen as a function of time, Experiment No. 6, injected side down.

stage which was not well defined, as seen from Figure 1(d); after 30 h it attained the final steady state with the heat flux equal to $(12.7 \pm 0.2) \text{ W}\cdot\text{m}^{-2}$.

At this stage the sample was turned upside down in the HFM apparatus and the heat flux monitored as shown in Figure 1(e). The system went through a very well defined initial steady state as in experiment no. 4 with a heat flux of $(38.9 \pm 0.4) \text{ W}\cdot\text{m}^{-2}$, which lasted for approximately 5.5 h. The final steady state was once again $(12.6 \pm 0.2) \text{ W}\cdot\text{m}^{-2}$.

Experiment No. 6

In this experiment the heat flux was monitored for three different pairs of surface temperatures, the moisture content in the specimen being the same as in experiment no. 5. The aim was to examine the effect of different temperature and vapour pressure gradients on the initial and final steady states. In all three cases the heat flux indicated a well defined intermediate steady state, as shown in Figure 1(f). The results of these measurements are summarized in Table 1.

DISCUSSION

Though these experiments were not aimed at the study of adsorption characteristics of glass-fibre insulations, they throw some light on these properties. The specimen was exposed to the laboratory conditions (say 294 K and 30 to 50% RH) for a long time and the amount of moisture adsorbed by it was very small—approximately 5 g for 487 g of insulation. Exposure of the material to streams of moist air of up to 93% RH resulted only in an

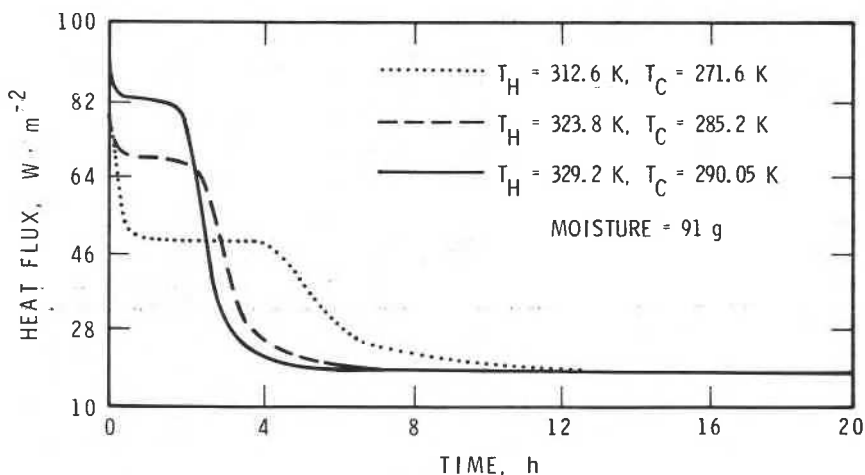


FIGURE 1(f). Heat flux through specimen as a function of time, Experiment No. 6, 3 pairs of surface temperatures.

Table 1. Experimental data on hot surface temperature (T_H), cold surface temperature (T_C), heat flux (q_i) at the initial steady state, heat flux at the final steady state (q_f), the equilibrium vapour pressures P_H and P_C at T_H and T_C and the approximate duration (t_s) of the moisture transport*: n is the mass flux calculated using Equation (2).

T_H (K)	T_C (K)	Q_i ($W \cdot m^{-2}$)	Q_f ($W \cdot m^{-2}$)	P_H (Pa)	P_C (Pa)	t_s (h)	n ($g \cdot m^{-2} \cdot s^{-1}$)
312.5	284.7	38.9	12.6	7105	1357	8.0	0.01027
312.6	271.6	48.0	18.1	7143	543	6.5	0.01135
323.8	285.2	67.5	18.1	12706	1402	4.0	0.01904
329.2	290.05	81.2	18.9	16505	1925	3.2	0.02410

*The time corresponding to the mid-point of the transient process that links the initial and final steady states is considered here as the approximate duration of the moisture transport.

insignificant amount of moisture being adsorbed; experiments 1 and 2 show that this adsorption has negligible effect on the heat transfer characteristics of the material.

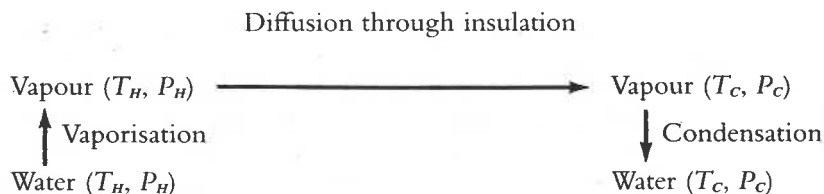
All the experiments show beyond doubt that in the presence of the thermal gradient, moisture is transferred from the hot surface and deposited at the cold surface. In the process represented by Figure 1(b), water is already midway between the hot and cold surfaces because of the manner in which it was introduced in the specimen. The amount of moisture present in this case is identical to that involved in the process represented by Figure 1(c). Both these processes are characterized by an initial steady state but the heat flux at the initial steady state in the latter case is higher ($39.3 W \cdot m^{-2}$) than that in the former ($18.1 W \cdot m^{-2}$). This is simply because in the latter case, moisture has to traverse a larger distance, the full thickness (and hence a larger temperature gradient) of the specimen. At the same time the energy involved in these moisture transfers is identical, as is estimated from the shaded areas in Figures 1(b) and 1(c); in each case this energy is $370 kJ \cdot m^{-2}$. Thus, apparently, the extra energy involved depends only on the amount of moisture and not on the initial region of its occurrence in the specimen. Once the moisture is transferred completely to the colder surface, the material behaves identically to the dry material and moisture no longer contributes to the heat transfer through the insulation.

In the process represented by Figure 1(d), water is initially present in two different regions and the total moisture transfer is achieved through two different intermediate stages; the first of these is similar to that in Figure 1(c) and represents the transfer of moisture closer to the hot surface. The other one represents the transfer of the moisture introduced by injection.

In the process represented by Figure 1(e), which involves the same amount of moisture as in Figure 1(d), the total transfer is achieved in a single stage.

This is identical to that in Figure 1(c) except that the initial steady state is longer (about $5\frac{1}{2}$ hr) in comparison with the 3 h in Figure 1(c). This is simply because more water is to be transferred in this process. The total energy involved in this process is $640 \text{ kJ}\cdot\text{m}^{-2}$, in comparison with $370 \text{ kJ}\cdot\text{m}^{-2}$ in Figure 1(c); the total amount of moisture involved here is 91 g, in comparison with 57 g in Figure 1(c). To a first approximation, the total energy involved in the moisture transfer is directly proportional to the amount of water transferred.

All the three processes represented by Figure 1(f) are identical, except for the hot and cold surface temperatures. The most important feature of these processes is that, during the initial steady state, moisture is transferred from the hot surface to the cold surface at a steady rate. This steady rate is maintained as long as both surfaces contain liquid water. From the theory of irreversible processes, the actual rate at which the transfer occurs should depend on the difference in temperature and on the difference in the chemical potential (Gibb's free energy) of water at the two states. For all these studies the temperatures chosen are appreciably lower than the normal boiling temperature of water and it may be hypothesized that the chemical potential can be adequately represented by the vapour pressure of water at the surface temperature. This hypothesis will be particularly valid when the vapour pressure is significantly lower than atmospheric pressure. The initial steady state process in these cases may be schematically represented as follows:



The result of this process is that water is transferred from one temperature point to another through the specimen. Let us assume that this is achieved as follows. Water is evaporated at a constant rate at T_H , the vapour is driven through the specimen and condensed back into water at T_C . As stated earlier, in all the experiments the heat fluxes were monitored at both surfaces. Within the limits of the precision of these measurements, at each initial and final steady state, the difference between the heat fluxes at the hot and cold surfaces was negligible. Hence it may also be hypothesized that at the initial steady state, the rate of evaporation at the hot surface is equal to the rate of condensation at the cold surface. This thermodynamic model neglects any possibility of the condensed water returning to the hot surface. The moisture content in all the experiments was less than 1% by volume of the insulation

and it is believed that the above condition is not violated. Furthermore, the identical final steady states attained by the dry and moist specimens in experiments 1 and 3 also suggest that the above condition is fulfilled. Suppose the rate of vaporization and condensation is n . Thermodynamically the heat (q_n) transported in this process will be

$$\begin{aligned} q_n &= n \Delta_i^v H + (nH_H - nH_C) \\ &= n [\Delta_i^v H + (H_H - H_C)] \end{aligned} \quad (1)$$

where $\Delta_i^v H$ is the average specific enthalpy of vaporization between T_H and T_C , H_H is the specific enthalpy of water at T_H , and H_C , that at T_C . It is assumed that the enthalpy change involved in this process as a result of the resistance offered by the material is negligible.

In Equation (1), $\Delta_i^v H$ may be estimated as a mean value for the temperature range T_H to T_C by the application of the Clausius-Clapeyron equation. Thus Equation (1) may be written as

$$q_n = n \left[\frac{RT_H T_C}{(T_H - T_C)} \ln \frac{P_H}{P_C} + (H_H - H_C) \right] \quad (2)$$

where R is the gas constant, and P_H and P_C are equilibrium vapour pressure of water at T_H and T_C .

From the experimental measurements

$$q_n = q_I - q_F \quad (3)$$

where q_I and q_F are the heat fluxes at the initial and final steady states. The quantities P_H , P_C , H_H and H_C are available from standard tables [3] and the only unknown quantity, n , in Equation (2) can be calculated.

This calculation was carried out with the data corresponding to Figures 1(e) and 1(f) and the results are summarized in Table 1.

The validity of this hypothetical calculation can be checked as follows. From the values for n from Table 1, knowing the total amount of water involved in the transport process and the area of the specimen, the duration of the moisture transport process can be calculated and compared to the experimental values. The total amount of moisture is 91 g, distributed over an area of 0.3364 m². Hence the total moisture to be driven across the specimen can be expressed as 270.5 g·m⁻². For the process represented by Figure 1(e), $n = 0.01027$ g·m⁻²·s⁻¹. Hence the moisture should be driven within 7.3 h. Similarly, the processes represented by Figure 1(f), the moisture should be transferred within 6.6 h, 4 h and 3.1 h. It can be seen from Table 1 that these

calculated values agree very well with the values estimated from Figure 1(f).

Let us now examine the dependence of n on $\Delta P = P_H - P_C$ and $\Delta T = T_H - T_C$. From data in Figure 2, n appears to be linearly dependent on ΔP . A linear least squares analysis of the data gave the equation

$$n = K_1 + K_2 \Delta P \quad (4)$$

where $K_1 = 1.06 \times 10^{-3} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ and $K_2 = 1.58 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$ with a linear correlation coefficient = 0.9998. Equation (4) reveals a non-zero intercept and suggests that even in the absence of a vapour pressure gradient, moisture transfer may exist. In other words a driving force other than ΔP is also responsible for the moisture transport. The obvious choice for the second potential in the present experimental investigation is ΔT .

Thus $n = n(\Delta P, \Delta T)$. For a narrow range of pressure and temperature one may assume a linear relationship such as

$$n = K_3 \Delta P + K_4 \Delta T \quad (5)$$

A least-squares analysis showed that, in comparison with Equation (4), the data in Table 1 are equally well represented by Equation (5) with $K_3 = 1.58 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$ and $K_4 = 2.745 \times 10^{-5} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{K}^{-1}$. Further, the constants K_3 and K_4 in Equation (5) have physical significance: K_3 is the water vapour permeability and K_4 is the coefficient of thermal vapour diffu-

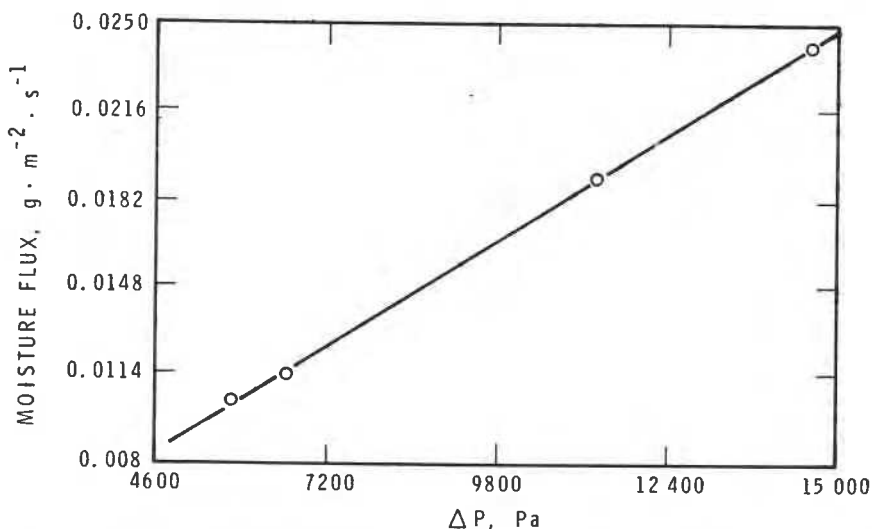


FIGURE 2. Linear dependence of moisture flux (n) on vapour pressure difference (ΔP) across the specimen.

ERRATA

Moisture Transport through Glass-Fibre Insulation in the Presence of a Thermal Gradient, by M.K. Kumaran

Journal of Thermal Insulation, Vol. 10, April 1987

Page 252

Paragraph immediately following Equation 5:

Second line: Please change $K_d = 1.58 \times 10^{-6} \text{ g}\cdot\text{m}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$

to

$$K_3 = 1.58 \times 10^{-6} \text{ g}\cdot\text{m}^{-2}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$$

Fifth line: Please change "permeability" to "permeance."

Table 2. Experimental results from the measurements on the second specimen of glass fibre insulation; the symbols have the same meaning as in Table 1.

T_H (K)	T_C (K)	Q_i ($W \cdot m^{-2}$)	Q_F ($W \cdot m^{-2}$)
307.8	286.9	39.6	13.9
307.9	286.9	39.6	14.0
312.9	287.1	53.8	17.4
317.3	287.3	67.9	20.6
321.8	287.5	84.2	23.7
326.2	287.7	102.8	27.0

sion. Two separate determinations of K_3 of the specimen by the standard dry-cup method [4] gave the values 1.5×10^{-6} and $1.6 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$, in good agreement with $K_3 = 1.58 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$ calculated from the thermal measurement.

Admittedly, the data in Table 1 do not represent a large variation in ΔT and hence do not establish the need for ΔT term in Equation (5). Therefore, to confirm the validity of Equation (5) another series of measurements, as in experiment no. 6, was done on a second specimen of glass fibre insulation with a bulk density of $30.0 \text{ kg} \cdot \text{m}^{-3}$ and average thickness 5.47 cm. The results of these measurements are summarized in Table 2. Analysis of the data in Table 2 in terms of Equation (4) resulted in

$$K_1 = 1.60 \times 10^{-3} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$$

$$K_2 = 2.20 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$$

with a linear correlation coefficient equal to 0.9996. This once again establishes the non-zero intercept in Equation (4) and leads to Equation (5) as discussed earlier. Reanalysis of the data in terms of Equation (5) yielded

$$K_3 = 2.15 \times 10^{-6} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$$

$$K_4 = 7.70 \times 10^{-3} \text{ g} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{K}^{-1}$$

with an overall correlation coefficient equal to 0.9993.

CONCLUSIONS

Adsorption of moisture from air with RH up to 93% in the form of water vapour does not significantly affect the thermal performance of the specimen. In this specimen water is apparently transferred predominantly as

water vapour in the presence of a thermal gradient. Once the transfer is complete, the insulation performs as if it were a dry material. For a given specimen, the rate of moisture transfer is defined by the difference in the vapour pressure at the two points of transfer.

The heat flux measurements done on this material are used to calculate two moisture transport characteristics that describe the transport of moisture in the presence of a thermal gradient. It may be possible to formulate a test method based on these experiments, applicable to wet glass-fibre insulation in which all the moisture is initially at the hot surface. In such a test method, two moisture transport characteristics in addition to the conventional apparent thermal conductivity will be determined using a heat flow meter apparatus. These three material characteristics, used together in predictive models for simultaneous heat and moisture transfer, should give a more realistic description of the transport processes through glass-fibre insulation, in comparison with the traditional method of using an "apparent thermal conductivity of a moist thermal insulation." To exploit this, more measurements must be done for a wider temperature range, not only on other specimens of glass-fibre insulation, but on all materials that are used as thermal insulation.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the technical assistance of Mr. R. G. Marchand and Mr. J. G. Theriault. This paper is a contribution of the Institute for Research in Construction, National Research Council of Canada.

REFERENCES

1. Langlais, C., M. Hyrien and S. Klarsfeld. "Moisture Migration in Fibrous Insulating Materials Under the Influence of a Thermal Gradient and its Effect on Thermal Resistance," *Moisture Migration in Buildings*, ASTM special technical publication 779, p. 191 (1982).
2. ASTM standard test method C518. "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter." 1981 Annual book of ASTM standards, p. 224.
3. *CRC Handbook of Chemistry and Physics*. 66th edition, pp. D-171 and D-189 (1985).
4. ASTM standard test method C355. "Standard Test Method for Water Vapor Transmission of Thick Materials." 1981 Annual book of ASTM standards, p. 124.

BIOGRAPHY

Dr. M. K. Kumaran is an Associate Research Officer at the Institute for Research in Construction, National Research Council of Canada. He

received his BSc (Chemistry and Physics) and MSc (Pure Chemistry) degrees from Kerala University, India, in 1965 and 1967 and Ph.D. (Chemical Thermodynamics) degree from University College, London, England, in 1976. He worked as a Lecturer in Chemistry at Sree Narayana College, Cananore, India (1967-1980) and as a Research Fellow at Massey University, New Zealand (1980-1981) before he joined the NRCC as a Research Associate in the Division of Chemistry. He joined the research staff of IRC in 1984.

This paper is being distributed in reprint form by the Institute for Research in Construction. A list of building practice and research publications available from the Institute may be obtained by writing to the Publications Section, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario, K1A 0R6.

Ce document est distribué sous forme de tiré-à-part par l'Institut de recherche en construction. On peut obtenir une liste des publications de l'Institut portant sur les techniques ou les recherches en matière de bâtiment en écrivant à la Section des publications, Institut de recherche en construction, Conseil national de recherches du Canada, Ottawa (Ontario), K1A 0R6.