OUTLOOK AT APPLICATION OF BIPHASE PULSING CONTOUR WITH INTERMEDIATE VESSEL

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Abstract

The new opportunity concept of creation of a heat transport system of multi-purpose assignment on the basis of biphase pulsing thermosyphon contours, in which the circulation of the heat-carrier is carried out by auto fluctuations of vapor pressure during heat transfer from a source to a sink, is discussed.

The basic variant of biphase pulsing contour is described

The mathematical model of heat- and mass transfer processes in a basic pulsing contour is accounted. This model is based on the solution of the equations of flows, of heat and mass in various elements of system for non-stationary conditions.

The results of experimental researches of a breadboard model of a heat transport system and their comparison with results of numerical calculations based at the offered model are given.

Opportunities of applications of multiloop heat-technology schemes, including at least one biphase pulsing contour, allowing to use them for development of industrial heat and cold supply systems with presence of secondary and renewed sources of energy are offered and analyzed (a pumpless vapor-ejecting refrigerating machine with pulsing working contour, pump heat action, heat supply system)

KEYWORDS

heat transport system, pulsing contour, biphase loop, renewed sources, mathematical model, experiment, pumpless vapor ejecting refrigerator.

INTRODUCTION

An extensive number of biphase heat transport systems successfully used in practice of construction of a thermal control system for various objects, creation of heat recovery equipment, nowadays is well known. The thermosyphons and heat pipes [1], the biphase circulating contours with capillary, mechanical or jet pumps [2] concern to their number. A variety of principles of their functioning is defined in generally distinction of driving forces, under which action the condensate comes back in a zone of evaporation of a working liquid, but common feature is following: the character of heat and mass transfer processes does not vary via time except for a starting period.

The applicability of that or other type of the listed devices is defined mainly by their heat transport ability, opportunity of heat transfer at given distance with the minimal thermal resistance with the minimal expenses of a financial and material resources and maximal degree of reliability. These requirements frequently contradict each other. So, for example, the increase of transport opportunities in circulating systems by use mechanical pumps results in reduction of their reliability and necessity of additional expenses of energy. The same purpose in contours with the capillary pump is achieved at the sharp increase of economic expenses because of necessity of use of high technologies. Thermosyphon being the most reliable and cheap devices, have limited heat transport ability and cannot transfer of heat to a direction of a field of gravitation.

At last years, in connection with sharp increase of industrial wastes of heat, and also increased interest to use low potential and renewed sources energy for systems of air condition, there are represented rather perspective development of a vapor-ejecting refrigerators with a low boiling heat-carriers [7, 8].

It is interesting, that some problems as a heat transfer systems, so cold supply system, can be solved by creation of the scheme and devices on the basis of biphase pulsing contours, in which the circulation of the heat-carrier is carried out owing to auto fluctuations of vapor pressure during heat transfer from a source to a sink with any their mutual position [3,4,5].

PRINCIPLE OF FUNCTIONING OF A PULSING SYSTEMS

In spite of the fact, that at the present time the researchers have extensive experimental data, concerning of the characteristics of various types of a pulsing heat transport systems, of a physical substantiation of a principle of their functioning is not given yet. Nevertheless, this principle can be explained on the generalized scheme of a pulsing contours, submitted at Fig.1.

The basic attention in the present work is given just to this class of a heat systems having large duration of cycles, allowing in a number cases to consider a heat transfer processes as quazistationary and to use these devices in the technical application for development of industrial heat and cold supply systems and development of a heat preserving technologies with use of secondary and renewed sources of energy.

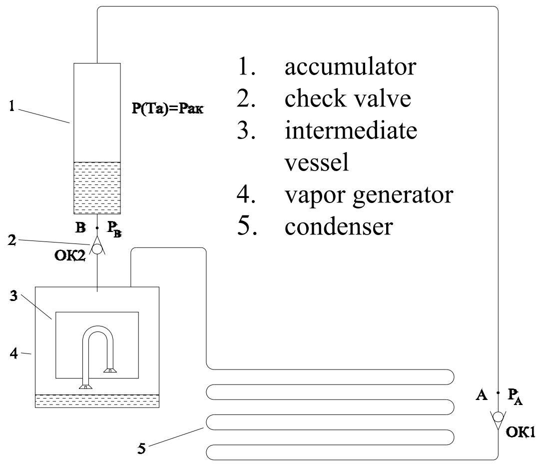

Fig. 1. Scheme of a base heat transport contour.

All devices of a similar type include evaporator, where a vapor generation is occur, the condenser, accumulator, vapor and condensate tubes with the check valves, ensuring a unidirectional movement of heat carrier. The functioning of the device is carried out as follows. With heat loading Q to evaporator, filled by a working liquid, the vapor generation begins. Further vapor is condensed and through check valves flow to the accumulator with pressure approximately equal to pressure of saturation of an evaporating liquid. When the liquid will evaporate from the generator completely, the pressure in it will decrease owing to proceeding vapor condensation in the condenser. The liquid from an accumulator under action of a difference of pressure in it and evaporator will fill throw an intermediate vessel in the generator and heat - and mass transfer processes will be repeated.

It is necessary to note, what even it is enough of the experienced data to allocate two classes of similar devices: highly and low-frequency pulsing system. To the first class it is possible to attribute multiloopback closed or opened contours from capillary tubes [3] or singleloopback contours with check valves [6], in which filling of a liquid of evaporator is carried out in amount incommensurably smaller in comparison with total volume of a liquid in a contour.

The second class involves devices, in which volume of the heat-carrier, evaporating for a running cycle, is commensurable with total volume of a liquid in a contour. It is reached by installation of the additional elements, ensuring a delay of receipt of a liquid in drained vapor generator with subsequent unobstructed its submission, even for period of growth of a vapor pressure with filling of an evaporator.

As it is visible from a Fig. 1, for prevention of growth of pressure in a vapor generator up to complete drainage of a condensate, intermediate accumulation vessel with U-type hydrosyphon to provide filling of necessary volume of a working liquid for creation of the required charge of vapor under high pressure in duration of one cycle, is established inside of vapor generator. In practice the given scheme can be used as a biphase single-loop system for a cooling high heat loaded elements.

MODELING OF A HEAT AND MASS TRANSFER PROCESSES IN A PULSING CONTOUR.

Analytical and experimental researches of a heat and mass transfer processes were carried out for a base contour, schematically represented at a Fig. 1.

The principle of functioning of a base contour completely corresponds to the described above.

The mathematical modeling of a heat and mass transfer processes in various elements qualitatively reflected at Fig. 2.

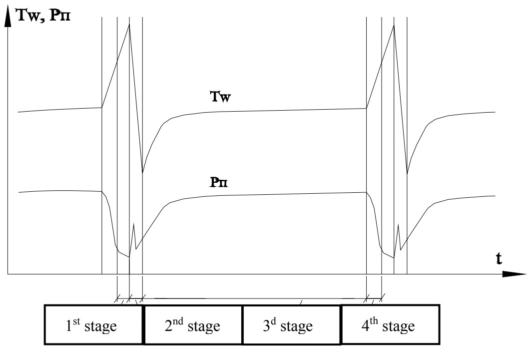

Fig. 2. Qualitative character of change of a vapor pressure
and temperature of heated wall of generator in a pulsing cycle

The established pulsing cycle consists of 4th stages:

1st stage - drainage of liquid from the accumulator to an intermediate vessel. As generator at this stage is completely drained, temperature of a heated surface t_w increases up to the maximal value, and the vapor pressure p_v is reduced slightly by supply of a cold liquid in an intermediate vessel.

2nd stage - drainage of liquid from an intermediate vessel in generator through hydrosyphon. Temperature of a heated surface begins to reduce, and pressure p_v and vapor temperature t_v begin to grow. As it is visible from cyclegramm, at this stage some peak of change of parameters, caused by hit of the first drops of a liquid at a superheated surface, is observed.

3^{d} stage - a steam generation during boiling a liquid and evacuation it in the condenser up to the moment of complete draining of generator. At this stage there is moving a condensate through the check valve to the accumulator of a liquid.

4th stage - change of parameters of a state of saturated vapor in a system “drained generator - cooled condenser”. At this stage there is a fall of vapor pressure up to value, with which becomes possible drainage of a liquid from the accumulator to generator.

The features of the described stages result in (during mathematical modeling) necessity of the solving of system of the equations heat and mass transfer, including a number of correlation.

The hydrodynamic condition of drainage of a liquid from the accumulator to an intermediate vessel through the check valve is defined by an inequality:

$$p_a + \rho \cdot g \cdot h_a - p \geq \Delta p_{ch} \cdot \tag{1}$$

The speed of a drainage liquid from the accumulator in an intermediate vessel with a variable driving pressure drop turns out from the equation of a movement in the form of the equation Bernoulli:

$$w_a(\tau)=\sqrt{\frac{2\cdot g\left(\frac{p_a-p-\Delta p_{ch}-\Delta p_p}{\rho\cdot g}+h_a+h_{ch}\right)}{1-\frac{S_p^2}{S_a^2}}}. \tag{2}$$

The equation for a calculation of a speed of a drainage liquid from an intermediate vessel to generator is writing as the equation of Torrichelli with adjusting factor φ_i, determined experimentally for a particular type hydrosyphon:

$$w_{a(\tau)}=\varphi_i\cdot\sqrt{\frac{2\cdot g\cdot h}{1-\frac{S_p^2}{S_a^2}}}. \tag{3}$$

The equation of thermal balance of a generator has a form:

$$dQ_g=dQ_w+dQ_l+dQ_r+dQ_v\cdot \tag{4}$$

Where: dQg - is heat loaded to generator from a heater; dQ_w, dQ_l, dQ_v - is heat, spent on heating of a wall of generator, liquid and vapor, accordingly; dQ_r - is heat, spent on evaporation of a liquid.

The equation (4) can be written down through parameters of process as follows:

$$q\cdot F_g=M_w\cdot c_w\cdot\frac{dT_w}{d\tau}+M_l\cdot\frac{dH_l}{d\tau}-r(T_v)\cdot\frac{dM_l}{d\tau}+M_v\cdot\frac{dH_v}{d\tau}, \tag{5}$$

Or

$$q\cdot F_g=M_w\cdot c_w\cdot\frac{dT_w}{d\tau}+\alpha_g\cdot F_g\cdot(T_w-T_v)\cdot \tag{6}$$

The rate of removal of a liquid from the condenser is determined by intensity of condensation and size of an active part of its surface, i.e.

$$\frac{dM_c}{d\tau}=\frac{k_c\cdot F_c\cdot(T_v-T_e)}{r(T_v)}. \tag{7}$$

The change mass of vapor in system “generator - condenser” depends on intensity vapor production and condensation, defines volume and length of an active part of the condenser and can be determined from equations:

$$\frac{dM_v}{d\tau}=-\frac{dM_l}{d\tau}-\frac{dM_c}{d\tau}. \tag{8}$$

The system of the equations (1) ÷ (8), having updating for each stage of a pulsing cycle, was solved numerically by method Eiler for an estimation of change of temperature and vapor pressure, temperature of a wall of generator, weight of a liquid in various elements of a contour via time.

COMPARISON EXPERIMENTAL AND CALCULATION DATA.

For confirmation of the offered concept of development of a pulsing heat transport system, the experimental researches of the working characteristics of base model were executed according to the circuit submitted in a Fig. 1.

The experimental installation represents a folding contour with a detachable elements.
Vapor generator 4, fabricated from stainless steel, was made as a cylindrical vessel with diameter of 160/150 mm and height 80 mm. The intermediate vessel 3 with hydrosyphon was fastened to the top cover of inner cavity of generator. In experiments two variants of vessels was used with different in volume ($94{,}2\cdot10^{-6}$ m^3 and $374{,}5\cdot10^{-6}$ m^3) and size of a pipe of hydrosyphon (6/4 mm and 8/6 mm).

For visualization of drainage process the accumulator of a liquid 1 was made from a quartz pipe with a diameter of 60/54 mm and length of 200 mm.

The condenser 5 consists from three consecutive parts: a vertical single row bunch of copper pipes with a diameter of 10/6 mm (4 pipes of common length 2,2 m), a single row horizontal serpentine bunch of copper pipes with a diameter of 6/4 mm (8 pipes of common length 4,4m) and a single row horizontal serpentine bunch of glass pipes with a diameter of 5/3 mm (12 pipes of common length 6,6 m).

A heat load of generator was carried out by an electrical heater with step regulation of capacity. In process experiment the measurements of temperature of a heated surface of generator, pressure of vapor in the accumulator and generator, speed of filling and drainage of a liquid in the accumulator, volume of draining liquid were carried out.

For an estimation of conditions of a condensate's drainage from the accumulator to an intermediate vessel, experiment were carried out both for the closed system, and for a case, when the accumulator incorporated to an environment (opened system) and the pressure in it remained constant on the whole extent of a cycle.

The typical experimental data for closed and opened systems are submitted at Fig. 3 and Fig. 4, accordingly. There the results of the numerical analysis at the offered model are submitted. As it is visible from the diagrams, opened system has a higher temperature level of vapor generator because of more high pressure of saturation of vapor. In both systems, time of drainage of a liquid from the accumulator (the site of sharp fall of pressure) is a few of tens seconds only, therefore sharp increase of temperature of a heated surface does not occur.

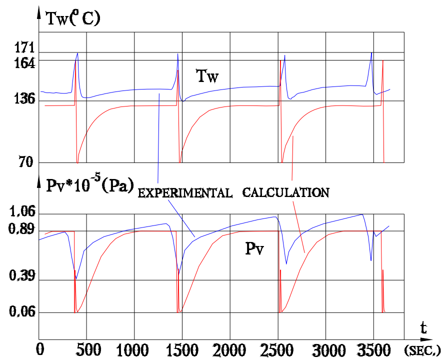

Fig. 3. Comparisons of results of experiment with calculated data for closed system

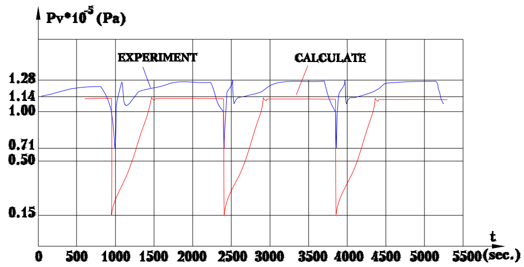

Fig. 4. Comparisons of results of experiment with calculated data for opened system

As it is visible from Fig. 3, amount of a liquid, passing from the accumulator to an intermediate vessel, can change from a cycle to a cycle, therefore their duration can a little bit deviate from calculated meaning, determined by height hydrosyphon.

The given data also show, that the analytical model not only is qualitative, but also quantitatively reflects mechanisms of a heat and mass transfer processes in pulsing cycle and can be used for designing similar systems for the given conditions of functioning. For most long of 3rd stage of a cycle, a divergence between an experimental and calculated data does not exceed 20%.

The tests of a heat supply system also have shown perspective of the chosen direction of development. With distance of a heating devices from generator more, then 6m, installation was provided transport through a heating contour of the heat-carrier with the average charge of 0.025 kg/s with downturn of the heat-carrier temperature in 20^0C It corresponds to loading at the device approximately 1 kW with an expense 1700 W of capacity in generator.

OPPORTUNITIES OF APPLICATIONS

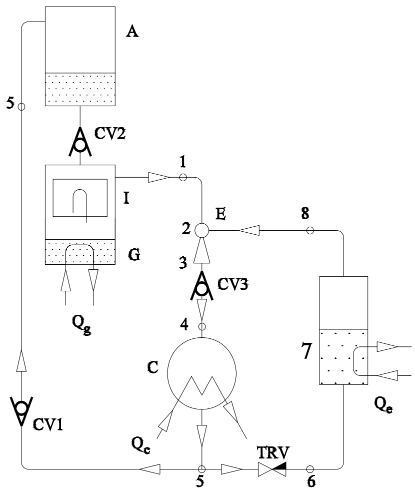

Fig. 5: Basic scheme of a pumless vapor ejecting refrigerating machine.
A - Accumulator, E - ejector, CV - check valve, E - evaporator, TRV - thermocontrol valve.

In the scheme of cold supply system at Fig. 5 in a vapor generator of a base contour supersonic ejector is established for creation of the lowered pressure in evaporator of a refrigerating contour.

The offered mathematical model of calculation of forced contour of the refrigerating machine, complemented by an original method of calculation of a supersonic ejector [9], was used for an estimation of the functional characteristics two-loop vapor-ejecting of refrigerators included in structure of an air condition system and using energy of untraditional sources of heat (solar and geothermal energy). This estimation was carried out with account of an alternative choice of the heat-carrier and included the following elements:

- Choice of parameters of a refrigerating cycle for the given conditions of functioning,
- Definition of achievable factor of injecting and geometry of a vapor-jet ejector,
- Calculation of parameters in characteristic points of forced and refrigerating contours in a running cycle,

Some comparative characteristics of calculated parameters for vapor-ejecting refrigerators with freons R21, R22 and NH3 are submitted in Tab. 1.

Table 1. Calculated parameters of a refrigerating cycle

Calculated parameters	Unit	NH_3	R21	R22
Temperature of working flow	^{0}C	70	90	90
Temperature of injected flow	^{0}C	15	15	15
Temperature of mixed flow	^{0}C	45	45	45
Pressure of working flow	10^{-5}Pa	33.117	10.684	44.43
Pressure of injected flow	10^{-5}Pa	7.2881	1.29145	7.892
Pressure of mixed flow	10^{-5}Pa	17.826	3.4512	17.266
Diameter of critical cross section of nozzle	Mm	1,2		
Factor of injection		0.03313	0.17770	0.13145
Head load of a generator	W	7562	1123	3707
Cooling capacity	W	248	171	17
Head removal from condenser	W	7810	1294	4224
Refrigeration coefficient	%	3.28	15.23	13.95

Calculated parameters of a refrigerating cycle, submitted in Tab. 1, reflects purpose of installation (at a temperature level of work of low temperature evaporator), condition of cooling of the condenser with natural convection of an environment and temperature potential of a source of heat in a generator (low-potential secondary or renewed sources). The results of calculations show, that freon R21 is the best refrigerant.

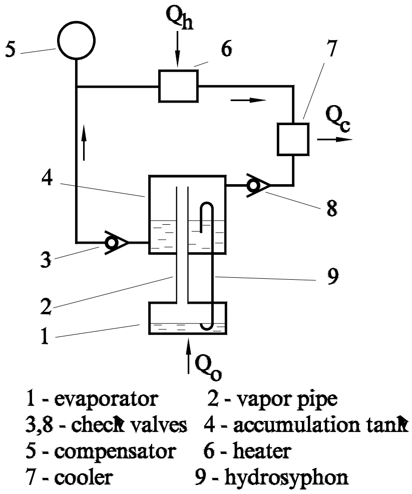

Fig. 6. Pump circuit scheme.

In the scheme of a heat supply system at a Fig. 6 a vapor generator of the base circuit the jet pump is established. Simultaneously it is carrying out a role of the condenser, and, ensuring circulation of a liquid heat-carrier in a heating contour with involved in it according to the standard scheme boiler 3 and accumulator 5. Filling of a drained vapor generator is carried out by a drainage of the heat-carrier from accumulator in an intermediate vessel and subsequent (with a delay) it's drainage to a generator.

In the pump scheme at Fig. 7 the biphase pulsing contour serves as a pump of volumetric action for a liquid in a outer heat transport loop.

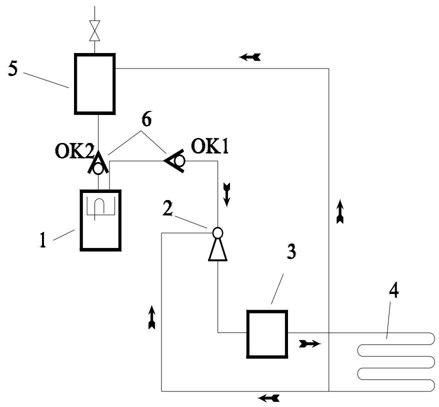

Fig. 7. The scheme of pulsing heat supply system
1 - generator, 2 - jet pump, 3 - boiler, 4 - heating device, 5 accumulator, 6 - check valves.

CONCLUSION

Carried out theoretical and the experimental researches low-frequency of a pulsing heat transport system have shown their good perspectives in development of a heat technology schemes and installations of energy saving engineering. By the greatest image, their advantage are displayed with use of secondary and renewed sources of energy in autonomous heat and cold supply systems.

Nomenclature

c - heat capacity, F - surface, g - acceleration, h - height, H - enthalpy, M - mass, p - pressure, r - latent heat of vaporization, S - cross section, t - temperature, q - specific heat flax, Q - heat flux, α - heat exchange coefficient, φ - correcting coefficient, ρ - density, τ - time,

Indexes:
a - accumulator, c - condenser, ch - check valve, e - environment, g - generator, i - intermediate vessel, l – liquid, v - vapor, p - draining pipe, w - heated wall,

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