ANTIGRAVITATIONAL HEAT TRANSMITTING LOOP WITH PULSATION OF WORKING FLUID

Vasily Buz
Thermophysic department
Odessa Mechnikov's National University
2, Dvorianskaya St., Odessa, 65026, Ukraine
Tel.: 380-0482-427677, E-mail: buz@farlep.net

Boris Afanasyev
Thermodynamic department
Odessa State Academy of Refrigeration
1/3, Dvorianskaya St., Odessa, 65026, Ukraine
Tel.:380-0482-246369, E-mail: aiec@tm.odessa.ua

Abstract

The research results of a natural circulation two-phase loop, which is not containing of valves and providing heat transfer from above downwards are submitted. The contour contains evaporator, condenser, compensation chamber and two hydro-locks. Evaporator represents a usual pipe without porous structure. The principle of action is based on periodic short-term drying of an evaporator internal surface and decrease of pressure in steam volume. The long-term work of this device is provided due to simultaneous action of weight forces, pressure and inertia. With the check purpose of this loop serviceability a breadboard of glass pipes is made. The working fluid is water. The experiences have shown an opportunity of long-term and steady work of a loop. The simplified mathematical model of the offered device and examples of solutions results is submitted. The qualitative and quantitative conformity of solutions results and experiences is observed. The solutions results also have shown, that there are top and bottom limits of a contour serviceability both on value of thermal loading, and on elevation of evaporator above the condenser. The long-term steady work of a contour is possible only at the certain ratio of the loop elements geometrical sizes.

KEYWORDS

Two-phase loop, evaporator, condenser, pulsating, hydro-lock, gravity, heat transfer, modeling, experimentation.

INTRODUCTION

The wide circulation in ground thermoregulation and heat transfer systems was received two-phase heat transmitting device with transfer of the working fluid by forces of weight – two-phase thermosiphons, loops of natural circulation. They favourably differ from systems with a mechanical forcing of the working fluid by autonomy, high reliability, profitability of operation, self-regulation of work. However, such devices work only in a field of forces of weight and are capable to transfer heat only from below upwards. For carry of heat in an opposite direction in the literature the wide enough spectrum of independent devices with a various principle of action is known which differ essentially by smaller efficiency and reliability. On a way of moving of the working fluid such devices can be divided into three basic groups:

1. Device with moving of the working fluid at the expense of forces of a superficial tension - usual heat pipes and loop heat pipes.
2. Devices with moving of the working fluid by pressure forces - various designs of two-phase loops of periodic action with switches and valves [1, 3, 4],
3. Devices with moving of the working fluid by forces of pressure and inertia - pulsating heat pipes [1,2, 5, 6].

In last 10 years the interest to second and third groups, by quantity of the publications, sharply has grown. Nevertheless, the work of all these devices differs by small transmitted heat flows, low reliability, problems of start up and regulation of work.

DESCRIPTION OF THE PROPOSED DEVICE

In the present work the two-phase loop of natural circulation providing transmitting of heat from above downwards is offered without valves. This loop, probably, in some cases can become alternative to devices, known in the literature. The long work of the offered device is provided due to simultaneous action of weight forces, pressure forces and inertia forces. The circuit of a loop is submitted in a Fig. 1. The loop consists from hydro-locks 1 and 2, evaporator 3, condenser 4 and reservoir 5.

A principle of a loop action the following. When evaporator walls become dry, the inflow of vapor mass in vapor volume of evaporator and condenser is stopped, while the outflow of vapor mass at the expense of condensation is continuous. There is a fast fall of pressure in vapor volume. Owing to this the liquid from a reservoir 5 through hydro-locks 1 directs in evaporator, and from hydro-lock 2 - in the condenser. Having got on a overheating wall the liquid is boils, owing to this the pressure in vapor volume is increased. The increasing of pressure is promoted also by that to this moment the condenser is partially flooded with a liquid from hydro-lock 2. Because increasing of pressure in vapor volume the return movement of a liquid in hydro-locks begins. This process continuous and after replacement of a liquid from evaporator (owing to various hydraulic resistance of sites moving of a liquid in hydro-locks 1 and 2 is various). Under action of pressure forces and inertia forces the liquid in hydro-locks 2 moving upwards against forces of weight and some part of a liquid is poured in a reservoir 5. After drying a film of a liquid on a evaporator wall the process repeats. Such significant moving of a liquid in hydro-locks occur at weak change of a liquid level in reservoir 5.

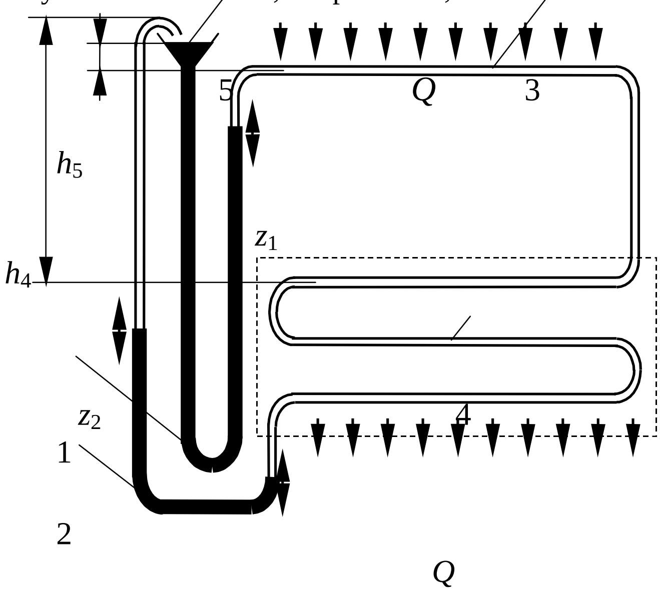

Fig. 1. The scheme of antigravitational heat transmitting loop with the pulsating working fluid.

It is necessary to note, that the described process will repeat long time only at the certain ratio of the geometrical sizes, which are selected experimentally or as a result of numerical solutions.

EXPERIMENTATION

If for all others, considered above, types of heat transmitting devices there is an extensive experimental material and the fact of their serviceability does not cause doubts, for an offered antigravitational two-phase loop of such data is absent. With the purpose of basic check of serviceability of this loop the breadboard model from glass pipes is made according to the scheme on the Fig. 1. Evaporator represented pipe from a quartz glass with an outside heater from nichrome string. Evaporator length $l_3 =$ 0.44 m, evaporator heat power $Q = 50 \div 70$ W, working fluid - water, total length of the condenser $l_4 = 1.8$ м, cooling of the condenser - air. An internal diameter of a contour $d = 4$ mm, total length of a loop $l_\Sigma = 7.3$ m, evaporator elevation above the top point of the condenser 0.45 m.

In experiences except visual supervision the measurements of vapor-liquid fronts coordinates, amplitudes and the periods of their fluctuations, the average flow rate of the working fluid in a loop and heat power of the electro-heater was defined.

Results of experiences testify to the following:

1. Long steady work of the device in the established regime is possible.
2. There are problems with start up of a device. Before start the loop was completely filled by water. At a heat loading and appearance of a vapor phase in the evaporator intensity of fluctuations is too small and to achieve spontaneous start up of a device, as a rule, it was not possible. After creation of several compulsory fluctuations of a liquid in hydro-locks there was steady autonomous fluctuations of the working fluid.
3. Work of a contour does not depend on reservoir 5 position concerning the evaporator.
4. In the basic modes of operation owing to the big amplitude of fluctuations the liquid periodically is filling about 80-90 % of the evaporator length.
5. Under the same conditions there is a second steady mode of operation at which the liquid periodically is filling only about 10 % of the evaporator, and the basic part of the condenser is flooded.
6. In separate cases the fluctuations may be so large, that the liquid fills in all evaporator, and then and all loop. Boiling in the evaporator thus on some time stops because the large amount coming of the overcooled liquid. After this the restart of a loop begins. This restart occasionally occurs independently. The phenomena marked in item 2 are observed.
7. At the big heat loading and insufficient condenser length the vapor completely oust a liquid from second hydro-lock. At that the first hydro-lock and the evaporator steadily work in a former regime, and a noncondensate part of the vapor go to environment.

MODELING

Let's consider the simplified mathematical model of the offered device. According to the scheme on Fig. 1 we think, that in the evaporator and the condenser there is the uniform steam volume separated from an environment two hydro-locks with lengths of columns of a liquid l_1' And l_2'. The equations of preservation of quantity(amount) of movement for hydro-locks 1 and 2 we shall write down, accordingly, as:

$$\rho' l_1' \frac{d^2 z_1}{d\tau^2} = \left(p_0 - p\right) - \frac{A l_1' \mu'^n \rho'^{1-n}}{d^{1+n}} \left(\frac{dz_1}{d\tau}\right)^{2-n} + \rho' g\left(h_1' + z_1 - l_1'\right), \qquad (1)$$

$$\rho' l_2' \frac{d^2 z_2}{d\tau^2} = \left(p_0 - p\right) - \frac{A l_2' \mu'^n \rho'^{1-n}}{d^{1+n}} \left(\frac{dz_2}{d\tau}\right)^{2-n} + \rho' g\left(h_2' - z_2\right), \qquad (2)$$

where members represent, correspondently, forces of inertia, pressure, friction and weight. It is accepted, that at a laminar flow case $A = 64$, $n = 1$, At turbulent flow $A = 0.316$, $n = 0.25$.

The combined equations of material and thermal balance of vapor volume, liquid volume in the second hydro-lock and a liquid film on a wall of the evaporator, accordingly, have the following view:

$$r \frac{dm_2''}{d\tau} = \frac{\lambda'}{\delta} \pi d l_3 \left(t_w - t_s\right) - k_4 \pi d l_4'' \left(t_s - t_0\right), \qquad (3)$$

$$r\rho' \frac{\pi d^2}{4} \frac{dl_2'}{d\tau} = k_4 \pi d\, l_4''(t_s - t_0), \qquad (4)$$

$$\frac{d\delta}{d\tau} = -\frac{G_3}{\rho' \pi d l_3}, \tag{5}$$

The system is closed by the equation of a vapor volume condition which in the elementary kind we shall write down:

$$\frac{dp}{d\tau} = \frac{kR(t_s + 273)}{\omega l''^2}\left[l''\frac{dm''}{d\tau} - m''\frac{dl''}{d\tau}\right], \tag{6}$$

It is necessary to add the following conditions to system of the equations:

Overflowing into a reservoir condition, if $z_2 < 0$ then $l_2' = l_2' + z_2$;

Drying of the evaporator condition, if $\delta < 0$ then $\delta = 0$

Filling of the evaporator condition, if $z_1 > l_1$ then $\delta = \delta_0$

Length of a condensation part of condenser $l_4 = l_\Sigma - l_1 - l_n - z_2 - l_2'$

The system of the equations (1) - (6) represents Coshy task to which Runge-Cutt solution method was applied

RESULTS AND DISCUSION

Examples of established regime calculations results for experiment conditions are submitted on Fig. 2. The calculated pulsations qualitatively well correlate to results of experiment. Quantitative comparison which also can be counted satisfactory, is presented in Table 1. At achievement of the maximal value z_1 (see Fig. 2) occurs the covering by liquid of overheated evaporator walls and the quick growth of pressure in vapor volume of evaporator and condenser. At that z_1 and z_2 begin to decrease. z_2 is decreasing up to zero and at this moment occurs the liquid overflow from hydro-lock 2 in reservoir 5 (Fig. 1).

Table 1

Parameters	Experimentation	Modeling
Period of low-frequency pulsations, s	4	3.8
Period of high-frequency pulsations, s	0.5	0.8
Amplitude of a liquid pulsations in the first hydro-lock, m	0.3÷0.4	0.45
Amplitude of a liquid pulsations in the second hydro-lock, m	0.5÷0.7	0.8

Influence calculation results of thermal loading Q significance and heights of a loop h_4 are submitted on Fig. 3. There are upper limit and lower limit of a loop serviceability both in dependence from Q, and in dependence from h_4. At decreasing Q the maximal pressure difference between vapor volume in the evaporator and the condenser is decreasing, the amplitude of pulsations is decreasing and at some minimal value Q the liquid ceases overflowing from the second hydro-lock to the reservoir 5, the condenser gradually is filling, pulsations die away also a loop work is stop.

At excessive increase Q the pulsations amplitude is increasing, in result is decreasing the liquid length in the second hydro-lock which according to Fig. 3 achieves zero at Q = 80 W.

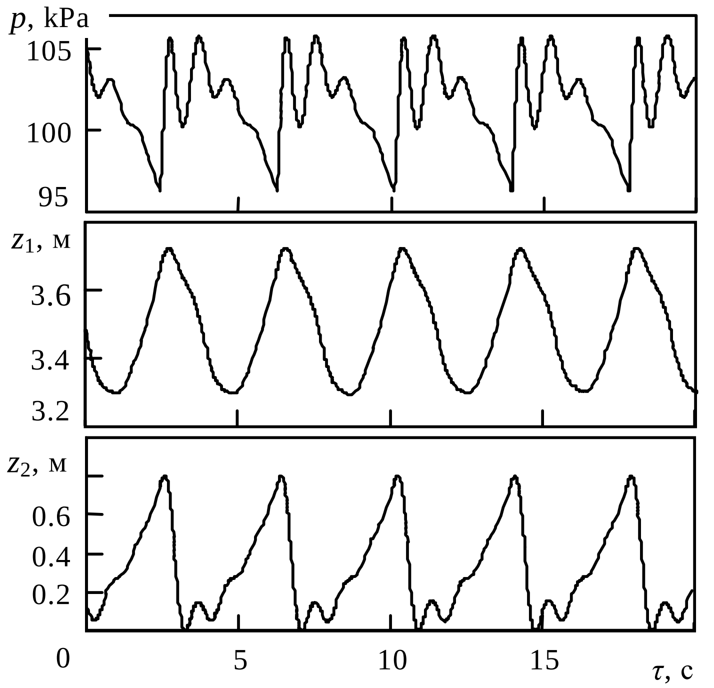

Fig. 2. Calculations results of change in the time of pressure p in vapor volume of evaporator and condenser, coordinates of vapor-liquid fronts z_1 - before evaporator in 1 hydro-lock and z_2 - in elevating branch hydro-lock 2 (the beginning of z - surface of a liquid in reservoir 5)

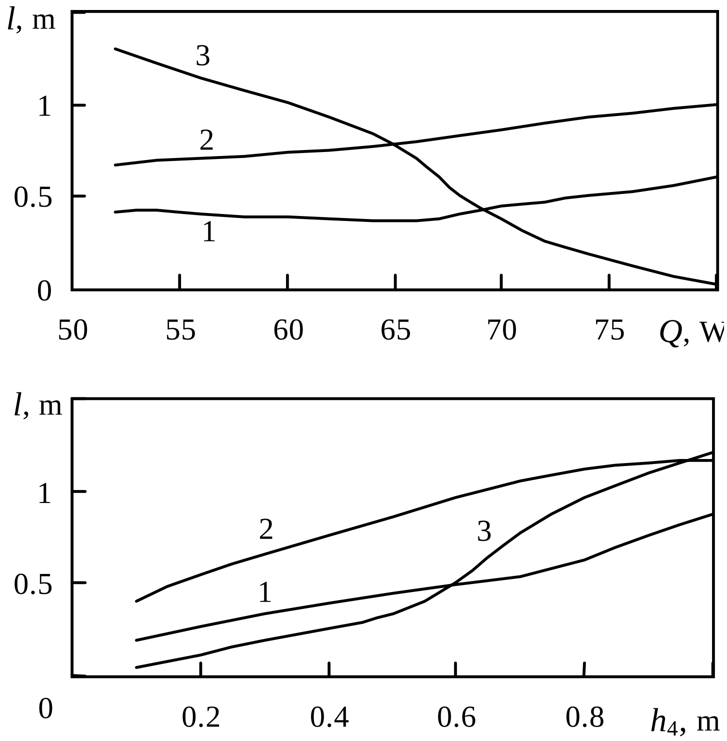

Fig. 3. Dependence of fluctuations amplitude in the first (line 1) and the second (line 2) hydro-lock, lengths of a liquid lock (line 3) in the second hydro-lock from heat power loading on evaporator Q (at h_4 = 0.5 m) and from height of a loop h_4 (at Q = 70 W)

The increase h_4 (due to increase of distance between the evaporator and the condenser) results in growth of amplitude of pulsations, that finally bring to filling by a liquid of the evaporator and all contour. According to results of calculations, for a considered contour it occurs at h_4 = 0.9 m.

The submitted results of calculations and experiments are showing, on the one hand, basic serviceability of an offered antigravitational heat-transmitting loop, on the other hand, are showing enough complicated behaviour, at first sight, the simple device.

CONCLUSION

Experimental and numerical researches have shown basic serviceability of the offered heat-transmitting loop with the pulsating of working fluid. The opportunity of long steady work of a pulsating loop is experimentally confirmed.

Problems are possible at start up of a loop and the transitive regimes, connected by the discontinuance of pulsations. The physical reasons of this phenomenons are revealed in the report.

There is a upper and lower borders of the loop serviceability on value of a heat power, and on value of the evaporator elevation above the condenser. Values of these borders may be calculated by the offered model.

Nomenclature

A - numerical coefficient
d - diameter, m
G - mass flow rate, kg/s
g - gravitation acceleration, m/s^2
h - height, m
k - adiabatic parameter
$k_{3,}$ k_4 - factors of a heat transfer in evaporator and condenser, W/(m^{2}K)
l - length, m
m - mass, kg
n - numerical coefficient
p - pressure, Pa
Q - heat power, W
R - gas constant, J/K
r - latent heat, J/kg
t - temperature, ^{O}C
z - coordinate along a loop, m
ρ - density, kg/m^3
μ - viscosity, Pa $\cdot$ s
λ - heat conductivity, W/(m $\cdot$ K)
τ - time, s
ω - area of cross section, m^2
δ - liquid film thickness on the evaporator wall, m

Indexes:
‘ - liquid
“ - vapor
0 - environment; initial data
1, 2 - number of hydro-lock
3 - evaporator
4 - condenser
s - saturation
Σ - summary

References

1. Akachi H., Structure of a Heat-Pipe, *US Patent No 4.921.041*.1990.
2. Maezawa S., Nakajima R., Akachi H., Experimental Study on Chaotic Behavior of Thermohydraulic Oscillation in Oscillating Thermosyphon, *Proceedings of 10th Int. Heat Pipe Conf.*, Stuttgart, Gegmany, 1997, paper F-3.
3. Sasin V. Ya., Borodkin A.A., Bolotin E.M. etc., Development and research twophase nonpumping heat-transmitting systems, *2nd Russian National Heat Transfer Conference*. Moscow, 1998, V.5, pp.93-96.
4. Kawataba K., Hashimoto N., Kamiya Y., Anti-gravity Heat Pipe, *Proc. of the 5th Int. Heat Pipe Symposium ‘Heat Pipe Technology. Theory, Application and Prospects’*, Melbourne, 1996, pp. 168–175.
5. Kuznetsov I.O., Smirnov H.F., Garda A.N., Experimental research Pulsating Heat Pipe with nonsegregated channel performance, *2nd Russian National Heat Transfer Conference*. Moscow, 1998, V.4, pp.364-367.
6. Borisov V., Buz V., Coba A., Kuznetzov I., Zacharchenko A., Smirnov G., Modeling and Experimentation of Pulsating Heat Pipes, *Proceedings of 12th Int. Heat Pipe Conf.*, Moscow, Russia, 2002, paper B-3.