THERMOSIPHON WITH SEPARATED VAPORIZER AND CONDENSER RESEARCH

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Abstract

Availability of large dimension thermosiphon as an element of steam generating plant was considered. We have executed experimental investigation in thermosiphon boiling zone. Possibility of intensification of heat exchange was considered. As a result of this investigation we have got data about temperature distributions of heating wall, temperature of water-steam mixture lengthwise of evaporation zone, local heat flaws and boiling heat-transfer coefficients were accounted. Possibility of increasing of heat-transfer coefficient by organization of boiling in inhibited conditions in particular in annular gaps.

KEYWORDS

Two-phase thermosiphon, steam generating plant, experiment, heat transfer enhancement.

INTRODUCTION

Dniepropetrovsk National University (DNU) during last ten years very successfully had been doing research and development of two-phase thermosiphons of different construction and functions in traditions and untraditional execution. On the base of these thermosiphons we created compact and automated plants, which provided heat generator and transport for the purpose of heating and thermostating of objects for different function, these plants are very reliable and simple in exploitation.

To reduce size and weight of thermosiphons and to increase reliability of heating elements the task of intensity of heat exchange during the boiling in the two-phase thermosiphons is a very relevant. One of the most perspective ways of intensity of heat exchange is the fulfillment of boiling in contracted conditions in particular in annular gaps.

There is lot of researches dedicated to the processes of heat exchange in contracted conditions. But results of these researches are not suitable to evaluate the main descriptions of heat exchange in large-scale thermosiphons. On the base of research laboratory DNU we executed complex of experimental researchers of heat and mass exchange during the boiling in the large-scale thermosiphons.

CONSTRUCTION OF THE LARGE-SCALE THERMOSIPHONS

Different electric heaters application applies essential features to the constructions of vaporizers of thermosiphons. As the heaters in the vaporizer tubular electric heating element, cathode heaters and developed by our organization active-inductive heaters are used.

Active-inductive heaters is a vertically-placed pipe (diameter 130 mm, length 1000 mm), there is a helical flute outside covering by insulating coating. This coating keeps its properties at temperature 500 ^{o}C. The current installing steel wire is put into the helical flute. Such heating blocks have electric power from 15 to 25 kW. Vaporizer of thermosiphons can consist from several heaters; their number is determined by necessary power transferred by thermosiphons. The total power of vaporizers reach 300 kW, steam pressure reaches 3 MPa.

In case of tubular electric heating elements application these elements are installed into horizontal or vertical pipes. In the thermosiphons with such heaters steam pressure can reach 8 MPa, total power – 800 kW.

The vaporizers combined with the induction-active heaters and tubular electric heating elements were used. They are installed into the internal steam pocket of the vaporizer. As a result such heater black has got 40-45 kW power.

The organic coolants as dowtherm and naphthalene are used in the thermosiphons. It is necessary the steam temperature in the thermosiphons to be heated up to 380 ^{o}C.

Various heat exchangers, autoclaves, press plates heated by steam and other devices served as a condenser for the thermosiphons with separated vaporizer and condenser (fig.1).

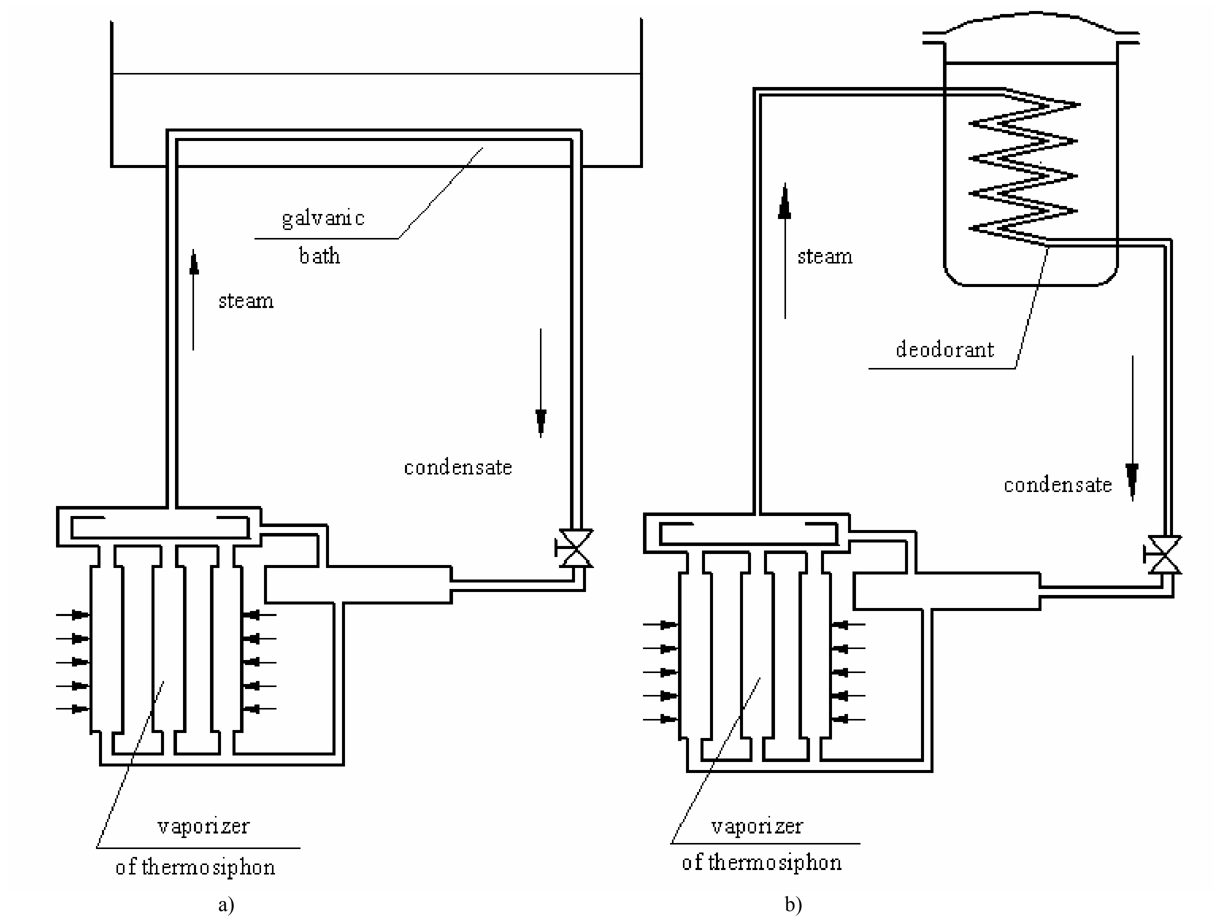

Fig. 1. Thermosiphon contour scheme: a) condensation zone — galvanic bath; b) – condensation zone– deodorant

The double-circuit steam generators are used to receive a consumption of steam for technological purposes. The primary circuit is a closed thermosiphon, where a condenser is a shell-and-tube heat exchanger on which surface steam consumption is generated. The heat exchanger could be disposed either vertically or horizontally. With a vertical disposition of the heat exchanger an instable work of the primary circuit was observed. The reason of it was provoked by a heat carrier handing up on the internal surface of the pipes.

THE AIM OF THE RESEARCHMENTS

The necessity to reduce overall dimensions and weight of thermosiphons keeping their absolute efficiency and reliability required providing the investigations to intensify heat exchange processes in the zone of vaporizers. One of the most perspective ways of intensity of heat exchange is the fulfillment of boiling in contracted conditions in particular in annular gaps. The main purpose of the investigation was to define the temperature distribution lengthwise a boiling zone of the thermosiphon and boiling heat-transfer coefficients in the large scale thermosiphons. It is also important to define an influence of an annular gap on the heat transfer enhancement.

THE EXPERIMENTAL PLANT

The experimental plant was developed to satisfy the suggested task. The boiling process in the plant was performed in a annular gap 1000 mm high, by 140 mm external diameter and 3, 4 and 5 mm slit width. The heat was supplied by steam toward the internal wall of the gap. The plant included a experimental unit, heating facilities and a calorimeter (fig 2). The test unit was like a boiling zone of closed two-phase thermosiphon. It was performed like two annular tubes that formed a slit gap (7) and (8). The boiling process was going on the internal surface of a steel pipe by 140 mm diameter and 5 mm wall thickness. The external pipe 180 mm and 3 mm wall thickness formed a ring space with internal pipe. The height of the boiling zone was 1000 mm.

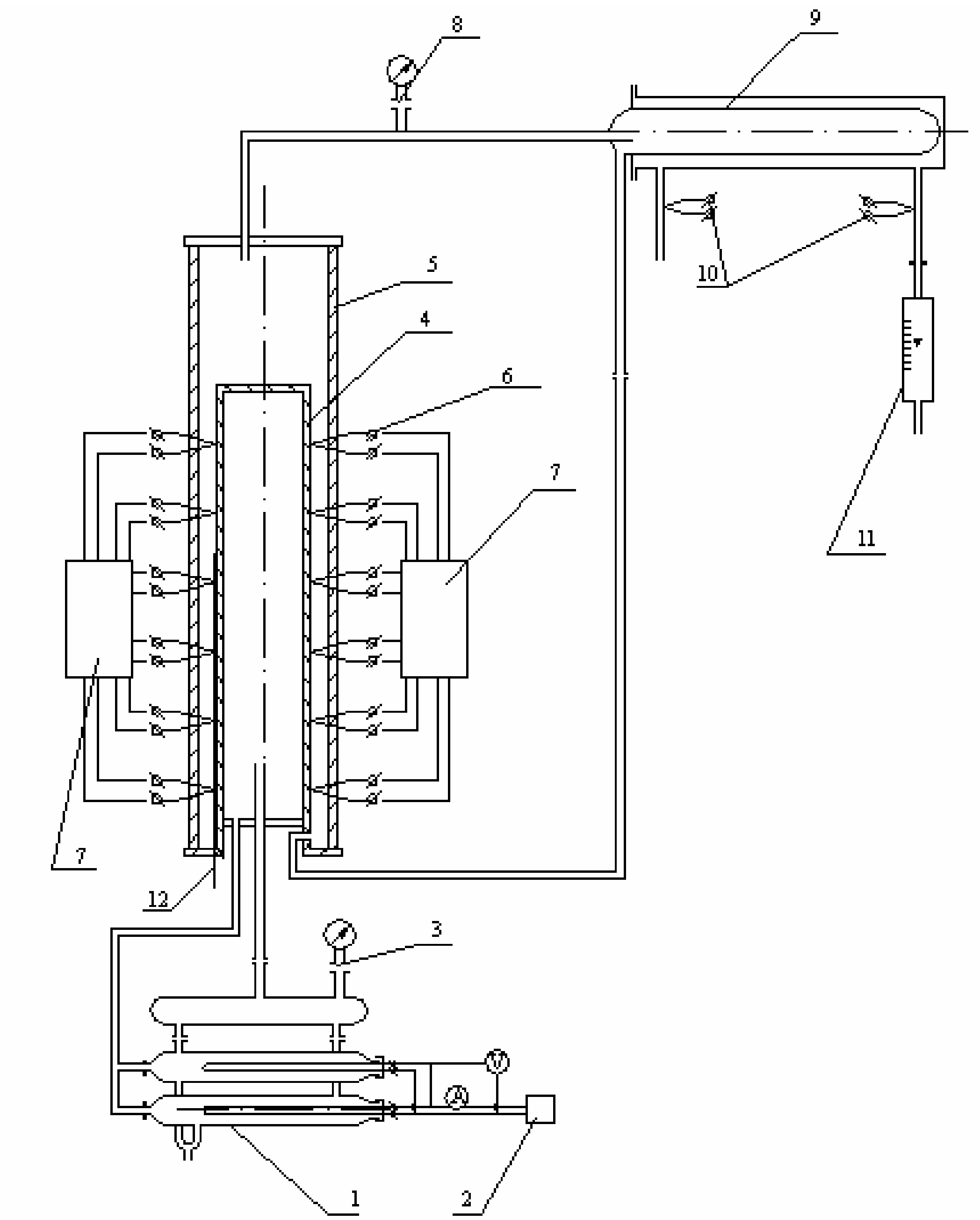

Fig. 2. Experimental plant scheme: 1 – heating facilities; 2 – measurement system, 3, 8 - manometers, 4-heating wall, 5 – frame, 6, 10 – thermocouples, 7 - measurement system, 9 – calorimeter, 11 – rotameter, 12 - thermocouple probe

The heating process was performed under steam of high pressure that flowed into an internal space of a steel tube. On the external and internal surfaces of the experimental unit in 6 sections with 150 mm pitches that were welded on 12 chromel-copel thermocouple by a spot-welding (6 thermocouples in the internal surface and 6 in the external one). The cold ends of the thermocouples were output through the pressure seal installed into the bottom. The temperature of the liquid-vapor mixture in the annular gap was estimated by the thermocouple probe set into the tube by 2 mm diameter.

The experimental plant measurement system included:

- different measurements of the temperature difference of the experimental unit walls;
- the absolute temperature wall measurement;
- the temperature measurement of the liquid-vapor mixture according to the height of the experimental unit;
- the temperature measurement of the cooling water;
- the measurement of the water consumption;
- the measurement of the electrical power input;
- the measurement of the pressure in the experimental unit and heating facilities.

Heat-flux density varied from 10 to 50 kW/m^2, pressure in thermosiphon changed from 0,1 to 0,7 MPa.

ROUTINE OR EXPERIMENT

The experimental unit and heating facilities were filled by heat carrier – water to the level 1200 mm lengthwise the height of the evaporation zone. Nondensables were moved off the plant. Defined level of the power was established.

Necessary pressure in the experimental unit was provided by the choice of cool water discharge. After steady-state conditions appearance temperature distributions of heating wall, temperature of liquid-vapor mixture lengthwise of evaporation zone, temperature of heating steam were measured. Water temperature in the exit and entrance of the calorimeter, water discharge and electrical power were measured simultaneously. Steady-state conditions in another level of pressure established by water discharge change.

The experiments were made in the thermosiphon without intensificator in so-called “large volume”, with heat exchange intensificators as the cylindrical deflectors, which provided annular gaps 5, 4 and 3 mm.

Using obtained data about temperature distributions of heating wall in the evaporation zone and saturation temperature for each regime the average meanings of heat-transfer coefficient were accounted:

$$\overline{\alpha} = \overline{q} \, / \, (T_w - T_s), \tag{1}$$

where $\overline{q}$ - average heat-flux density;

T_s - saturation temperature;

T_w – temperature of heating wall.

The average heat-flux density was determined from the formulas:

$$\overline{q_н} = I\, U / S, \tag{2}$$

$$\overline{q_н} = m\, c_p\, \Delta\, t / S, \tag{3}$$

where S – total surface of heat exchange in the heating zone;

I - current strength;

U – voltage;

m - cooling water discharge;

$\Delta\, t$ – temperature difference of cooling water, $\Delta\, t = T_{ex} - T_{int}$;

c_p - average heat capacity in the range from T_{ex} to T_{int}.

Local meanings of the heat exchange koefficients in the heating zone were estimated. Local heat flux is determined from the formula

$$q_i = \lambda_w \cdot \Delta T / \delta, \tag{3}$$

where λ_w - heat conductivity koefficient of wall material;

ΔT – temperature difference between internal and external surface of the wall ($\Delta T = T_{in} - T_{ex}$);

δ – the thickness of the heating wall.

Local coefficient of the heat exchange is determined from formula

$$\alpha_i = q_i / (T_w - T_s), \tag{4}$$

where T_w – local temperature of the wall internal surface.

THE RESULTS

The results of experimental researches of boiling heat exchange in thermosiphon at heat flow density 22 kW/m^2 and 44 kW/m^2 are represented (at the given construction that corresponds to powers 10 and 20 kW).

The characteristics of temperature distributions of heating wall, temperature of water-steam mixture lengthwise of evaporation zone are obtained, local heat flows and heat exchange coefficients are accounted.

The typical temperature distribution of heating wall and heat exchange coefficient in the boiling zone are shown in figure 3.

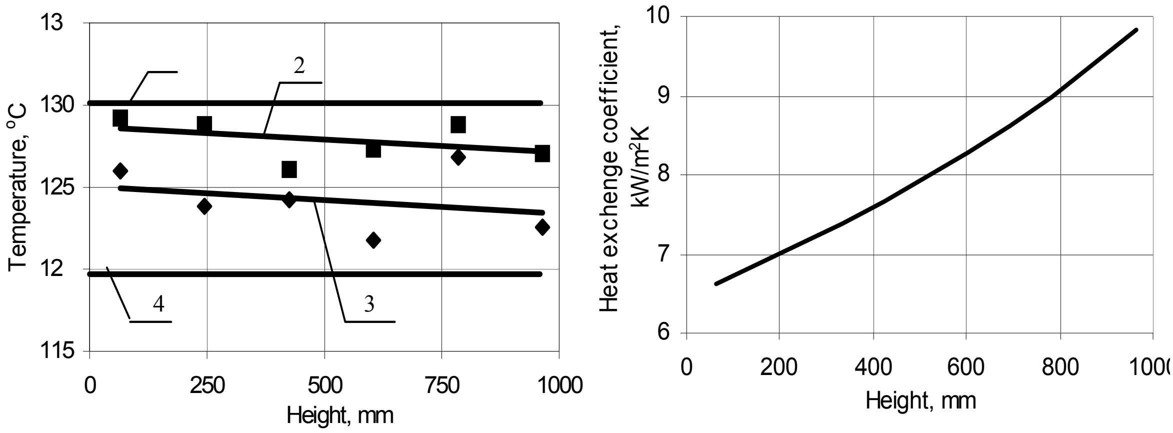

Fig. 3. Temperature distribution and heat exchange coefficient lengthwise of evaporation zone1 – heating stream temperature, 2 – temperature of inner heating wall, 3 – temperature of external heating wall, 4 – temperature of liquid-vapor mixture

Heat flow density 22 kW/m^2, annular gap 5 mm, pressure 0.197 MPa.

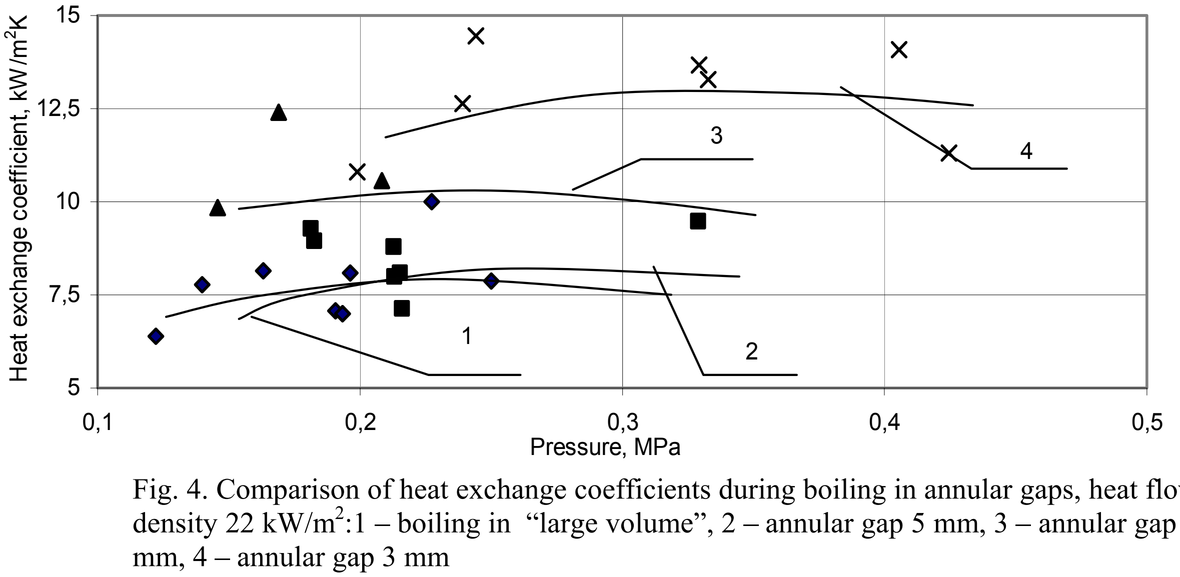

Fig. 4. Comparison of heat exchange coefficients during boiling in annular gaps, heat flow density 22 kW/m^2:1 – boiling in "large volume", 2 – annular gap 5 mm, 3 – annular gap 4 mm, 4 – annular gap 3 mm

As it can be seen from fig. 3 the temperatures of external and internal heating wall are decreasing along evaporation zone of the thermosiphon. It can be explained by following: steam quality is increasing lengthwise evaporation zone in annular gap. It leads to increasing of heat exchange coefficient, which decreases wall temperatures.

Comparisons of heat exchange coefficients during boiling in annular gaps 3, 4 and 5 mm and in "large volume" depending on pressure in the thermosiphon are shown in figure 4 and 5.

The heat exchange coefficient increase at heat flow density 22 kW/m^2 were observed starting from annular gap 4 mm, heat exchange coefficient at boiling in the gap 5 mm differed insignificantly from heat exchange coefficient at boiling in "large volume".

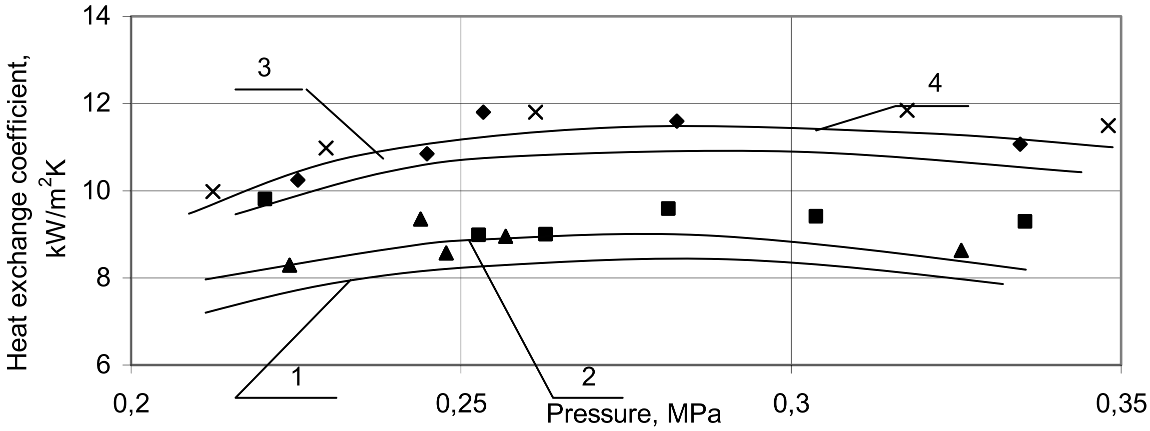

Fig. 5. Comparison of heat exchange coefficients during boiling in annular gaps, heat flow density 44 kW/m2:1 – boiling in "large volume", 2 – annular gap 5 mm, 3 – annular gap 4 mm, 4 – annular gap 3 mm

As it can be seen from fig. 4, 5 annular gaps 3 and 4 mm have the largest intensificating influence to heat exchange. Heat exchange coefficient in the gap 3 mm increased greatly the value of heat exchange coefficient in "large volume".

The decrease of heat exchange coefficient in gap 3 mm at heat flow density q=44 kW/m^2 in comparison with q=22 kWt/m^2 is explained by high steam quality and steaming liquid-vapor flux and, probably, drainage of wall.

CONCLUSIONS

The constructive properties of large dimension thermosiphons and the ways of their application in the industry are considered in the work. The experimental researches of heat exchange processes in the evaporation zone of thermosiphon are carried out.

The influence character of the size of annular gap to the heat transfer enhancement is defined. These researches show the possibility of increasing of heat exchange coefficient during the boiling in annular gaps in comparison with boiling in "large volume". The possibility of intensification of heat exchange by using deflectors which are formed annular gaps is proved experimentally.