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Microstructured Heat Exchanger Pipe for Improving Parameters of Radiator Based on an Independent Evaporate Circuit

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Abstract

The radiator based on an independent evaporate circuit has a lower heat transfer and the noise of boiling liquid inside the thermal panel during operation as compared with a traditional radiator. The main objective of this article is experimental research aimed to find required shape of the heat exchanger pipe manufactured by deformation cutting technology for increase heat transfer and reduce the noise during operation in the radiator based on an independent evaporate circuit. The result of this article will be the comparison between the heat transfer of radiator prototype with the smooth heat exchanger pipe and the radiator with the heat exchanger pipe manufactured by deformation cutting technology.

Keywords: heat pipe, heat exchanger pipe, deformation cutting technology, independent evaporate circuit, thermosyphon radiator, microstrured surfaces

1 Introduction

In existing heating radiators such as bimetal, panel or cast iron, circulates the same heating transfer agent as in a main pipeline. Working principle of heating radiators does not change for over a century. Often radiators are clogged due to a poor water quality in heating systems – dirt and impurities. After several years of working, the standard radiators are lose the heating output about 50-70%. The radiator manufactures have the minimum cost of goods using the latest technologies and the main cost in the cost structure is the cost of raw materials. The radiators must withstand high pressure, which exists in the heating system and manufactures cannot reduce the thickness of the walls of the radiators. Otherwise, the radiators will have poor quality and reliability.

The principle of the technology based on an independent evaporate circuit is similar with heating pipe. The radiator consists of two independent circuits. Thermal energy comes from a trunk-heating pipe to the first circuit (heat exchanger pipe) of the appliance. Through the heat exchanger pipe, the energy transmitted to the small amount of the low-boiling liquid that located in the second circuit (sealed thermal panel). The pressure inside the thermal panel is reduced to 30–50 kPa. Therefor the low-boiling liquid begins to boil from 30–35 degrees Celsius. The resulting steam begins to rise up inside the thermal panel and condenses in the inner surface of the panel. During condensation, the thermal energy is transmitted to the surface of the panel and condensate flows downward by gravity, after that the cycle repeats (Figure.1). According that, the thermal energy transmitted from trunk heating pipe to the surface of the panel that respectively transmitted heating energy to the room. The difference between the temperature of the heating transfer agent in the trunk heating pipe and the surface of the thermal panel is about 7–9 degrees Celsius. It depends on the various operating modes of the radiator.

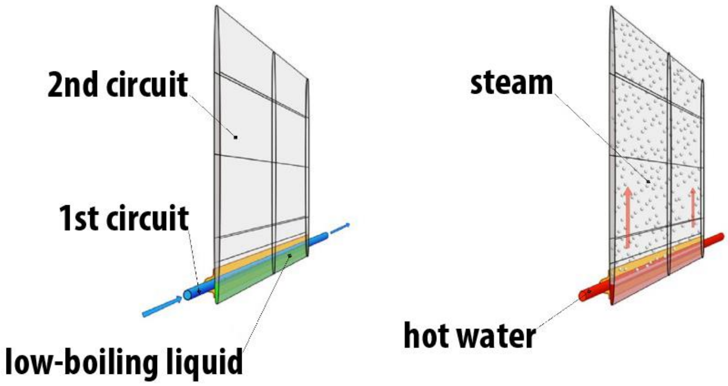

Figure 1. The principle of the independent evaporate circuit in the radiator

The heating pipe technology is the basis of the all radiators based on independent evaporate circuit and the main description of this technology is given in the book [1]. The heating pipe technology has proven records in the different areas such as space [2], thermal storage [3], harnessing of renewable energy [4], heat recovery of various processes [5], domestic energy efficient air conditioning systems [6-7] and in microelectronics [8]

The main issues in the radiators based on an independent evaporate circuit are the low heat transfer and the noise of boiling liquid inside the thermal panel during operation. In the patent GB 2099980 A, publ. 15.12.1982 [9] radiator consists of two independent circuits. The first circuit is a vacuumed thermal panel with the first heat transfer agent inside and the second one is a pipe covered by metal grid with the second heat transfer agent from a main pipeline. Herewith, the first heat transfer agent in the thermal panel is partially contact with the surface of the pipe. The significant disadvantage of this radiator is additional thermal resistance due to the inability to create a good thermal contact between the metal grid and the pipe. In addition, the radiator power is limited by the bandwidth of the metal grid. In the patent US 20020134427 A1, publ. 26.09.2002[10] radiator consists of the hollow sealed evacuated panel and a heat-exchanger pipe. The pipe is partially immersed in a transfer agent. The significant disadvantages of this radiator are noise during the operation and low heat output due to incomplete immersion of the pipe in the transfer agent.

In the patent RU 2322643 [11] radiator consists of the hollow sealed evacuated steel panel with transfer agent inside and a heat-exchanger pipe made of copper. The disadvantage of this radiator is that boil in a confined space creates the noise during the operation. The entire volume of the heat panel is filled with a transfer agent that caused an additional pressure inside the radiator during operation. Likewise, using the copper pipe is inefficient solution, in terms of economic cost.

There are the same disadvantages in all radiators based on an independent evaporate circuit. The analysis of the criteria of heat exchanger pipe and the choice of the optimal alternative to increase the heat transfer efficiency and reduce the noise during the operation will be a result of this work.

One of the method to increase a heat transfer in the heat exchanger pipe and simultaneously save the requirement dimension of the pipe is a deformation cutting technology. In the article [12-13] described this technology, which were used for design the microstructure surfaces on the heat exchanger pipe in this article.

The information from the articles [14-15] which described the different types of the liquid boiling on a smooth and rough surfaces were used in a selection of wide variety of the tubes manufactured by deformation cutting technology for experiment in this article in order to reduce the noise during the operation.

Studies related to the present paper and using the same technical foundation have been carried out in [18].

2. The experimental setup and measurement procedure

The experimental setup is imitating the operation of the radiator based on an independent evaporate circuit. This type of radiators consists of two independent circuits.

The experiments were carried out at a setup (Figure 2) consisting of the following components. In the first circuit, hot water flows from the local heating system into the testing pipe (3). The thermal sensors (9) measure the input and output temperatures in the testing pipe. The flow meter (10) measures the water flow in the testing pipe. In the second circuit there are condenser (1), where vaporized low-boiling liquid condenses, transparent pipe (2) made of plastic, pipelines (4), valves (5) for flow control, condensate container (6), vacuum gaskets (7), supply vessel (8) for support the required level of a liquid in the transparent pipe during the experiment, pressure sensor (11) and vacuum pump (12) for setting the required pressure in the second circuit.

In the testing pipe, the stationary flow rate and temperature of water are set. The second circuit is evacuated from vapor pressure of low-boiling liquid, which is filled into the transparent pipe. In this case, it was isopropyl alcohol. The condensate container's valve is closed; the system has reached the stationary operating condition

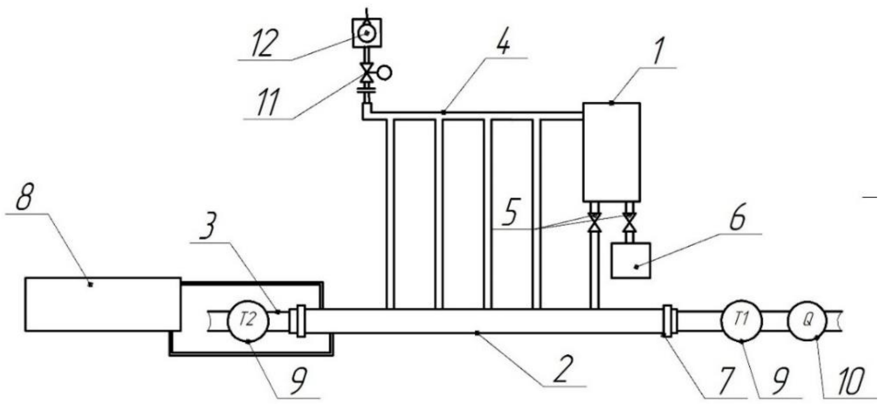

Figure 2. Experimental setup scheme

Next the condensate container's valve is opened and the transparent pipe's valve is closed at the same time. Condensate begins to drain into the condensate container. Measured values during the experiment are: the mass of evaporated isopropyl alcohol depending on the time, input and output temperatures of the water in the testing pipe, the water flow rate, pressure and level of isopropyl alcohol in the transparent pipe.

The graphs of the mass of evaporated isopropyl alcohol depending on time are obtained based on the results of the experiment. The graph is divided into the sections, corresponding to the different levels of isopropyl alcohol in the transparent pipe. After that, the angular inclination dm/dt is derived at each site. Thermal power of the pipe is calculated according to the formula:

$$W = q\frac{dm}{dt}.$$

Where q- unit heat of evaporation of the isopropyl alcohol.

3. The types of heat exchanger pipe

The technology of the deformational cutting was chosen like a perspective method to improve heat transfer and reduce noise in the radiators based on an independent evaporate circuit. All samples were 20 mm diameter, 2.5 mm wall thickness, made of steel B20. The length of all the samples was 1000 mm. The inner pipe surface area was 0.0471 m2. Four samples with different outer surfaces obtained by deformation cutting technology were provided for the experiment. (Figure 3). The main characteristics of the pipes is shown in the Table 1. [16-17].

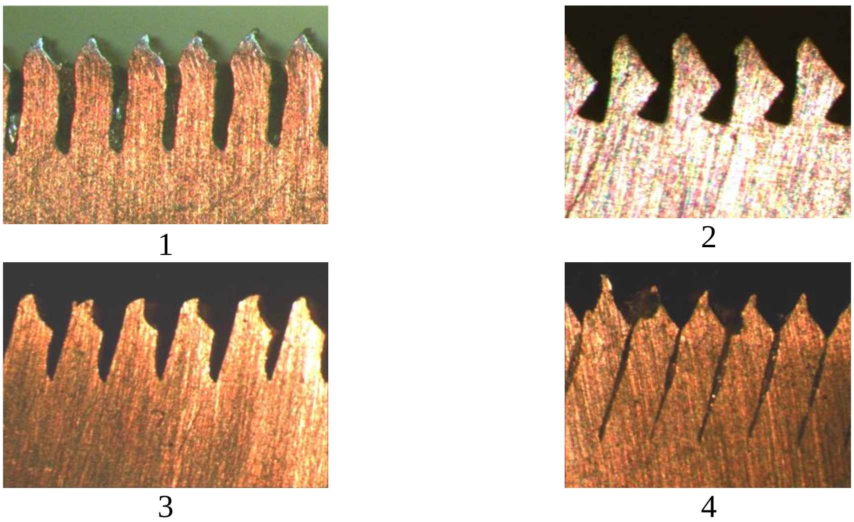

Figure 3. The types of microstructured pipe (Type №1, №2, №3, №4)

Table.1 Characteristics of microstructured pipes

Parameters /Types	№1	№2	№3	№4
Step of the edges. mm	0.4	0.5	0.4	0.4
The average height of the structure . mm	0.95	0.75	0.65	1.15
The average width of the intercostal gap. μm	130	250/100	100	40
Deviation from the vertical ribs	0	0	15	15

4. The results of the experiment

The pipes with different outer surfaces are compared to the standard pipe with the smooth surface. The relation between the thermal power and temperature in the testing pipe are obtained for different immersion levels of isopropyl alcohol in the testing pipe. The most revealing immersion level (Figure 4) was found after several iterations and it was studied more thoroughly

For the immersion level 1, all of the test samples worked loudly in the nucleate boiling regime. The pipes manufactured by deformation cutting technology showed the increased heat output more than 15-20% than the standard pipe. The experimental data showed in the Figure 5.

For the immersion level 2, all the pipes manufactured by deformation cutting technology showed significantly greater heat output (from 30% to 100%, depending on the temperature) than the standard pipe with smooth surface. This is because the pipes manufactured by deformation cutting technology have high thermal conductive capillary channels. Evaporation takes place within the entire surface of the pipes. At the same time, different types of surfaces display different features.

Figure 4. Immersion levels

For the type 1, at the temperatures up to 65 degrees Celsius, the pipe actively evaporates alcohol from the entire surface. Film boiling occurs, which significantly reduces the noise during operation. In the range of 65-75 degrees Celsius the capillary channels begin to dry out, parts of the pipe are no longer wet. In result, heating power does not increase with increasing temperatures. Film boiling continues at the temperatures of over 75 degrees Celsius, the process follows to the active phase of the nucleate boiling. In this case, since the gap between the pipe and the inner surface of the transparent pipe is sufficiently small, and the formed spray covered the entire surface of the pipe, the capacity significantly increases. For the types 2 and 3, at the temperatures up to 65 degrees Celsius, the pipes have similar specifications as the type 1. At the temperature of over 65 degrees Celsius, the nucleate boiling begins, so the power failure is not observed. For the type 4, the surface evaporation continues to up to 80 degrees Celsius, and the capillary channels do not dry out. At the high temperatures (more than 80 degrees Celsius), the process follows to the nucleate boiling phase. The experimental data is shown in the Figure 6.

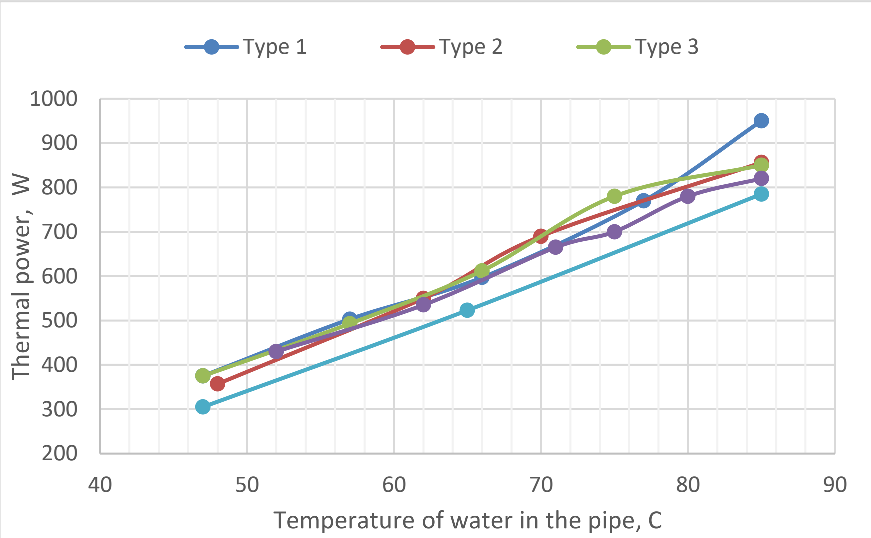

Figure 5. Immersion level 1

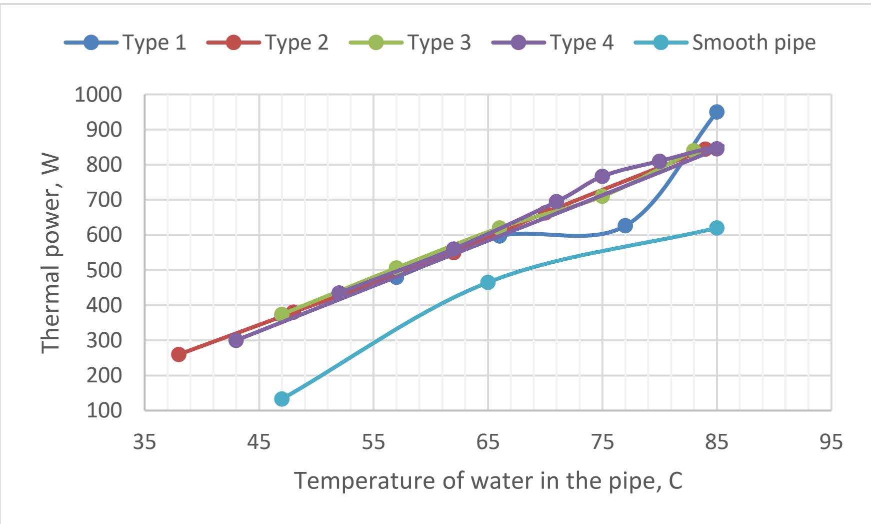

Figure 6. Immersion level 2

4. The results of the experiment

The heat chamber was built in the laboratory for testing the efficiency of using the pipe manufactured by deformation cutting technology in the radiator based on independent evaporate circuit. The schematic diagram and photo of the heat chamber are shown in the Figure 7.

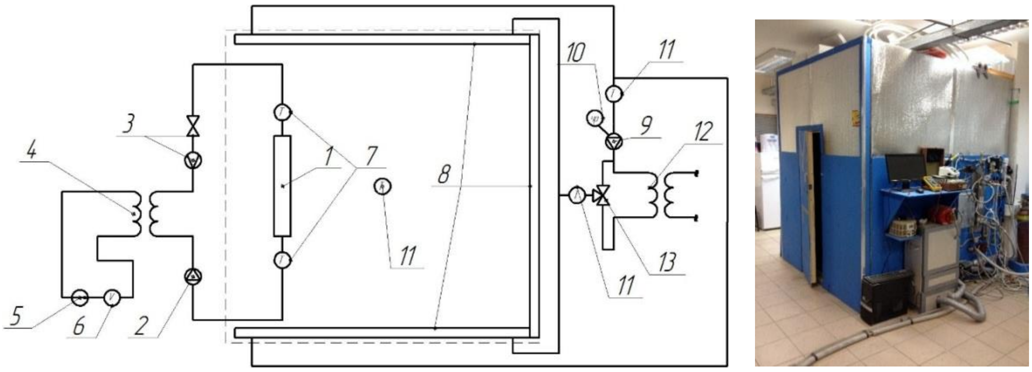

Figure 7. The schematic diagram and photo of the heat chamber

The heat chamber is an insulation chamber with dimension 184x187x236 cm with heating and cooling circuits. The heating circuit consists of the circulation pump (2), flow meter and valve (3) for adjust the flow rate 0,1 kg/s, heaters for maintain temperature condition of the water up to 95 degrees Celsius, power supply with adjustable output current (5), DC voltmeter (6), output and input thermal sensors (7) and the testing radiator (1). The cooling circuit consists of the cooling panels (8) mounted along the walls of the chamber, circulation pump (9), thermal sensor (11) which sends a signal to a frequency controller (10), heat exchanger (12), three-way valve(13) that regulates temperature of the water in the cooling circuit, thermal sensors (11).

The experiment was carried out for compare the heat output of radiator with the smooth pipe (diameter 20mm, wall thickness 2,5mm made from steel B20) and the pipe manufactured by deformation cutting technology (type №4) with the same dimensions. Type №4 were choose like more appropriate sample for reducing noise during operation of radiator and increasing the heat output according to the experimental data.

Two equal prototypes of radiator based on independent evaporate circuit (Figure 8) were made with dimensions 400x600mm with the smooth pipe and the type №4 pipe of heat exchanger. The radiators based on independent evaporate circuit also compared with the standard panel radiator (type 10) in order to evaluate the heat output parameter.

Figure 8. Prototype of radiator based on independent evaporate circuit

5. Measurement procedure and results of heating output of the prototypes

Water circulated by a pump through the boiler and tested radiator. Heat flow is defined as the difference between the electric power input and heat losses. Heat losses in the working range of temperature is determined by the short well insulated jumper mounted instead of the testing radiator. Heat losses of the jumper is well known. The air temperature is measured at the central vertical axis at a distance of 0.75m from the floor. The water temperature is measured in the input and output from the radiator. At least three consecutive trials at a constant flow of water at temperature differences from 35 to 75 degrees Celsius is conducted to determine the nominal heat flow rate. The range of the temperature difference is divided into equal, or as close to equal intervals as possible. Water consumption in all tests should be 0,1 ± 0,01 kg/s. Temperature in the chamber should be maintained in the range of 20 ± 1,5 degrees Celsius.

To check the correctness of the heat chamber measurements, the measurements were compared with those from other laboratories. Panel radiator Purmo V-11 with the same dimensions like prototypes (400x600mm) was taken for control measurement. Production company, referring to the measuring ISO in Stuttgart in Germany, provides a rated power dependence of the radiator from the coolant temperature. This radiator has also been tested by Russian company "Vitaterm" and NII Santehniki and in our laboratory. The difference between the results for the whole range does not exceed 5-7% between all three laboratories.

The nominal heat output was measured in the heat chamber for the radiator based on independent evaporate circuit with a smooth and a microstructured pipe (type №4) manufactured by deformation cutting technology. The heat output for prototype with a smooth pipe was 315W and in the same time for the prototype with a type №4 pipe the heat output was 396W and the noise during the operation was reduced. Application the pipe manufactured by deformation cutting technology increased the heat output more than 20% and reduce the noise due to film boiling of the coolant inside the radiator. In compare with standard panel radiator the radiator based on independent evaporate circuit has the similar heat output but has improved characteristics for the working pressure and service life.

6. Conclusion

The experiment for finding technological parameters of heat exchanger pipe for improved the heating output and reduce the noise during the operation in the radiator based on independent evaporate circuit was carried out in this article

For all tested samples, the heat output higher by 30-100% than heat output from a smooth pipe. The differences in heat output depend on the temperature and type of surface in the pipes. Type 1 has a power failure in the range of water temperature 65 -75 degrees Celsius. Type 1 and 4 can significantly improve the performance of heat exchangers, providing significant heat output increase and noise reduction in a wide range of temperature. Type 4 is showed the best performance on heat transfer rate. The heat exchanger surface, similar to the type 4 surface could be recommended for the using in the radiator based on independent evaporate circuit. Based on the experimental data, we may conclude that using the pipe manufactured by deformation cutting technology is efficient way to increase heating output and reduce the noise during the operation of the radiator based on independent evaporate circuit.

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