2. I. L. Povkh, A. I. Toryanik, B. P. Makogon, and V. M. Abrasimov, Inzh. Fiz. Zh., 37, No. 6, 1012-1014 (1979).
3. Yu. V. Tanchuk and G. S. Pop, Ukr. Khim. Zh., 41, No. 8, 833-835 (1975).
4. V. P. Budtov, VMS, 9A, No. 4, 765-771 (1967).
5. A. A. Tager, G. O. Botvinnik, and V. E. Dreval', Achievements in Polymer Rheology [in Russian], Moscow (1970), pp. 229-240.
6. S. T. Rafikov, V. P. Budtov, and Yu. B. Monakov, Introduction to the Physical Chemistry of Polymer Solutions [in Russian], Moscow (1978).
7. P. A. Privalov, Biofizika, 13, No. 1, 163-177 (1968).
8. T. B. Zheltonozhskaya, L. N. Podolyak, B. V. Eremenko, and I. A. Uskov, VMS, 29A, No. 12, 2484-2493 (1987).
9. P. Peyser and R. C. Little, J. Appl. Pol. Sci., 15, 2623-2637 (1971).

CONTROL OF GAS GENERATION USING A GAS-REGULATED HEAT PIPE

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The authors have performed an experimental and numerical invvestigation of the temperature field along the wall of a heat pipe, to provide a data base for the operation of gas generation control sensors for a gas-regulated heat pipe.

To solve some problems in material behavior it is important to know gas generation processes in a field of nuclear radiation. The specific conditions of operation of nuclear reactors (high temperature, corrosive medium, radiation, etc) limit the choice of the method of measuring gas generation inside the active zone in the immediate vicinity of the take-off points [1].

A method of control of gas generation was proposed in [2, 3], using a gas-regulated heat pipe (GRHP). The noncondensible fission products are stored in a gas reservoir, increasing the gas pressure, the result being displacement of the vapor-gas front and variation of the vapor temperature. Consequently, by varying the wall temperature of the GRHP in the transport zone we can evaluate the amount of gas in the reservoir.

However, to have a measured basis for operation of gas generation sensors using the GRHP we need to describe the temperature field along the GRHP mathematically as a function of the amount of noncondensible gas and the heater power.

Considering the internal space of the heat pipe as a channel through which there is isothermal mass transfer, and postulating the existence of an ideal vapor-gas boundary, we can describe the temperature field along the GRHP wall by a one-dimensional mathematical model, accounting for heat transfer at the wall and the location of the vapor-gas boundary.

We restrict ourselves to the case of low heat flux, when the vapor-gas boundary is located in the transport zone. Then the temperature distribution along the wall is described by the following system of equations:

$$\lambda\delta \frac{d^2T_w}{dx^2} = -q + \alpha_{c_v}(T_w - T_v),\quad 0<x<L_1; \tag{1}$$

$$\lambda\delta \frac{d^2T_w}{dx^2} = \alpha_{c\cdot v}(T_w - T_v) + \varepsilon\sigma(T_w^4 - T_{med}^4),\quad L_1<x<L_1+l; \tag{2}$$

$$\lambda\delta \frac{d^2T_w}{dx^2} = \varepsilon\sigma(T_{med}^4 - T_{med}^4),\quad L_1+l<x<L_1+L_2, \tag{3}$$

$$\lambda\delta \frac{d^2T_w}{dx^2} = \alpha_{c\cdot\ell}(T_w - T_\ell),\ L_1+L_2<x<L_1+L_2+L_3, \tag{4}$$

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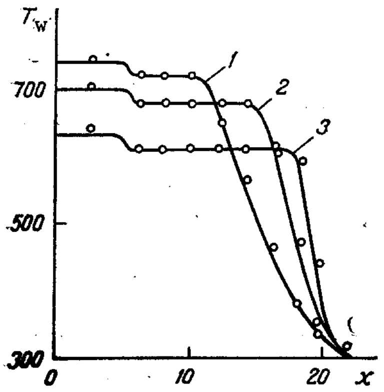

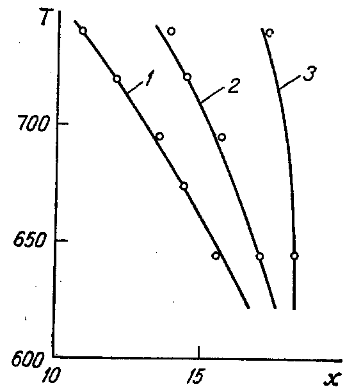

Fig. 1 Fig. 2

Fig. 1. Temperature profile over the height of a GRHP, evaluated at constant supplied heat power (Q = 28 W): 1) P_g = 6.66; W; 2) 2.66; 3) 0.66 T_r) T_w is in K, and x is in cm.

Fig. 2. Location of the vapor-gas boundary as a function of the pressure of noncondensible gas: 1) Q = 28 W; 2) 35; 3) 45, T is in K.

with the following boundary conditions:

$$\left.\frac{dT_w}{dx}\right|_{x=0} = 0,\ \{T_w\}_{x=\begin{cases}L_1\\ L_1+l\\ L_1+L_2\end{cases}} = 0;\ \left\{\frac{dT_w}{dx}\right\}_{x=\begin{cases}L_1\\ L_1+l\\ L_1+L_2\end{cases}} = 0,$$
$$T_w\,|_{x=L_1+L_2+L_3} = T_\ell, \tag{5}$$

where $\{T\}_x = T_{x+0} - T_{x-0}$.

An estimate of the characteristic parameters shows that $\alpha L_i^2/(\lambda\delta) \gg 1$ (i = 1, 2,3). Therefore, the system (1)-(4) belongs to the class of singularly perturbed equations. Using the method developed in the work of Vasil'ev [4], we can write the solution of the system (1)-(4) in the form:

$$\begin{aligned}
T_w &= C_1 e^{-A_1 x} + D_1 e^{A_1(x-L_1)} + T_{w0}^{(1)}, \quad 0 < x < L_1;\\
T_w &= C_2 e^{-A_2(x-L_1)} + D_2 e^{A_2[x-(L_1+l)]} + T_{w0}^{(2)},\ L_1 < x < L_1 + l;\\
T_w &= C_3 e^{-A_3 x} + D_3 e^{A_3 x} + \bar{T}_w,\ L_1 + l < x < L_1 + L_2;\\
T_w &= C_4 e^{-A_4[x-(L_1+L_2)]} + D_4 e^{A_4[x-(L_1+L_2+L_3)]} + T_{w0}^{(4)},\\
&\quad L_1 + L_2 < x < L_1 + L_2 + L_3,
\end{aligned} \tag{6}$$

where $T_{w0}^{(i)}$ are the limiting solutions [4]:

$$T_{w0}^{(1)} = T_v + \frac{q}{\alpha_{c\,v}},$$
$$\alpha_{c\cdot v}(T_{w0}^{(2)} - T_v) + \varepsilon\sigma(T_{w0}^{(2)4} - T_{med}^4) = 0,\quad T_{w0}^{(4)} = T_\ell, \tag{7}$$

and in solving Eq. (3) and constructing boundary functions for Eq. (2) we have linearized the corresponding equations and introduced the notation

$$A_1^2 = \frac{\alpha_{c\,med}}{\lambda\delta},\ A_2^2 = \frac{\alpha_{c\,v} + \alpha}{\lambda\delta},\ A_3^2 = \frac{\alpha_1}{\lambda\delta},\ A_4^2 = \frac{\alpha_{c0,\,\ell}}{\lambda\delta},$$
$$\alpha = \varepsilon\sigma T_v^3,\ \ \alpha_1 = 4\varepsilon\sigma\bar{T}^3,\ \bar{T} = \frac{(T_v + T_{med})}{2},\ \ \bar{T}_{med} = \frac{(T_{med}^4 - \bar{T}^4)}{4\bar{T}^3}. \tag{8}$$

Satisfying the boundary conditions, we find the constants (see the Appendix).

Substituting the solutions obtained into the condition for achieving the necessary heat removal

$$\varepsilon\sigma \int_{L_1}^{L_1+L_2} (T_w^4 - T_{med}^4)\, dx + \alpha_{c.,\ell} \int_{L_1+L_2}^{L_1+L_2+L_3} (T_w - T_\ell)\, dx = qL_1, \tag{9}$$

we obtain an equation relating the vapor temperature T_v and the condensation length ℓ.

For a given mass m of noncondensible gas

$$P_g = \frac{m}{\mu} RT_g \frac{1}{V_{res} + S(L_2 + L_3 - l)}, \tag{10}$$

where S is the area of cross section of the vapor channel.

According to the condition of operation of the gas regulated heat pipe [5]

$$P_g = P_v(T_v), \tag{11}$$

and then simultaneous solution of Eqs. (9)-(11) determines T_v and ℓ and therefore Eqs. (6) describe the temperature distribution along the gas-regulated heat pipe.

Thus, by measuring the wall temperature of the heat pipe in the transport zone (at a given heater power) and determining the length of condensation from Eqs. (7) and (9), we can determine the mass of gas from Eqs. (10)-(11).

To verify the above method we performed experimental investigations of the temperature field along a GRHP at various levels of heater power and gas pressure.

The basic characteristics of the experimental heat pipe are: total length of pipe 0.235 m; length of evaporator 0.05 m; length of condenser 0.035 m; cross section of vapor channel $5 \cdot 10^{-5}$ m^2; thickness of pipe wall $1 \cdot 10^{-3}$ m; and volume of gas reservoir $28.5 \cdot 10^{-6}$ m^3. The pipe was made of type Ch18Ni10T stainless steel, the heat transfer agent was cesium, and the the noncondensible gas was helium. The experiments were conducted for values of heater power of Q = 28, 35, 45 W, and the gas pressure was varied in the range 0.6-6 kPa.

Figure 2 shows the temperature distribution along the GRHP, calculated from the above model, and Fig. 2 shows the location of the vapor-gas boundary as a function of the gas pressure at different levels of thermal power.

The good agreement between the calculated (curves on Figs. 1, 2) and experimental data (points) is evidence that the proposed method of control of gas generation, based on the model developed, is correct.

APPENDIX

$$C_1 = 0; \quad D_1 = -\frac{A_2}{A_1 + A_2} (T_{w0}^{(1)} - T_{w0}^{(2)});$$

$$C_2 = \frac{A_1}{A_1 + A_2} (T_{w0}^{(1)} - T_{w0}^{(2)});$$

$$D_3 = -\frac{A_4(A_2+A_3)(\overline{T}_{med} - T_{w0}^{(4)})\, e^{-A_3(L_1+l)} - A_2(A_3 - A_4)(T_{w0}^{(2)} - \overline{T}_{med})\, e^{-A_3(L_1+L_2)}}{(A_2 + A_3)(A_3 + A_4)\, e^{A_3(L_2-l)} + (A_2 - A_3)(A_3 - A_4)\, e^{-A_3(L_2-l)}};$$

$$C_3 = \frac{A_2(A_3 + A_4)(T_{w0}^{(2)} - \overline{T}_{med})\, e^{A_3(L_1+L_2)} + A_4(A_2 - A_3)(\overline{T}_{med} - T_{w0}^{(4)})\, e^{A_3(L_1+l)}}{(A_2 + A_3)(A_3 + A_4)\, e^{A_3(L_2-l)} + (A_2 - A_3)(A_3 - A_4)\, e^{-A_3(L_2-l)}};$$

$$D_2 = C_3 e^{-A_3(L_1+l)} + D_3 e^{A_3(L_1+l)} + (\overline{T}_{med} - T_{w0}^{(2)});$$

$$C_4 = C_3 e^{-A_3(L_1+L_2)} + D_3 e^{A_3(L_1+L_2)} + (\overline{T}_{med} - T_{w0}^{(4)}).$$

NOTATION

T_w, T_v, T_{med}, T_ℓ, temperatures of the wall, vapor, surrounding medium, and cooling liquid, respectively; λ, thermal conductivity of the wall; δ, wall thickness; $\alpha_{w.v.}$, $\alpha_{w.\ell}$, heat transfer coefficient for the wall-vapor and wall-liquid; ε, emissivity; σ, Stefan–Boltzmann coefficient; q), specific heat flux; L_1, L_2, L_3, length of the evaporator; transport zone, and condenser respectively; ℓ, height of the vapor-gas boundary in the transport zone; P_g, p_v, pressure of the gas and the vapor; V_{res}, volume of the gas reservoir; m, mass of the gas; Q, heater power.

LITERATURE CITED

1. I. A. Trofimov, and V. V. Lappo, Measurement of the Parameters of Thermophysical Processes in Nuclear Power [in Russian], Moscow (1979).
2. I. G. Gverdtsiteli, A. G. Kalandarishvili, V. A. Kuchuzhidze, and P. D. Chilingarishvili, At. Energ., 56, No. 2, 103-104 (1984).
3. I. G. Gverdtsiteli, A. F. Kalandarishvili, Sh, P. Abramidze et al., At. Energ., 59, No. 3, 197-200 (1985).
4. A. B. Vasil'eva, Usp. Mekh. Nauk 18, No. 3, 15-86 (1963).
5. P. Dunn and D. Reay, Heat Pipes, Pergamon Press, New York (1975).

METHODS OF COMPUTATIONAL THERMOGRAPHY IN THE NONDESTRUCTIVE TESTING OF THE QUALITY OF HEAT PIPES AND HEAT EXCHANGE DEVICES BASED ON THEM

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In order to have a non-contact method of diagnosing the quality of heat exchangers, a scanning IR system has been developed and tested which records and analyzes the characteristic IR radiation of the heat exchanger under steady-state or transient conditions.

At present devices based on heat pipes have found applications in various technical fields. By making it possible to transfer large quantities of heat at high efficiency and with minimum losses and transforming heat flux densities over a wide range of temperatures they have successfully replaced more traditional constructions. To a considerable extent, the economics of heat pipe devices and the probable fields of their application are determined by their reliability, which depends both on the design itself of the heat pipes and also on the quality of their construction. As the mass construction of heat pipes has developed and their designs have become more complicated, the problem of checking the parameters (temperature conditions) of heat pipes both in the construction stage and in the period of use has assumed increasing importance [1].

The use of non-contact methods of IR diagnosis using thermographic systems for nondestructive testing ensures a high efficiency of the measurements with respect to time, space, temperature resolution, and reproducibility. An important extension in the functional possibilities of the IR imager as a measuring device was achieved by digital treatment of the infrared images which are obtained by the use of a computer operating in an interactive mode.

In the investigations which have been carried out to develop a method for testing the quality of heat pipes, use has been made of an automated system based on the TV-03 infrared imager which makes it possible to achieve a temperature resolution of at least 0.2 K at a level of 300 K. The determination of the absolute value of the temperature from the measured electrical signal of the photodetector U is carried out by means of the polynomial

$$T = \sum_{i=0}^{n} C_i U^i, \tag{1}$$

the coefficients C_i of which are calculated from the known spectral characteristics of the object, the IR imager, and the atmosphere [2], or are determined directly in the course of the experiment from results of comparisons with data from contact measurements to an accuracy of about 1 K.

The isothermal nature of the temperature distribution over the condensing zone of a heat pipe is a criterion for its ability to operate efficiently at the corresponding thermal load

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