frequency; $U_s$, $U_z$, components of the displacement vector in the direction and normally to the middle surface, respectively; $\varepsilon_s$, $\varepsilon_\theta$, $\varepsilon_z$, relative deformations of the piezoceramic material; $\nu$, Poisson ratio; $E_z^{(0)}$, electric field intensity; $d_{31}$, piezomodule; $s_{11}^E$, elastic pliability of the piezoceramic material; $C_{el}$, capacitance, v, volume of the transducer; E, Young's modulus; $e''_{31}$, $e''_{33}$, imaginary parts of the complex piezoelectric constants; $f_{\Delta R}$, relative error of measuring the thermistor resistance; $f_{\tan\alpha}$, error of measuring the tangent of the angle of slope of the tangent to the calibration curve; $\alpha_t$, heat-transfer coefficient; F, area of heat exchange; $q_n$, uniformly distributed mechanical load normal to the surface of the shell.

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# SPECIFIC HEAT IN THE $NH_4NO_3$—$HNO_3$—$H_2O$ SYSTEM

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The specific heat has been measured in this ternary system. A theoretical study has been made of the effects of temperature and of the electrolyte concentrations ($NH_4NO_3$ and $HNO_3$) on the specific heat.

One needs data on the specific heat in the $NH_4NO_3$—$HNO_3$—$H_2O$ system for technological calculations on the production of water-filled explosives and ammonium nitrate [1].

The specific heat in a ternary electrolyte system ($C_{p_3}$, $kJ \cdot kg^{-1} \cdot K^{-1}$) can be calculated theoretically from an equation derived by Zdanovskii from additivity:

$$C_{p_3} = C_{p_1}\frac{C_1}{X_1} + C_{p_2}\frac{C_2}{X_2}. \quad (1)$$

To calculate the specific heat of the ternary system containing $C_1$ and $C_2$ of each electrolyte component, it is necessary to know the specific heats $C_p$ and $C_{p_2}$ for the binary isopiestic solutions. The electrolyte concentrations in the binary isopiestic solutions $X_1$ and $X_2$ may be determined graphically from the activities of the water in them. However, the literature carries no data on the water activities in the $NH_4NO_3$—$H_2O$ and $HNO_3$—$H_2O$ binary systems at temperatures above 25°C. It was therefore necessary to measure the specific heats for aqueous solutions of $NH_4NO_3$ and the ternary system $NH_4NO_3$—$HNO_3$—$H_2O$ containing up to 80 mass % $NH_4NO_3$ and up to 30 mass % $HNO_3$ at temperatures between 20 and 80°C.

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TABLE 1. Specific Heat $C_{p_3}$ ($kJ \cdot kg^{-1} \cdot K^{-1}$) of the Binary $NH_4NO_3$—$H_2O$ System and the Ternary $NH_4NO_3$—$HNO_3$—$H_2O$ One

| Temp., °C | Mass % | $NH_4NO_3$ concn., mass % | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| | | **Binary system** | | | | | | | |
| 20 | 0 | 3,812 | 3,520 | 3,268 | 3,035 | 2,805 | 2,633 | — | — |
| 30 | 0 | 3,821 | 3,526 | 3,273 | 3,039 | 2,812 | 2,643 | 2,427 | — |
| 40 | 0 | 3,837 | 3,533 | 3,283 | 3,047 | 2,818 | 2,647 | 2,431 | — |
| 50 | 0 | 3,844 | 3,539 | 3,295 | 3,050 | 2,823 | 2,652 | 2,435 | — |
| 60 | 0 | 3,854 | 3,551 | 3,306 | 3,055 | 2,825 | 2,655 | 2,439 | 2,310 |
| 70 | 0 | 3,865 | 3,565 | 3,320 | 3,062 | 2,829 | 2,657 | 2,443 | 2,314 |
| 80 | 0 | 3,876 | 3,573 | 3,331 | 3,070 | 2,834 | 2,659 | 2,446 | 2,321 |
| | | **Ternary system** | | | | | | | |
| 20 | 10 | 3,446 | 3,205 | 2,986 | 2,865 | 2,708 | — | — | — |
| 30 | 10 | 3,446 | 3,220 | 3,000 | 2,876 | 2,718 | — | — | — |
| 40 | 10 | 3,489 | 3,242 | 3,013 | 2,887 | 2,728 | — | — | — |
| 50 | 10 | 3,502 | 3,266 | 3,030 | 2,895 | 2,739 | 2,510 | — | |
| 60 | 10 | 3,522 | 3,285 | 3,050 | 2,910 | 2,751 | 2,519 | 2,440 | |
| 70 | 10 | 3,548 | 3,305 | 3,067 | 2,921 | 2,764 | 2,530 | 2,448 | |
| 80 | 10 | 3,568 | 3,326 | 3,082 | 2,934 | 2,777 | 2,540 | 2,457 | |
| 20 | 20 | 3,143 | 2,990 | 2,792 | 2,618 | 2,464 | 2,397 | — | — |
| 30 | 20 | 3,163 | 3,014 | 2,810 | 2,644 | 2,478 | 2,413 | — | — |
| 40 | 20 | 3,192 | 3,036 | 2,830 | 2,659 | 2,498 | 2,420 | — | — |
| 50 | 20 | 3,220 | 3,062 | 2,853 | 2,684 | 2,523 | 2,434 | — | — |
| 60 | 20 | 3,253 | 3,080 | 2,870 | 2,700 | 2,537 | 2,445 | — | — |
| 70 | 20 | 3,281 | 3,105 | 2,892 | 2,729 | 2,562 | 2,452 | — | — |
| 80 | 20 | 5,310 | 3,124 | 2,904 | 2,758 | 2,578 | 2,465 | — | — |
| 20 | 30 | 3,022 | 2,793 | 2,638 | 2,492 | — | — | — | — |
| 30 | 30 | 3,056 | 2,813 | 2,659 | 2,505 | — | — | | |
| 40 | 30 | 3,080 | 2,830 | 2,674 | 2,524 | — | — | | |
| 50 | 30 | 3,108 | 2,852 | 2,689 | 2,544 | — | — | | |
| 60 | 30 | 3,135 | 2,877 | 2,699 | 2,560 | — | — | | |
| 70 | 30 | 3,160 | 2,898 | 2,718 | 2,575 | — | — | | |
| 80 | 30 | 3,180 | 2,915 | 2,735 | 2,588 | — | — | | |

The measurements were made by scanning calorimetry with an apparatus developed at the Institute of Physical Chemistry, Academy of Sciences of the Ukrainian SSR [2].

The experimental data (Table 1) were fitted to a polynomial of second degree that incorporated the effects of temperature and the concentrations of both electrolytes on the specific heat in the $NH_4NO_3$—$HNO_3$—$H_2O$ system. A Mir-2 computer was used to perform the fitting on 209 experimental points.*

The equation takes the form

$$C_{p_3} = 4.073 + 1.037 \cdot 10^{-2} t - 3.136 \cdot 10^{-2} C_1 - 3.641 \cdot 10^{-2} C_2 +$$
$$+ 3.660 \cdot 10^{-6} t^2 + 1.326 \cdot 10^{-4} C_1^2 + 1.749 \cdot 10^{-4} C_2^2 - 2.271 \cdot 10^{-5} C_1 t + 4.506 \cdot 10^{-5} C_2 t + 2.973 \cdot 10^{-4} C_1 \cdot C_2, \quad (2)$$

where $C_{p_3}$ is the specific heat in the ternary system in $kJ/kg^{-1} \cdot K^{-1}$, while $C_1$ and $C_2$ are the concentrations in mass % of the $NH_4NO_3$ and $HNO_3$ in the ternary system, and t is temperature in °C.

The relative standard deviation of the specific heats calculated from (2) from the experimental values was not more than 1.83%. The maximum relative error was 6.82%.

One can compare the measured $C_{p_3}$ (Table 1) with those calculated from additivity via (1), which shows that the deviations are not more than 2% relative below 55°C. The deviations increase at higher temperatures, which is due to the determination of $X_1$ and $X_2$ from the activity coefficients for water in binary solutions at 25°C.

Equation (2) can also be used to determine the specific heats of aqueous $NH_4NO_3$ solutions not containing $HNO_3$ in the region up to 80°C for $NH_4NO_3$ concentrations up to 80 mass %.

By using (2), one can avoid cumbersome graphical constructions in determining $X_1$ and $X_2$ as required in calculating $C_{p_3}$ from (1). Equation (2) also enables one to employ a computer in technological calculations.

*Program written by O. T. Popovich and G. A. Bochenko.

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# SEPARATION OF A BINARY MIXTURE IN A THERMODIFFUSION COLUMN WITH A SPIRAL WINDING


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The solution of the transfer equation in a thermodiffusion column with spiral winding in sampling conditions is given for the case c(1 − c) ≈ const.


In [1], the transfer equation for a cylindrical column with a spiral winding (Fig. 1) was obtained*

$$\frac{\partial c}{\partial\theta}=(\cos^2\varphi+k)\frac{\partial^2 c}{\partial u^2}+2\sin\varphi\cos\varphi\frac{\partial^2 c}{\partial u\partial v}+(\sin^2\varphi+k)\frac{\partial^2 c}{\partial v^2}-$$
$$-\cos\varphi\frac{\partial}{\partial u}[c(1-c)]-\sin\varphi\frac{\partial}{\partial v}[c(1-c)]-\varkappa\frac{\partial c}{\partial u},\tag{1}$$

where

$$u=\frac{H^{(0)}z}{K_c^{(0)}},\ v=\frac{H^{(0)}y}{K_c^{(0)}},\ \theta=\frac{H^{(0)2}t}{\rho\delta K_c^{(0)}},\ k=\frac{K_d^{(0)}}{K_c^{(0)}},\ \varkappa=\frac{\sigma}{BH^{(0)}}.\tag{2}$$

In the present work, a solution is given to the problem of separating a binary liquid mixture for which the condition c(1 − c) ≈ const = $a$ is observed throughout the whole process, and the coefficient k satisfies the inequalities

$$k\ll\cos^2\varphi;\ k\ll\sin^2\varphi.\tag{3}$$

Since in the separation of liquid mixtures k is of the order of $5\cdot10^{-3}$, it follows from Eq. (3) that

$$15^\circ\leqslant\varphi\leqslant75^\circ.\tag{4}$$

Then in the steady state Eq. (1) is replaced by

$$\cos^2\varphi\frac{\partial^2 c}{\partial u^2}+2\sin\varphi\cos\varphi\frac{\partial^2 c}{\partial u\partial v}+\sin^2\varphi\frac{\partial^2 c}{\partial v^2}-\varkappa\frac{\partial c}{\partial u}=0.\tag{5}$$

The solution of Eq. (5) must satisfy the following conditions.

1. The flux along the z axis — see Eqs. (2.7) and (2.9) of [1] — is determined by the expression

$$j_z^*=\frac{H^{(0)}}{\delta}c(1-c)\cos\varphi-\frac{K_c^{(0)}}{\delta}\cos^2\varphi\frac{\partial c}{\partial z}-\frac{K_c^{(0)}}{\delta}\sin\varphi\cos\varphi\frac{\partial c}{\partial y}+\frac{\sigma}{B\delta}c.$$

This flux at the outlet from the apparatus (when z = L) should be equal to $\sigma c_e/B\delta$, which, taking account of the first two expressions in Eq. (2), leads to the result

$$\left(a-\cos\varphi\frac{\partial c}{\partial u}-\sin\varphi\frac{\partial c}{\partial v}\right)_{u=u_e}=0,$$

*In [1], the errors corrected in [2, 3] were still present in Eq. (32).


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