

HEAT PIPES AND THEIR USE IN TECHNOLOGY.

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## HEAT PIPES AND THEIR USE IN TECHNOLOGY

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### I. Introduction

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Closed, self-contained evaporative-condensing devices are called heat-tubes. As yet a unified terminology has not been created for heat tubes and it is difficult to state what should be included in this concept. The very name "heat tubes" came from English publications and does not reflect completely the peculiarities of the process of heat and mass exchange in the closed evaporative-condensing devices.

Heat pipes are one of the surprising inventions of scientists in the 1960's and in their applicability and significance for the economy, in our opinion, may become as widespread as lasers.

The primary purpose of heat pipes is the transfer of heat from one region of space to another without significant losses. The ideal heat pipe in this sense must have slight thermal resistance, several thousand times less than the thermal resistance of copper rods of the same geometrical dimensions.

In addition, it is successfully employed, for example, as a temperature regulator (thermostat), heat diode, transformer, storage battery, device for transforming thermal energy into mechanical, electric, etc. With the help of

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\*Numbers in the margin indicate pagination in the original foreign text.

heat pipes one can store thermal energy and quickly realize it at the necessary moment. In this respect the requirements for them differ from the requirements for the classic samples of heat pipes.

## II. Certain Aspects of the Theory of Heat Pipes

1. In so far as in any heat pipe there is a liquid and its vapors, the temperature range of its work is limited, on the one hand, by a triple point  $T_{TP}$ , on the other hand, by the critical point  $T_K$ . Depending on what temperature the heat pipe is used at (near  $T_{TP}$  or  $T_K$ ), different factors play the decisive role: near the triple point the determining factors are the dynamics of steam, the sound limit, the limit of interaction between the steam and the liquid, the kinetics of phase transitions, etc.; near the critical point high pressure can produce mechanical destruction of the structure, lower the amount of latent heat in the steam generation of liquid.

From the viewpoint of the thermodynamics a pattern of work near the critical point is preferable since the curve for the dependence of the steam pressure on the temperature in this region is flatter and the drop in pressure produces insignificant temperature changes. /906

According to the Clayperon-Clausius equation, on the border of the section liquid-steam within the heat pipes there must exist a condition of phase equilibrium  $f(P,T)=0$ , and if the latent heat of steam generation is taken as a constant amount, while steam is considered an ideal phase, then the following relationship is valid:

$$(P/P_0) = \exp\left(-\frac{1}{R^*T}\right) \quad (1)$$

As a consequence of the curvature in the surface of the section liquid-steam in the pores of the evaporator of the heat pipe and the temperature gradient, the liquid in the evaporator must be overheated. When this superheating reaches the critical amount, the process of boiling of the liquid begins.

In the condenser of the heat pipe the steam is overheated in relation to

the liquid in the pores. Consequently, under specific conditions it is possible for drops of liquid to exist in the steam (mist) both in the evaporator and in the condenser of the heat pipe.

The process of steam transfer in the heat pipe to a certain extent is analogous to the process of transfer in convergent-divergent nozzle. In its adiabatic zone expansion of the steam can occur, accompanied by the joule-thomson effect [1].

In relation to the fact that there is great diversity in the design (several dozen) of heat pipes and steam chambers in which the common signs are only the process of heat exchange in the evaporator and condenser in the presence of phase transfers, and the method and type of mass transfer and the peculiarities of the occurrence of the phase transfers may be the most diverse, then it can probably be stated that it is impossible to create a unified theory for the process of the transfer of energy and substance in the heat pipes.

It is convenient to establish certain general concepts of the analysis of the transfer process in heat pipes for the classic heat pipes employed in a fixed pattern. The problem of the mechanics of liquid and steam in the classic pipes has three components:

- 1) transfer of steam along the heat pipe from the evaporator to the condenser;
- 2) transfer of liquid from the condenser to the evaporator under the influence of the gradient of the capillary potential;
- 3) interaction of steam and liquid.

The analytical solution of all of these tasks presents great difficulty, especially the tasks of liquid transfer in the porous structure of heat pipe core. The boundary conditions at the entrance and exit (evaporator and condenser) are in strong dependence on the temperature field, the field of liquid concentration and the thermodynamic conditions of equilibrium.

A change in the working conditions of the heat pipe may influence the nature of the transfer processes occurring in it. Thus, for example, depending on the heat load and the working temperature the pattern of steam movement may be laminar or turbulent, and the steam--condensable or noncondensable. The characteristic of a certain pattern for the flow of steam may be given in relationship to the amount of the Reynolds number  $Re$  and Mach number  $M$  in the adiabatic zone;

$$Re = \frac{QR_v}{\pi R_v^2 L \eta_v}, \quad M = \frac{Q}{\pi R_v^2 LP} \sqrt{\frac{\rho_v}{c_p} \frac{R}{\mu} T_v}. \quad (2)$$

Therefore a separate examination of the transfer process in the steam phase or of liquid is possible only with specific assumptions. In particular, the isothermic nature of the steam current is accepted, the constancy of the thermal load in the evaporator and condenser which permits an examination of the dynamics in the steam flow independently of the temperature field and the flow of liquid in the core.

It is probable that the formulation of the task of transfer in the heat pipe as interdependent is more exacting when all the main processes of transfer in the steam and liquid phase are examined jointly. In particular, this statement of the task was given in publication [2]. For long cylindrical high-temperature pipes with a capillary structure in the form of a coaxial gap between the body and perforated screen in the presence of turbulent mixing, those parameters of steam such as density  $\rho_v$ , temperature  $T_v$ , are slightly dependent on the radial coordinate  $r$  (fig. 1).

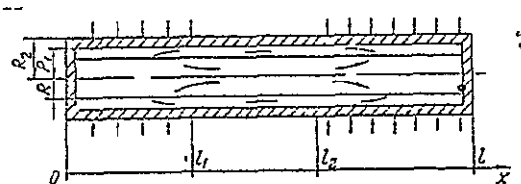


Fig. 1. Heat pipe.  $R$ --radius of perforated insert;  $R_1, R_2$ --radii of inner and outer body surfaces.

In relation to this, the system of equations which is the average for a cross section of the steam passage and which describes the movement of steam has the following form:

$$\frac{d}{dx} (\rho_V v) = -\frac{2}{R} \tau^*|_{r=R}; \quad (3)$$

$$\frac{d}{dx} [\rho_V + \beta \rho_V v^2] = -\frac{2}{R} \tau_w^*, \quad (4)$$

$$\frac{d}{dx} \left[ \rho_V v \left( H_V + \frac{\alpha v^3}{2} \right) \right] = -\frac{2}{R} (\tau^* H_V)|_{r=R}, \quad (5)$$

$$P_V = \frac{\rho_V R^* T_V}{M_V}, \quad (6)$$

$$v = \frac{2}{R^2} \int_0^R v_x r dr, \quad \beta = \frac{2}{v^2 R^2} \int_0^R v_x^2 r dr, \quad (7)$$

$$\alpha = \frac{2}{v^3 R^2} \int_0^R v_x^3 r dr,$$

$v_x$  -- component of steam velocity along x axis.

The system of equations (3)-(6) can be closed if the quantities are known for the coefficient of flow of impulse  $\beta$ , the strength of friction  $\zeta_w$  and the condensation coefficient  $k$ .

The transfer in the shell and core of the heat pipe includes transfer of heat and filtering of liquid through the capillary structure. In the shell of the heat pipe the spread of heat is described by the equation

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} = 0, \quad (8)$$

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