TEMPERATURE DEPENDENCE OF THE BARODIFFUSION COEFFICIENT OF WATER IN CERAMIC MIX

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To describe the transfer of water in a ceramic mix it is necessary to know the barodiffusion coefficient and its temperature dependence. The latter can be determined experimentally by the method based on driving water by suction through a layer of granular material. A simpler but less precise determination consists of an estimate based on the knowledge of the temperature dependence of the viscosity of water.

INTRODUCTION

Knowledge of the barodiffusion coefficient and its temperature dependence is a precondition for a quantitative description of water transfer in a saturated ceramic mix due to a pressure gradient. In a ceramix mix, the pressure gradient is created under the effect of capillary suction in the menisci on the non-saturated surface of the ceramic body. As has been found [1], this capillary pressure gradient can be substituted with an external pressure gradient when using suitable conditions. This principle was utilized in the method using suction for driving water through a layer of granular material in order to determine the barodiffusion coefficient. The method was used for determining the barodiffusion coefficient of water in a saturated porcelain mix at one temperature $T = 293$ K.

The present study is concerned with determining the temperature dependence of barodiffusion coefficient in a water saturated ceramic mix.

The knowledge of this dependence and of the temperature relationships of the diffusion coefficient [2] and of the thermodiffusion coefficient [3] provides data for the resolving of problems of unidimensional moisture transfer, described by the equation for the volume flow of moisture:

$$h = -D\ \partial C/\partial x - (D_T/T)\ (\partial T/\partial x) - (D'_P/P)\ (\partial P/\partial x) \tag{1}$$

and for the moisture balance:

$$\partial C/\partial \tau = \partial/\partial x[D\ \partial C/\partial x + (D_T/T)\ (\partial T/\partial x) + (D'_P/P)\ (\partial P/\partial x)], \tag{2}$$

where D is the diffusion coefficient, D_T is the thermodiffusion coefficient and D'_P is the barodiffusion coefficient, C is the volume moisture content, T is temperature, P is pressure, τ is time and x is the ordinate in the direction of the diffusion.

Estimate of the temperature dependence of the barodiffusion coefficient

The temperature dependence of D_P can be estimated on the basis of the viscosity of water, which is the property changing most distinctly with temperature. This relationship is described by Darcy's law, which has the following form [4] when the gravity term is neglected:

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$$h_P = -(k/\mu)\, \partial P/\partial x, \tag{3}$$

where h_P is the volume flow of water due to the pressure gradient, k is the permeability coefficient and μ is the viscosity of water.

During isothermic suction of water through a body, a pressure and a moisture profile arise inside the body and the total volume flow of moisture is given by the equation:

$$h = -D\, \partial C/\partial x - (D_P'/P)\, \partial P/\partial x. \tag{4}$$

Equation (4) can also be written in the form:

$$h = h_C + h_P, \tag{5}$$

where h_C is the volume moisture flow due to the moisture gradient, and in the case of a water saturated body with a nonsaturated boundary [1], h_P is the moisture flow due to capillary barodiffusion. The h_P flow may also be effected by an external pressure gradient in the case of a saturated body with a saturated boundary. A comparison of equations (3), (4) and (5) then yields:

$$k/\mu = D_P'/P. \tag{6}$$

On simplifying equation (6) by relating the barodiffusion coefficient to the given pressure, P (i.e. $D_P = D_P'/P$) and when using the relationship for the temperature dependence of viscosity of water,

$$\mu = A \exp(B/T), \tag{7}$$

then for a given temperature T, when knowing the corresponding D_P, one can calculate the value k from equations (7) and (6). Within a narrow temperature interval, the temperature dependence k can be neglected and for a rough estimate of the temperature dependence D_P, the following equation can be obtained by joining equations (6) and (7):

$$D_P = D_{0P} \exp(-B_2/T), \tag{8}$$

where B_2 and D_{0P} are constants ($D_{0P} = k\, A^{-1}$). In using the value $D_P = 2 \times 10^{-4}\ m^2\ s^{-1}\ Pa^{-1}$ determined for a saturated porcelain mix at $T = 291$ K [1] and the corresponding viscosity of water, the rough estimate of the temperature dependence of the barodiffusion coefficient has the following form:

$$D_P = 6 \times 10^{-12} \exp(-1\,624 K/T)\ m^2\ s^{-1}\ Pa^{-1}. \tag{9}$$

MEASURING PROCEDURE AND RESULTS

The D_P value for the given T was measured by suction of water through a layer of granular material on a cylindrical body 2 cm in diameter and 1 cm in length. The bodies were prepared from a porcelain mix on a vacuum auger. After forming, the bodies were insulated and placed for 48 hours in a water saturated environment to achieve a uniform moisture distribution throughout the body volume. Before measurement, the insulation was removed from both body bases, one of the basis was placed on a frit and together placed in a vessel with water of constant temperature. A vacuum pump was used for creating pressure P_2. On attainment of a state of equilibrium, the volume flow of water through the body was determined. The body was then cooled down to $T = 278$ K, its insulation removed and the body was cut in the direction x into slices 2 mm thick for moisture profile determination.

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Using approximation of the moisture profile according to a linear dependence, the volume moisture contents C_1 and C_2, corresponding to the positions $x = 0$, $P = P_1$ and $x = L$, $P = P_2$ were expressed.

The diffusion coefficient, D, for the given temperatrue T was calculated from its temperature dependence determined for the given porcelain mix by the diffusion couple method [2]:

$$D = 5.52 \times 10^{11} \exp \left(-14\,484K/T\right) \text{ m}^2 \text{ s}^{-1}. \tag{10}$$

The barodiffusion coefficient was calculated from the equation:
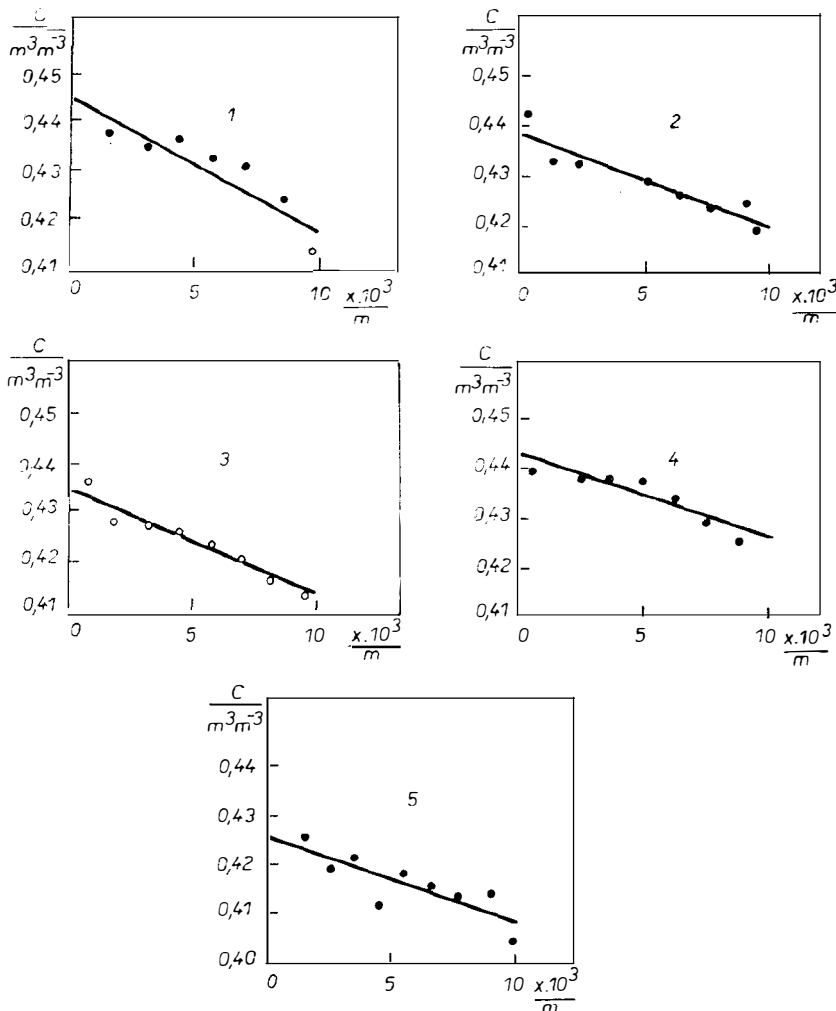
$$D'_P = (D(C_1 - C_2) - \mathbf{h}L)/\ln (P_2/P_1) \tag{11}$$

Fig. 1. Moisture profiles in the body at various working temperatures:
$1 - T = 278$ K, $2 - T = 288$ K, $3 - T = 298$ K, $4 - T = 303$ K, $5 - T = 313$ K.

and the value D_P' was related to the value of mean pressure given by the equation:

$$\bar{P} = (P_1 - P_2)/\ln (P_1/P_2).\tag{12}$$

The moisture profile and the volume moisture flow at the given T were measured four times. The same procedure was used at all the working temperatures. The mean values were calculated of the D_P determined at one temperature, and the error $\sigma = ((\sum_{i=1}^{n} (\bar{D}_P - D_{Pi})^2) (n - 1)^{-1})^{1/2}$ was expressed. Some typical moisture profiles measured at the working temperatures used are plotted in Fig. 1. The calculated mean values of D_P are listed in Table I.

Table I

The values of the barodiffusion coefficient at various temperatures

$\dfrac{T}{\text{K}}$	$\dfrac{P_1}{\text{Pa}}$	$\dfrac{P_2}{\text{Pa}}$	$\dfrac{D_P \times 10^{14}}{\text{m}^2\,\text{s}^{-1}\,\text{Pa}^{-1}}$	$\dfrac{\sigma \times 10^{14}}{\text{m}^2\,\text{s}^{-1}\,\text{Pa}^{-1}}$
278			0.9	0.1
288			1.0	
298	104 274	1 200	2.0	
303			3.3	0.2
313			5.4	

DISCUSSION AND CONCLUSION

The temperature dependence of D_P within the temperature range measured, $T \in \langle 278\ \text{K}; 313\ \text{K} \rangle$ was approximated by equation (8) for the values in Table I. The values of the constants are as follows:
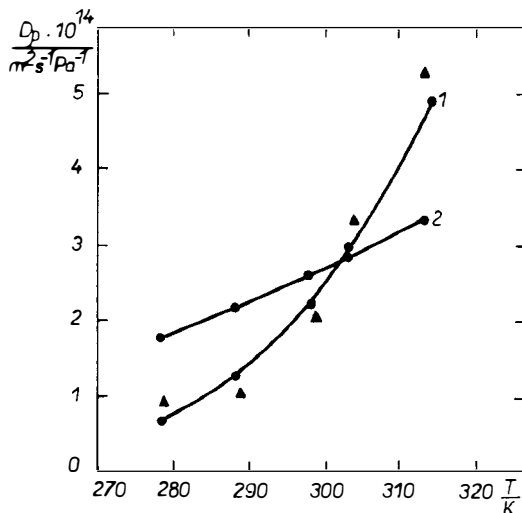

Fig. 2. Temperature dependence of the barodiffusion coefficient;
1 — experimental, 2 — estimate.

$$D_{0P} = 1.78 \times 10^{-7} \text{ m}^2 \text{ s}^{-1} \text{ Pa}^{-1}, \qquad B_2 = 4\ 729 \text{ K}. \tag{13}$$

The comparison of the measured and the estimated temperature dependence of D_P (cf. Fig. 2) indicates that the difference between the two courses amounts on the average to 30 %. This difference is due to the fact that the effect of change in density and in surface tension of water in terms of temperarature is not considered in the equation (9) and the dependence of k on T is neglected. An explanation may also be seeked in the change in the properties of water adsorbed on the surfaces of capillaries in clay minerals. At low temperatures, the water is adsorbed in several molecular layers, so that the capillary diameter is decreased and consequently also the volume flow of vater. An increase in temperature will lead to partial liberation of the adsorbed water molecules and thus to an increase in the diameter of the capillaries and thus to an increase in the volume flow of water.

It may be concluded that the estimate of the temperature dependence of the barodiffusion coefficient of water in a saturated ceramic mix, that considers just the temperature change in the viscosity of water, is very rough. The actual temperature dependence of the barodiffusion coefficient of water for the given mix is expressed as follows:

$$D_P = 1.78 \times 10^{-7} \exp\left(-4\ 729 K/T\right) \text{ m}^2 \text{ s}^{-1} \text{ Pa}^{-1}.$$

References

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TEPLOTNÍ ZÁVISLOST BARODIFÚZNÍHO KOEFICIENTU VODY V KERAMICKÉ SMĚSI

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Pro kvantitativní popis přenosu vody v nasycené keramické směsi je nutné znát teplotní závislosti barodifúzního koeficientu. Tuto závislost je možno získat buď odhadem z teplotní závislosti viskozity vody, nebo experimentálním stanovením. K experimentálnímu stanovení teplotní závislosti barodifúzního koeficientu lze použít metodu založenou na prosávání vody vrstvou zrnitého materiálu.

Z porovnání obou závislostí plyne, že odhad teplotní závislosti barodifúzního koeficientu je velmi hrubý. Pro její skutečné stanovení se jeví výhodnější použít experimentální stanovení. Experimentálně byla stanovena teplotní závislost barodifúzního koeficientu ve tvaru:

$$D_P = 1{,}78 \cdot 10^{-7} \exp\left(-4\ 729\ K/T\right) \quad \text{m}^2 \text{ s}^{-1} \text{ Pa}^{-1}.$$

Obr. 1. Vlhkostní profily v tělese při různých pracovních teplotách: $1 - T = 279$ K, $2 - T = 288$ K, $3 - T = 298$ K, $4 - T = 303$ K, $5 - T = 313$ K.
Obr. 2. Závislost barodifúzního koeficientu na teplotě;
    $1 - experiment; 2 - odhad.$

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ТЕМПЕРАТУРНАЯ ЗАВИСИМОСТЬ БАРОДИФФУЗИОННОГО КОЭФФИЦИЕНТА ВОДЫ В КЕРАМИЧЕСКОЙ СМЕСИ

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Для количественного описания переноса воды в насыщенной керамической смеси необходимо знание температурной зависимости бародиффузионного коэффициента. Такую зависимость можно получить приблизительным определением, основывающемся на температурной зависимости вязкости воды, или экспериментальным путем. Для экспериментального определения температурной зависимости бародиффузионного коэффициента можно использовать метод, основывающийся на проникании воды через слой зернистого материала.

Из сопоставления обеих зависимостей следует, что приблизительное определение температурной зависимости бародиффузионного коэффициента весьма неточно. Для его действительного определения оказывается наиболее пригодным экспериментальный путь. Таким образом установили температурную зависимость бародиффузионного коэффициента в виде:

$$D_p = 1{,}78 \cdot 10^{-7} \text{ эксп. } (-4\,729 \text{ K/T}) \text{ м}^2 \text{ с}^{-1} \text{ Па}^{-1}$$

Рис. 1. Профиль влаги в теле при разных температурах работы: 1 — T = 278 К, 2 — T = 288 К, 3 — T = 298 К, 4 — T = 303 К, 5 — T = 313 К.

Рис. 2. Зависимость бародиффузионного коэффициента от температуры: 1 — эксперимент, 2 — приблизительное определение.

C. A. RONAN: THE CAMBRIDGE ILLUSTRATED HISTORY OF THE WORLD'S SCIENCE (Ilustrovaná historie světové vědy z Cambridge). Cambridge University Press, Newnes Books, Cambridge 1983. 583 str. cena 12.95.

Věda je dobrodružství poznání a její dějiny jsou přinejmenším stejně zajímavé jako dějiny různých národů a států. Je ovšem nesnadné zvolit hledisko, ze kterého má být vývoj vědy popisován. Ronan se rozhodl vylíčit historii vzniku a vývoje myšlenek a objevů, které směřovaly k poznání Přírody, tj. které ovlivnily naše názory na svět. Autor tedy vypustil historii objevů, jejichž cílem byly praktické aplikace. Zabývá se původem vědy, jejími počátky v Babylónii, Egyptě, Číně, Indii, Arábii, Římě a také ve středověké Evropě. Ukazuje, jaký převrat znamenala renesance a jaký rozvoj všech vědních disciplín následoval v 17., 18. a 19. století.

Stejně jako v dějinách národů a států vystupují lidé, kteří hráli významnou roli v důležitých událostech, setkáváme se v dějinách vědy s osobnostmi, které podstatně přispěly k objektivnímu a pravdivému poznání světa. Ocenit, v čem byla taková osobnost dále než všichni její současníci se podaří teprve tehdy, vidíme-li ji v podmínkách doby, ve které žila. A to se znamenitě podařilo Ronanovi v jeho díle, jehož cílem je vyložit vývoj vědy, tj. proniknout do souvislostí s vývojem názorů a vývojem celé naší civilizace.

Ronanova historie vědy je psána poutavým způsobem a můžeme ji číst jako historii báječných objevů, triumfů lidského rozumu a vynalézavosti. Ronan je autorem celé řady knih o astronomii a historii vědy. Studoval historii a filozofii věd na Londýnské univerzitě, 13 let pracoval v sekretariátu Královské společnosti a je členem Královské astronomické společnosti.

Kniha uspokojí naši přirozenou touhu poznat co bylo dříve a dodá nám navíc optimismu pro výhled vědy do budoucnosti.

Šatava