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AN ANALYTICAL STUDY OF RESISTANCE, HEAT TRANSFER AND STABILITY IN EVAPORATIVE COOLING OF A POROUS HEAT-PRODUCING ELEMENT

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Abstract—The paper presents physical and analytical models of evaporative cooling of a porous heat-producing element and considers regularities in resistance and heat transfer of an evaporating coolant flow. Hydrodynamic and thermal characteristics of the evaporative cooling are constructed that allow an analysis of the process stability. The method of improving the system stability by means of an additional internal porous layer of smaller permeability is proposed and justified. The parameters of a stable system are specified.

NOMENCLATURE

c, heat capacity;
G, $g = G/G_1$, dimensional and non-dimensional specific flow rates of a coolant;
i, enthalpy;
h_v, volumetric heat-transfer coefficient;
K, $k = K/\delta$, dimensional and non-dimensional coordinates of the end of evaporation region;
L, $l = L/\delta$, dimensional and non-dimensional coordinates of the beginning of evaporation region;
P, pressure;
q_v, density of volumetric heat generation;
r, heat of vaporization;
$Re = G_1(\beta/\alpha)/\mu'$, Reynolds number of a coolant flow in porous material;
t, T, temperature of coolant and porous material;
v, specific volume of coolant;
x, mass vapour content in two-phase flow;
Z, $z = Z/\delta$, dimensional and non-dimensional coordinates.

Greek symbols

α, β, viscous and inertial resistance coefficients of porous material;
Γ, $\gamma = \Gamma/\delta$, dimensional and non-dimensional thickness of an internal layer;
δ, thickness of porous element;
λ, thermal conductivity of porous material;
μ, ν, dynamic and kinematic viscosities.

Superscripts

$'$, $''$, refer to saturated liquid and vapour properties at ambient pressure;
s, refers to parameters at saturation state;
$*$, refers to limiting parameters.

Subscripts

1,2,3, refer to parameters of liquid, two-phase and vapour sections;
l, k, refer to parameters at the beginning and at the end of evaporation region;
I, II, refer to results obtained with account for formulae (12) and (13).

INTRODUCTION

A COMPACT system of porous cooling of a heat-producing element acquires a number of qualitatively new properties when a liquid coolant, evaporating inside a porous structure, is used. These are high rate of volumetric heat removal, appreciable increase in coolant efficiency due to the heat of vaporization, small specific volume of a liquid coolant and possibility of attaining low temperatures, cryogenic including.

Until the present time there has been no published information on theoretical developments or successful embodiment of the method of evaporative cooling of a porous heat-producing element. A few available experimental studies [1, 2] have a qualitative character since aperiodic instability, typical of all the systems with phase changes of the working body, has immediately manifested itself there, thus excluding the possibility of performing thorough investigation of the main regularities in resistance, heat transfer and in the structure of an evaporating flow in a porous heated material.

The present paper generalizes the basic points of a detailed analytical study separate results of which are reported in [3–6].

THE MODEL OF A PROCESS

The postulated physical model of a one-dimensional steady-state evaporative cooling of a porous heat-producing element is shown in Fig. 1(a).

†Longitudinal pressure drop is small compared to general pressure level.

By the action of the pressure drop $P_0 - P_1$, a liquid coolant of initial temperature t_0 is forced through a porous element with the thickness δ and constant volumetric heat generation q_v. As the liquid moves in a porous structure, its pressure goes down, while the temperature rises. At some distance L from the entrance, the coolant attains the saturation state, whereupon its gradual evaporation begins within the section LK with subsequent vapour superheat over the section $K\delta$.

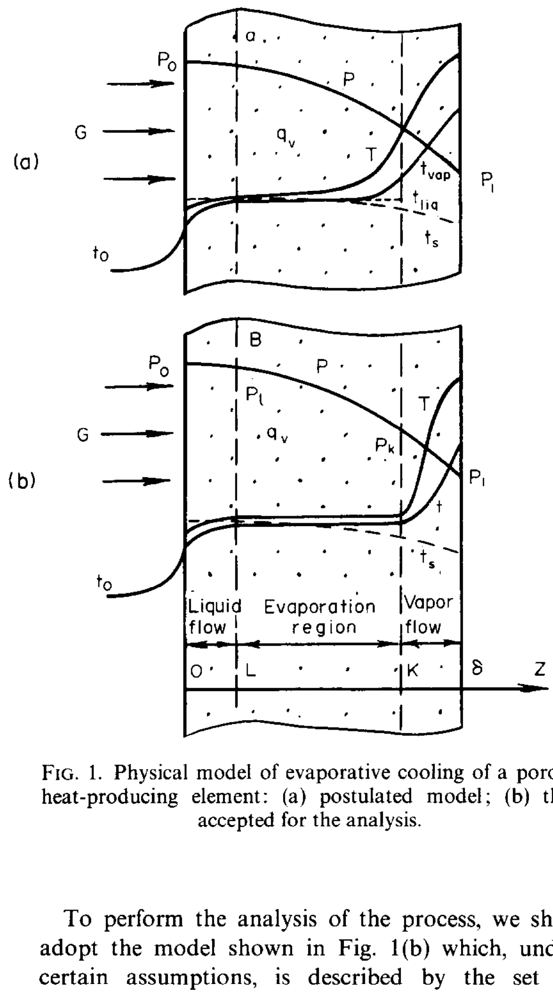

FIG. 1. Physical model of evaporative cooling of a porous heat-producing element: (a) postulated model; (b) that accepted for the analysis.

To perform the analysis of the process, we shall adopt the model shown in Fig. 1(b) which, under certain assumptions, is described by the set of equations:

$$G = \text{constant}; \tag{1}$$

$$-\frac{dP}{dZ} = \alpha\mu v G + \beta v G^2; \tag{2}$$

$$\lambda \frac{d^2 T_1}{dZ^2} + q_v = h_v(T_1 - t_1), \quad 0 < Z < L; \tag{3}$$

$$Gc' \frac{dt_1}{dZ} = h_v(T_1 - t_1), \quad 0 < Z < L; \tag{4}$$

$$\lambda \frac{d^2 T_3}{dZ^2} + q_v = h_v(T_3 - t_3), \quad K < Z < \delta; \tag{5}$$

$$Gc'' \frac{dt_3}{dZ} = h_v(T_3 - t_3), \quad K < Z < \delta; \tag{6}$$

subject to the following boundary conditions

$$Z = 0, \ \lambda \frac{dT_1}{dZ} = Gc(t_1 - t_0); \tag{7}$$

$$\begin{gathered} Z = L, \ \lambda \frac{dT_1}{dZ} = \lambda \frac{dT_2}{dZ} = 0; \\ t_1 = t_2 = t_s(P_l); \ T_1 - t_1 = T_2 - t_2 = \Delta T; \end{gathered} \tag{8}$$

$$\begin{gathered} Z = K, \ \lambda \frac{dT_2}{dZ} = \lambda \frac{dT_3}{dZ} = 0; \\ t_2 = t_3 = t_s(P_l); \ i_3 = i''(P_l); \end{gathered} \tag{9}$$

$$Z = \delta, \ \lambda \frac{dT_3}{dZ} = 0, \ P = P_1; \ T_3 \leqslant T^*. \tag{10}$$

For the evaporation region

$$v = v' + x(v'' - v') \tag{11}$$

and to evaluate the effect of the kinematic viscosity of a two-phase flow on the final results, the following expressions are assumed

$$\nu_{\text{I}} = \nu' + x(\nu'' - \nu') \tag{12}$$

$$\nu_{\text{II}} = [\mu' + x(\mu'' - \mu')][v' + x(v'' - v')]. \tag{13}$$

These relations are shown in Fig. 2.

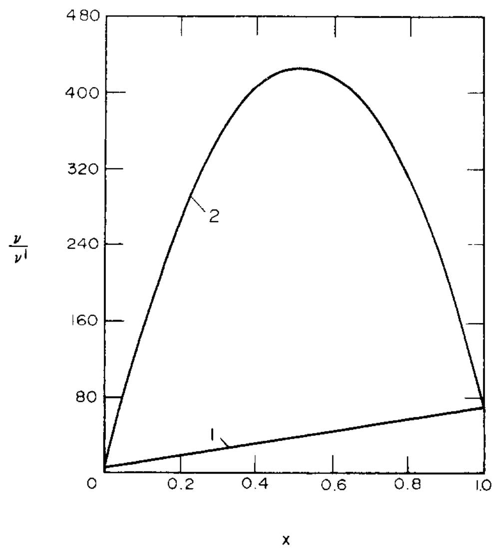

FIG. 2. Kinematic viscosity of a homogeneous two-phase vapour–water flow vs mass vapour content at P_1 = 1 bar:

(1) $\frac{\nu_{\text{I}}}{\nu'} = 1 + x\left(\frac{\nu''}{\nu'} - 1\right)$;

(2) $\frac{\nu_{\text{II}}}{\nu'} = \left[1 + x\left(\frac{\mu''}{\mu'} - 1\right)\right]\left[1 + x\left(\frac{v''}{v'} - 1\right)\right]$.

AIM OF THE ANALYSIS AND METHOD OF SOLUTION

The problem (1)–(13) of determining the pressure and temperature fields inside a porous heat-producing element is distinguished by high complexity due to the fact that resistance and heat transfer over each of the three sections of the coolant flow (liquid, two-phase and vapour) are described by a set of nonlinear equations provided the requirements for nonlinear thermodynamic equilibrium are met on their boundaries of which the position is to be found from solution.

Further, the final aim of the analysis is formulated in the most general form, i.e. with the prescribed independent parameters (such as q_v, P_1, t_0 and the kind of a coolant), the remainder parameters of the system being selected so that the external surface temperature of the element would not exceed the limiting value T^* with slow finite oscillations of the independent parameters.

The above formulation is characteristic of the problems on determining the region of stable and safe operation. This, therefore, requires a non-ordinary method of solution which consists in the following:

(1) The regularities in motion and heat transfer of an evaporating coolant flow in a porous heat-producing element are studied separately;

(2) The results obtained are integrated to study the stability of the process and to derive the condition of its stability;

(3) The stability condition is used to analytically determine the region of stable and safe operation of the system.

RESISTANCE AND HEAT TRANSFER OF A COOLANT FLOW EVAPORATING INSIDE A POROUS HEAT-PRODUCING ELEMENT

The hydrodynamic and thermal components of the process are separated by regarding the coordinate l of the beginning of the evaporation region to be an independent parameter. Below, the main attention is paid to investigation of the regularities in motion of the evaporating coolant since it is here that all the specific features of the process are hidden.

Integration of equations (1)–(2) over all of the three coolant flow sections yields

$$gm + g^2 nRe = 1 \tag{14}$$

where

$$m = \left[l + \int_l^k \frac{\mu v}{\mu' v'}\, dz + (1-k)\frac{v''}{v'} \right]; \qquad n = \left[l + \int_l^k \frac{v}{v'}\, dz + (1-k)\frac{v''}{v'} \right]. \tag{15}$$

Some of the terms on the LHS of equation (14) define a relative pressure difference introduced by the viscous and inertial components of resistance over each of the three flow sections. Thus, for the evaporation region

$$\frac{(P_l - P_k)_{\text{vis}}}{P_0 - P_1} = g \int_l^k \frac{\mu v}{\mu' v'}\, dz; \qquad \frac{(P_l - P_k)_{\text{in}}}{P_0 - P_1} = g^2 Re \int_l^k \frac{v}{v'}\, dz. \tag{16}$$

That equation (14) could be solved, it is necessary to calculate the integrals entering into equation (15) which, with the known (11)–(13) physical properties of the two-phase flow, reduces to determination of the limits of integration. The adiabatic conditions at the external surface of the porous element (10) and the both boundaries of the evaporation region (8)–(9) allow the relative dimensions of separate flow sections to be found

$$l = \frac{i' - ct_0}{i[P_1, t_3(\delta)] - ct_0}; \quad k = l\,\frac{i'' - ct_0}{i' - ct_0}. \tag{17}$$

Of a particular interest is the optimal regime of the system operation when a coolant flows out of the element in the form of a superheated vapour but the vapour temperature keeps to be lower than the limiting temperature t^*. In this regime the coordinate of the beginning of the evaporation region varies within $l^* < l < l^\Delta$. The coordinate l^Δ corresponds to the efflux of a dry saturated vapour from the element and the coordinate l^*, to the efflux of a superheated vapour with the limiting temperature t^*. The values of these coordinates are

$$l^\Delta = \frac{i' - ct_0}{i'' - ct_0}; \quad l^* = \frac{i' - ct_0}{i(P_1, t^*) - ct_0}. \tag{18}$$

With $l^\Delta < l < 1$, a two-phase mixture flows out of the element with the mass vapour content (void fraction) equal to

$$x = \frac{1-l}{l} \cdot \frac{i' - ct_0}{r}, \quad l^\Delta < l < 1. \tag{19}$$

In Fig. 3 relative dimensions of the flow sections are given. For calculation it is assumed that $t_0 = 20°\text{C}$, $t^* = 500°\text{C}$, water being a coolant.

Calculating, with regard for (11)–(13) and (18)–(19), the integrals

$$\int_l^k \frac{\mu v}{\mu v'}\, dz, \quad \int_l^k \frac{v}{v'}\, dz$$

and substituting the results into (15) give the expressions for the complexes m and n. For example, for n

$$n = \begin{cases} l + l\left(\dfrac{r}{i' - ct_0}\right)\left[1 + \dfrac{1}{2}\left(\dfrac{v''}{v'} - 1\right)\right] \\ \quad + \left(1 - l\,\dfrac{i'' - ct_0}{i' - ct_0}\right)\dfrac{v''}{v'}, \quad 0 < l < l^\Delta \\ l + l\left(\dfrac{r}{i' - ct_0}\right)\left[x + \dfrac{x^2}{2}\left(\dfrac{v''}{v'} - 1\right)\right], \quad l^\Delta < l < 1. \end{cases} \tag{20}$$

Equations (14)–(15) together with (20) make it possible to predict the non-dimensional coolant flow rate $g(l)$ as a function of the beginning of evaporation region. Then, using the expressions such as (16), relative pressure drops over separate flow sections and, consequently, pressure at the beginning of the evaporation region may be found. An analysis of these expressions shows that

$$g = g(l, Re, P_1, v_{\text{I,II}}, \text{kind of the coolant}) \tag{21}$$

$$P_l = P_l(l, Re, P_1, v_{\text{I,II}}, \text{kind of the coolant}). \tag{22}$$

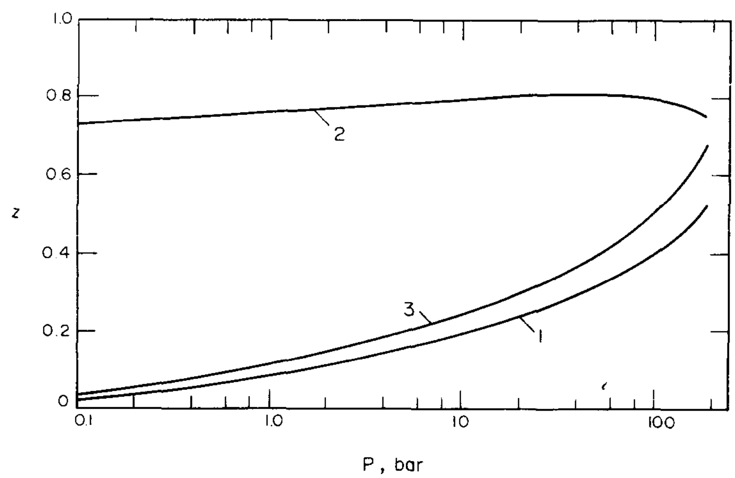

FIG. 3. Effect of the ambient pressure on position of the boundaries of flow sections: (1) l^*; (2) k^*; (3) l^Δ; ($k^\Delta = 1$).

Figures 4 and 5 present separate results on the effect of some of these parameters. Here and below, all the graphical data are obtained with the use of the physical properties of water and water vapour at saturation with $P_1 = 1$ bar.

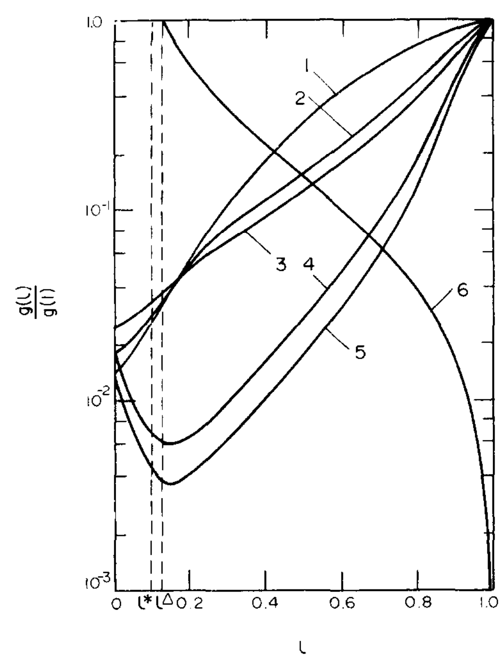

FIG. 4. Relative coolant flow rate vs the coordinate of the beginning of the evaporation region: (1) $Re \to 0$, $v = v_{\rm I}$; (2) $Re = 1$, $v = v_{\rm I}$; (3) $Re \to \infty$; (4) $Re = 1$, $v = v_{\rm II}$; (5) $Re \to 0$, $v = v_{\rm II}$; (6) mass vapour content, x.

If the coolant flow rate, the position and dimensions of the evaporation region as well as the saturation pressure (temperature) at the beginning of this region are known, the problems on determining the temperature field of the liquid and vapor sections may be solved completely and separately. Non-

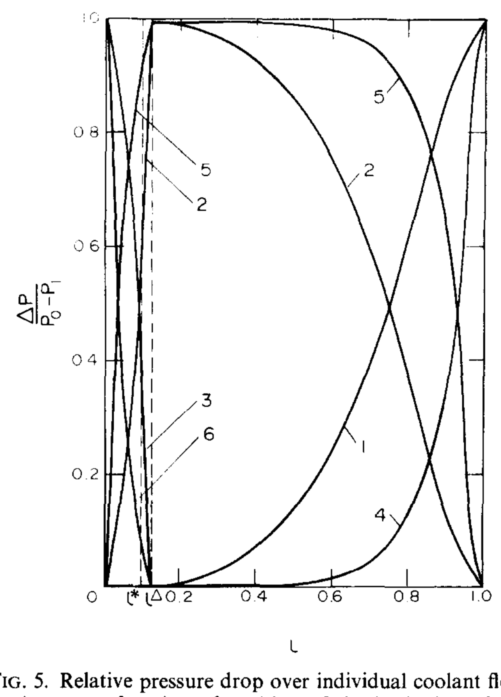

FIG. 5. Relative pressure drop over individual coolant flow sections as a function of position of the beginning of the evaporation region in viscous regime ($Re \to 0$):

$$(1)\ \frac{(P_0-P_l)_{\rm I}}{P_0-P_1};\quad (2)\ \frac{(P_l-P_K)_{\rm I}}{P_0-P_1};\quad (3)\ \frac{(P_K-P_1)_{\rm I}}{P_0-P_1};$$

$$(4)\ \frac{(P_0-P_l)_{\rm II}}{P_0-P_1};\quad (5)\ \frac{(P_l-P_K)_{\rm II}}{P_0-P_1};\quad (6)\ \frac{(P_K-P_1)_{\rm II}}{P_0-P_1}.$$

dimensionalized solutions of the systems of equations (3)–(4) and (5)–(6) have the same forms

$$\theta_j = c_{0j} + c_{1j}\exp(D_{1j}\xi) + c_{2j}\exp(D_{2j}\xi_j) + \xi_j; \quad (23)$$

$$\theta_j = c_{0j} + c_{1j}\frac{B_j}{D_{1j}}\exp(D_{1j}\xi_j) + c_{2j}\frac{B_j}{D_{2j}}\exp(D_{2j}\xi_j) + \left(\xi_j + \frac{1}{A_j}\right). \quad (24)$$

Here for the liquid $(0 < Z < L)$ section:

$$j = 1;\ \xi_1 = \frac{Z}{L};\ \theta_1 = \frac{t_1 - t_0}{t_s(P_l) - t_0};$$

$$\theta_1 = \frac{T_1 - t_0}{t_s(P_l) - t_0};\ A_1 = \frac{h_v L}{Gc'};\ B_1 = \frac{Gc'L}{\lambda};$$

and for the vapour $(K < Z < \delta)$ section:

$$j = 3;\ \xi_3 = \frac{Z - K}{\delta - K};$$

$$\theta_3 = \frac{t_3 - t_s(P_l)}{t_3(\delta) - t_s(P_l)};\ \theta_3 = \frac{T_3 - t_s(P_l)}{t_3(\delta) - t_s(P_l)};$$

$$A_3 = \frac{h_v(\delta - K)}{Gc''};\ B = \frac{Gc''(\delta - K)}{\lambda};$$

$$D_{1j,2j} = \frac{A_j}{2}\left[-1 \pm \left(1 + 4\frac{B_j}{A_j}\right)^{1/2}\right].$$

The integration constants c_{0j}, c_{1j}, c_{2j} are determined from the boundary conditions for appropriate sections.

THE PROCESS STABILITY

The results of separate solutions of the hydrodynamic and thermal components of evaporative cooling of a porous heat-producing element are combined when constructing the hydrodynamic and thermal characteristics provided the requirement for the thermodynamic equilibrium of phase transformation at the beginning of the evaporation region is met. The above characteristics allow investigation of the system stability. This method is applied by analogy with the method used to study the stability of such liable to instability processes as pool boiling and liquid flow evaporation in heated channels.

The hydrodynamic characteristic of an evaporative cooling system relates the coolant flow rate to the pressure drop over the porous heat-producing element. The specific coolant flow rate, G, at which phase transformation at the beginning of the evaporation region with the coordinate l is in equilibrium, is determined by the characteristic equation

$$\frac{G}{l} = \frac{q_v \delta}{(i'_{l=1} - ct_0)} - \left.\frac{\mathrm{d}i'}{\mathrm{d}P}\right|_{P_1} \frac{\alpha v' \delta}{(i'_{l=1} - ct_0)} \cdot \frac{(m - l)}{l} G^2$$

$$- \left.\frac{\mathrm{d}i'}{\mathrm{d}P}\right|_{P_1} \frac{\beta v' \delta}{(i'_{l=1} - ct_0)} \cdot \frac{(n - l)}{l} G^3. \quad (25)$$

The total pressure drop over the element with the known flow rate is predicted by the following expression

$$P_0 - P_1 = \alpha v' \delta m G + \beta v' \delta n G^2. \quad (26)$$

By the thermal characteristic of the system is understood the dependence of the volumetric heat generation q_v on the coordinate l. Pressure drop over the element is maintained constant. The thermal characteristic equation is that of thermal balance for the beginning of the evaporation region with the equilibrium phase transformation

$$q_v = \frac{G}{l\delta}\left[i'(P_l) - ct_0\right]. \quad (27)$$

Here, the enthalpy of the coolant, $i'(P_l)$, at the saturation state and its specific flow rate, G, depend on the coordinate l.

Figure 6 presents the hydrodynamic, and Fig. 7 the thermal, characteristics of the evaporative cooling system of the porous element with real parameters.

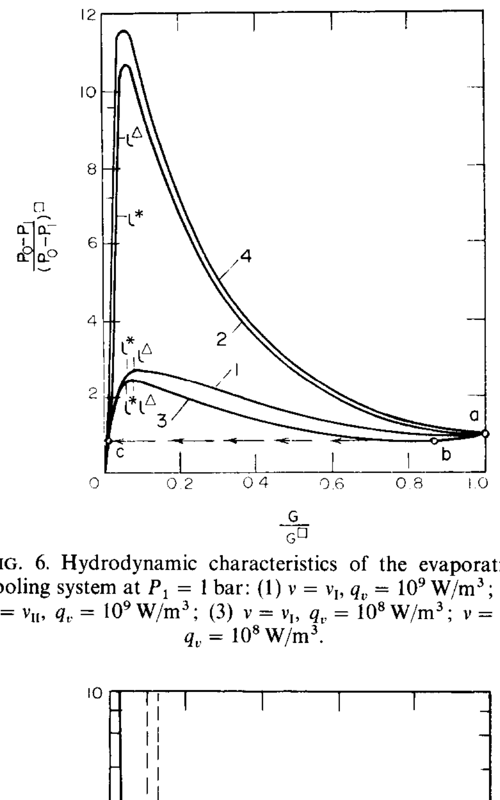

FIG. 6. Hydrodynamic characteristics of the evaporative cooling system at P_1 = 1 bar: (1) $v = v_{\rm I}$, $q_v = 10^9\ {\rm W/m^3}$; (2) $v = v_{\rm II}$, $q_v = 10^9\ {\rm W/m^3}$; (3) $v = v_{\rm I}$, $q_v = 10^8\ {\rm W/m^3}$; $v = v_{\rm II}$, $q_v = 10^8\ {\rm W/m^3}$.

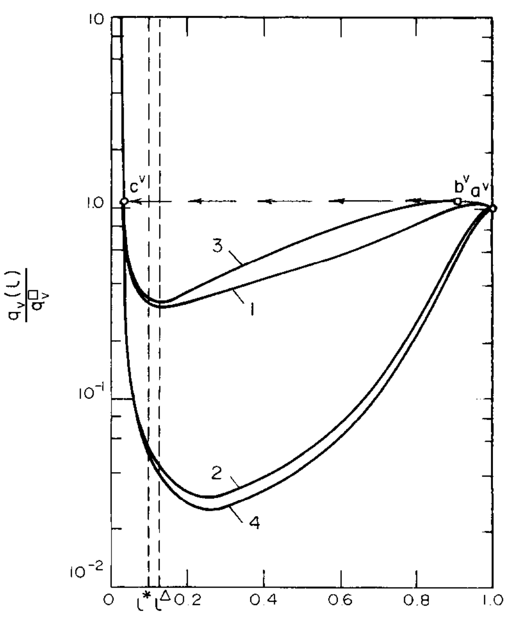

FIG. 7. Thermal characteristics of the system: (1) $v = v_{\rm I}$, $q_v = 10^9\ {\rm W/m^3}$; (2) $v = v_{\rm II}$, $q_v = 10^9\ {\rm W/m^3}$; $v = v_{\rm I}$, $q_v = 10^8\ {\rm W/m^3}$; (4) $v = v_{\rm II}$, $q_v = 10^8\ {\rm W/m^3}$.

In the hydrodynamic characteristics, the region of stable operation is an increasing section $d\Delta P/dG > 0$, while in thermal characteristics it is a falling section $dq_v/dl < 0$.

In spite of the fact that the optimal operation regime of the system, which corresponds to the range $l^* l^\Delta$, lies within the region of stable operation of all the systems, in reality none of the systems can operate in this regime since it is impossible to make the working point fall into this range. The only possible region of stable and safe operation is the section *ab* of hydrodynamic characteristics 1 and 3 and the section $a^v b^v$ of thermal characteristics 1 and 3. The point *b* indicates a maximum permissible pressure drop over the element, and the point b^v, the maximum permissible volumetric heat generation for stable and safe operation. It is important here to note that these regions correspond to the efflux from a porous heat-producing element of a two-phase mixture with very low void fraction x.

The examples given testify to the fact that the real systems of evaporative cooling of a porous heat-producing element possess a very small range of safe and stable operation.

IMPROVEMENT OF THE SYSTEM STABILITY

To extend the range of stable operation, it is recommended to use a two-layer porous heat-producing element in which the viscous, α_0, and inertial, β_0, resistance coefficients of the porous internal layer with thickness Γ are markedly greater than those of the main layer (Fig. 8). The volumetric heat generation of density q_0 may occur in the internal layer, but evaporation of the coolant should not begin inside this layer: $l > 0$.

Addition of the internal layer changes the quantitative relationships derived to predict the coolant flow rate and pressure drops over separate sections.

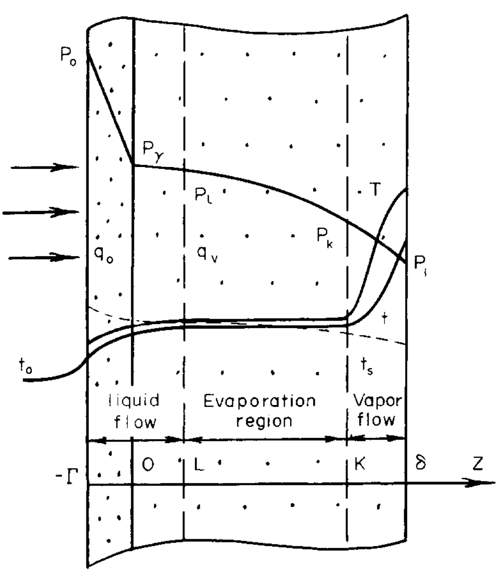

FIG. 8. A physical model of evaporative cooling of a two-layer porous heat-producing element.

For example, in contrast to (20), we have for n

$$n = \frac{\beta_0}{\beta}\gamma - \frac{q_0}{q_v}\gamma + \left(\frac{q_0}{q_v}\gamma + 1\right)\left\{l + l\left(\frac{r}{i' - ct_0}\right)\right.$$
$$\left.\times\left[1 + \frac{1}{2}\left(\frac{v''}{v'} - 1\right)\right] + \left(1 - l\frac{i'' - ct_0}{i' - ct_0}\right)\frac{v''}{v'}\right\},$$

provided $0 < l < l^\Delta$,

$$n = \frac{\beta_0}{\beta}\gamma + \frac{q_0}{q_v}\gamma + \left(\frac{q_0}{q_v}\gamma + 1\right)$$
$$\times\left\{l + l\left(\frac{r}{i' - ct_0}\right)\left[x + \frac{x^2}{2}\left(\frac{v''}{v'} - 1\right)\right]\right\}, \quad (28)$$

provided $l^\Delta < l < 1$, where

$$l^\Delta = \left(\frac{q_0}{q_v}\gamma + 1\right)\left(\frac{i' - ct_0}{i'' - ct_0}\right) - \frac{q_0}{q_v}\gamma. \quad (29)$$

In this case the specific coolant flow rate is a function of a number of additional parameters

$$g = g\left(l, Re, P_1, v_{\mathrm{I,II}}, \frac{\alpha_0}{\alpha}\gamma, \frac{\beta_0}{\beta}\gamma, \frac{q_0}{q_v}\gamma, \text{kind of a coolant}\right). \quad (30)$$

Figure 9 illustrates the effect of additional resistance of the internal layer $(\alpha_0/\alpha)\gamma$ on the thermal characteristics of the system. Here, $(q_0/q_v)\gamma = 0$, $(\beta_0/\beta)\gamma = 0$. From this it follows that an increase in the internal layer resistance contributes to the system stability.

Of a great practical interest is determination of such minimal parameters as $[(\alpha_0/\alpha)\gamma]^0$, $[(\beta_0/\beta)\gamma]^0$, starting from which the system becomes absolutely stable, i.e. stable in all the operation regimes with variation in the start of the evaporation region within $l^* < l < 1$.

These parameters are determined from the stability condition

$$\frac{dq_v}{dl} < 0, \quad l^* < l < 1. \quad (31)$$

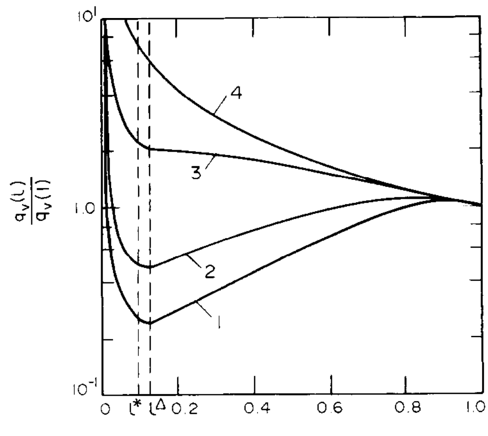

FIG. 9. Thermal characteristics of evaporative cooling of a two-layer porous heat-producing element in viscous regime ($Re \to 0$) at $P_1 = 1$ bar and $v = v_I$: (1) $(\alpha_0/\alpha)\gamma = 0$; (2) $(\alpha_0/\alpha)\gamma = 1$; (3) $(\alpha_0/\alpha)\gamma = 10$; (4) $(\alpha_0/\alpha)\gamma = 100$.

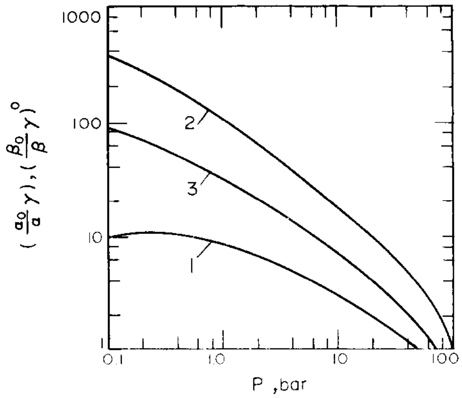

FIG. 10. Effect of the ambient pressure on boundary parameters of a stable system of cooling a two-layer porous heat-producing element: (1) $[(\alpha_0/\alpha)\gamma]^0_{\rm I}$, ($Re \to 0$, $\nu = \nu_{\rm I}$); (2) $[(\alpha_0/\alpha)\gamma]^0_{\rm II}$, ($Re \to 0$, $\nu = \nu_{\rm II}$); (3) $[(\beta_0/\beta)\gamma]^0$, ($Re \to \infty$).

Figure 10 shows the effect of the ambient pressure on the boundary values of the system parameters. From this, in particular, a conclusion may be drawn that a lack of experimental data on the kinematic viscosity of a homogeneous two-phase flow leads to a great uncertainty in the final results.

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ETUDE ANALYTIQUE DE LA RESISTANCE, DU TRANSFERT THERMIQUE ET DE LA STABILITE DANS LE REFROIDISSEMENT PAR EVAPORATION D'U N ELEMENT POREUX SOURCE DE CHALEUR

Résumé—On présente des modèles physiques et analytiques du refroidissement par évaporation d'un élément poreux source de chaleur et on considère la résistance et le transfert thermique d'un écoulement refroidissant avec évaporation. On établit les caractéristiques hydrodynamiques et thermiques du refroidissement par évaporation, ce qui permet l'analyse de la stabilité. On propose et on justifie la méthode d'étude de la stabilité du système au moyen d'une couche additionnelle poreuse, interne, de plus faible perméabilité. Les paramètres d'un système stable sont spécifiés.

EINE ANALYTISCHE STUDIE ÜBER WIDERSTAND, WÄRMEÜBERTRAGUNG UND STABILITÄT BEI VERDAMPFUNGSKÜHLUNG EINES PORÖSEN WÄRMEERZEUGENDEN ELEMENTS

Zusammenfassung—Die Arbeit befaßt sich mit physikalischen und analytischen Modellen der Verdampfungskühlung eines porösen wärmeerzeugenden Elements und betrachtet die Gesetzmäßigkeiten vom Widerstand und von der Wärmeübertragung eines verdampfenden Kältemittelstroms. Hydrodynamische und thermische Kennwerte der Verdampfungskühlung werden formuliert, die eine Analyse der Stabilität des Vorganges erlauben. Eine Methode zur Erlangung der Systemstabilität mittels einer zusätzlichen internen porösen Schicht von kleinerer Durchlässigkeit wird vorgeschlagen und begründet. Die Paramameter eines stabilen Systems werden angegeben.

АНАЛИТИЧЕСКОЕ ИССЛЕДОВАНИЕ СОПРОТИВЛЕНИЯ, ТЕПЛООБМЕНА И УСТОЙЧИВОСТИ В ПРОЦЕССЕ ИСПАРИТЕЛЬНОГО ОХЛАЖДЕНИЯ ПОРИСТОГО ТЕПЛОВЫДЕЛЯЮЩЕГО ЭЛЕМЕНТА

Аннотация — Представлены физическая и аналитическая модели процесса испарительного охлаждения пористого тепловыделяющего элемента. Выполнено исследование закономерностей сопротивления и теплообмена при движении испаряющегося охладителя. Построены гидродинамическая и тепловая характеристики процесса, позволяющие произвести анализ его устойчивости. Предложен и обоснован метод повышения устойчивости системы за счет применения дополнительного внутреннего слоя пористого материала меньшей проницаемости. Определены параметры устойчивой системы.