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SCIENTIFIC AND TECHNICAL ANALYSIS OF RESEARCH ON THE USE OF HEAT PIPES

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Abstract. This article presents a scientific and technical analysis of research into the use of heat pipes. The study covers the design features of heat pipes and their operating principles. Specifically, it was established that a heat pipe is a sealed structure, 0.2–0.5% of whose internal volume is filled with a coolant. In the heated portion of the heat pipe (the evaporation zone), the liquid coolant evaporates as a result of heat absorption. The resulting vapor passes into the cooled portion (the condensation zone), where it transfers its latent heat of evaporation to the heat exchanger and condenses. The condensed liquid returns to the evaporation zone under the action of capillary forces or gravity. The study also found that with a nanofluid mass concentration of 1%, the thermal efficiency of the system optimally increases by 16.8%.

Keywords: heat pipe, heat exchanger, condensation, condensation zone, tube, heat transfer, evaporation zone, capillary, thermosyphon, condenser, total coefficient.

Аннотация. В данной статье представлен научно-технический анализ научных исследований по применению тепловых трубок. Исследование охватывает конструктивные особенности тепловых трубок и принцип их работы. В частности, установлено, что тепловая трубка представляет собой герметичную конструкцию, 0,2–0,5% внутреннего объема которой заполнено теплоносителем. В нагретой части тепловой трубки (зоне испарения) жидкий теплоноситель испаряется в результате поглощения тепла. Образовавшийся пар переходит в охлажденную часть (зону конденсации), где передает свою скрытую теплоту испарения теплообменнику и конденсируется. Сконденсированная жидкость возвращается в зону испарения под действием капиллярных сил или силы тяжести. Также по результатам исследования установлено, что при массовой концентрации наножидкости 1% тепловой КПД системы оптимально увеличивается на 16,8%.

Ключевые слова: тепловая трубка, теплообменник, конденсация, зона конденсации, трубка, теплопередача, зона испарения, капилляр, термосифон, конденсатор, суммарный коэффициент.

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Annotatsiya. Ushbu maqolada issiqlik quvurlaridan foydalanish bo‘yicha olib borilgan ilmiy tadqiqot ishlarining ilmiy-texnik tahlili keltirilgan. Tadqiqotda issiqlik quvurlarining konstruktiv xususiyatlari hamda ularning ishlash prinsipi yoritilgan. Jumladan, issiqlik quvuri germetik yopiq konstruksiya bo‘lib, uning ichki hajmining 0,2–0,5 qismi issiqlik tashuvchi suyuqlik bilan to‘ldirilishi aniqlangan. Issiqlik quvurining isitiladigan qismida (bug‘lanish zonasida) suyuq issiqlik tashuvchi issiqlikni yutishi natijasida bug‘lanadi. Hosil bo‘lgan bug‘ sovitiladigan qismga (kondensatsiya zonasiga) o‘tib, u yerda o‘zining yashirin bug‘lanish issiqligini issiqlik almashtirgichga uzatadi va kondensatsiyalanadi. Kondensatsiyalangan suyuqlik esa kapillyar kuchlar yoki gravitatsiya ta’sirida yana bug‘lanish zonasiga qaytadi. Shuningdek, tadqiqot natijalariga ko‘ra nanosuyuqlikning massaviy konsentratsiyasi 1% bo‘lganda tizimning termik foydali ish koeffitsienti (FIK) optimal holda 16,8% ga oshishi aniqlangan.

Kalit so‘zlar: issiqlik quvuri, issiqlik almashtirgich, kondensatsiya, kondensatsiya zona, pilik, issiqlik uzatish, bug‘lanish zonasi, kapillyar, termosifon, kondensator, to‘liq koeffitsiyent.

INTRODUCTION

A heat pipe is the fundamental element of a heat exchange system, operating on the principle of a low-boiling liquid contained within closed tubes made of heat-conducting metals (aluminum, copper) and other materials. As a result of heat transfer, the liquid evaporates at the hot end of the heat pipe, absorbs the heat of evaporation, and condenses at the cold end. Heat pipes come in two types: those with a smooth inner wall and those with a porous inner lining. In smooth-walled tubes, the condensed liquid returns to the evaporation zone solely under the force of gravity. This means that these heat pipes operate only when the condensation zone is above the evaporation zone and the condensed liquid is able to descend into the evaporation zone. Heat pipes can operate in virtually any orientation, as the liquid returns to the evaporation zone through the pores under the force of capillary action, and gravity plays no role in this process.

LITERATURE ANALYSIS.

The choice of materials for heat pipes and coolants depends on the operating conditions: liquid helium and mercury are used for very low temperatures, while indium and other substances are used for high temperatures. However, most modern tubes recommend ammonia, water, methanol, and ethanol as working fluids. The first patent for this technology was issued to Gaugler in 1944. Heat pipes have a wide operating temperature range, where the speed of heat transfer exceeds the speed of sound, and a service life of over 20,000 hours, making them highly efficient and reliable technical systems. Water is used as the working fluid

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in the inner part. To boil the water inside the tube at low temperatures, the air must be evacuated from the heat pipes.

A heat pipe is a heat transfer device capable of transferring large heat capacities at low temperature gradients, and heat pipes (0.2-0.5) are hermetically sealed. In the heated portion of the heat pipe (evaporation zone), the liquid coolant evaporates as a result of heat absorption, and in the cooled zone of the heat pipe (condensation zone), water vapor, transferring its latent heat to the heat exchanger, condenses and enters the evaporation zone. The transition of vapor from the evaporation zone to the condensation zone occurs due to the difference in saturated vapor pressure, which is determined by the difference in temperature in the evaporation and condensation zones. Capillary heat pipes are very common. Lightweight, highly reliable, autonomous operation, high thermal conductivity of heat pipes, and the possibility of their use as thermostatic devices have led to their widespread use in power engineering, the chemical industry, space technology, electronics, and other industries [1]. Heat pipes are used to efficiently transfer thermal energy from one source to another. They are capable of transferring heat over long distances with minimal power loss.

RESEARCH METHODOLOGY.

Several types of heat pipes have been proposed, among which wick heat pipes are widely used. When the evaporation zone of the heat pipe is heated, the liquid in the evaporation zone is heated and evaporated, resulting in the formation of vapor. The vapor moves along the pipe to the condenser zone, where it condenses into liquid and then returns to the evaporation zone through the wick structure, forming a closed thermal cycle. This type of heat pipe is simple, reliable, and does not require an external source. Wick heat pipes are widely used in nuclear power plants [2] and in ventilation and air conditioning systems [3].

The main difference between thermosiphons and heat pipes is that thermosiphons use natural convection and gravity to transfer heat. The condensation zone is located above the evaporation zone due to gravity. They do not require an external heat source and are suitable for vertical heat transfer.

Thermosyphons are widely used in nuclear reactors [4], ceramic industry [5], solar collectors [6], coal liquefaction [7], HVAC systems [8], steel industry [9], flue gas heat recovery from coal combustion [10] and aluminum industry [11].

Flat heat pipes typically have a very thin cross-section and are used for heat transfer in confined spaces. They provide efficient heat transfer even in very thin structures. They are widely used in solar collectors [12], photovoltaic panels [13], and the metallurgical industry [14].

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Concentric tubular heat pipes consist of two concentric tubes, with the inner tube acting as an evaporator and the outer tube acting as a condenser. They provide long-distance heat transfer and exhibit high heat transfer efficiency [15].

Microstructured heat pipes are based on wick heat pipes and typically consist of multiple wick heat pipes. In microstructured heat pipes, the evaporation zone is located near the high-temperature heat source, while the condenser zone is located in a much cooler environment.

DISCUSSION AND RESULTS

When a high-temperature liquid, i.e., static heat, acts on the evaporation zone, the working fluid begins to boil and absorbs a large amount of heat. During this process, a phase transition occurs, and steam at a constant temperature is formed inside the tube. The steam then passes from the evaporation zone to the condenser zone at the speed of sound. When the steam flow encounters the cold in the condenser zone, it gives up heat and turns into liquid again. The condensed liquid then returns to the evaporation zone of the tube under the action of gravity or a wick structure. This process is continuously repeated. Iranian scientists Noye et al. [16] investigated the effect of the inclination angle and the integral coefficient on the thermal characteristics of a two-phase closed thermosyphon. A copper thermosyphon with an outer diameter of 16 mm, an inner diameter of 14.5 mm, and a length of 1000 mm was used in the calculation. Distilled water was used as the working fluid. The saturation coefficient was defined as the ratio of the volume of the working fluid to the volume of the evaporation section. Saturation factors were assumed to be 15%, 22%, and 30%. According to their findings, the heat transfer coefficient and condensation heat transfer rate increased with increasing saturation factor. Condensation heat transfer was highest at a saturation factor of 22%, as well as at an inclination angle of 30° and a saturation factor of 30%, and at an inclination angle of 45° and a saturation factor of 15%.

Taiwanese scientists Teng et al. [17] investigated the thermal efficiency of heat pipes filled with an aluminum oxide-based nanofluid. The heat pipe used in the experiment consisted of a copper tube with a diameter of 8 mm and a length of 600 mm. At a mass concentration of 1% nanofluid, the optimal thermal efficiency increased by 16.8%.

Malaysian scientists Idrus et al. [18] used a 300 mm long, 10 mm outer diameter copper heat pipe filled with water in their research. A K-type thermocouple was glued to the outer surface of the heat pipe. They studied the characteristics of the heat pipes at different heat transfer values and inclination angles. With a power consumption of 70-80 W and an inclination angle of 30° to 60°, the best characteristics were shown by heat pipes with a diameter of 10 mm.

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Taiwanese scientists Kang et al. [19] studied the thermal characteristics of heat pipes filled with a silver nanofluid with a diameter of 35 nm. The length of the heat pipes was 20 mm, and the outer diameter was 6 mm. The concentration of nanoparticles varied from 1 mg/L to 100 mg/L. A radiator was connected to the condenser section of the heat pipes. The condenser section is cooled with water. Thermal resistance decreases with increasing concentration and size of silver nanoparticles.

American scientist Plavsky [20] investigated heat pipes consisting of a sealed container with a wick mounted on the inner wall. Romanian scientists Guminici et al. [21] developed thermosiphon heat pipes using nanofluids and deionized water to compare the heat transfer rate in a thermosiphon. Iron oxide nanoparticles were obtained by laser pyrolysis, and their concentration was 0, 2, and 5.3%. The heat transfer rate in thermosiphon heat pipes filled with iron oxide nanoparticles was significantly higher than in thermosiphon heat pipes filled with water. The presence of a 2% concentration of iron oxide nanoparticles in the liquid increased the heat transfer rate by 19%. Increasing the concentration of nanoparticles increases the thermal resistance of the thermosiphon heat pipes and ensures high efficiency.

Dutch scientists Grooten et al. [22] investigated the influence of saturation temperature, inclination angle, and fill level on the maximum working heat flux of thermosyphons. R-134a was used as the working fluid. It was found that the thermosyphon operates best at an inclination angle of 83°. According to the results, the maximum working heat flux decreases with increasing saturation temperature and decreasing inclination angle. Also, an angle of 83° is not recommended for efficient operation of thermosyphons.

Iranian scientists Moraveji and Razvarz [23] studied the thermal characteristics of heat pipes using aluminum oxide nanoparticles with a diameter of 35 nm. They were made of copper tubes of varying lengths with a sand wick structure. The studied mass concentrations of the nanofluid were 0.1 and 3%. The results were compared with those of heat pipes filled with water. According to the results, the wall temperature increased with increasing heat transfer, and the wall temperature of the heat pipes with nanofluid was lower than the wall temperature of the heat pipes filled with water. Also, the wall temperature and the temperature difference decreased with increasing nanoparticle concentration. However, it was found that heat pipes with nanofluid had lower thermal resistance than heat pipes filled with water.

CONCLUSIONS AND SUGGESTIONS.

Increasing or decreasing the amount of heat transferred to heat pipes affects their efficiency. In this case, heat pipes with an outer diameter of 6.35 mm and a

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length of 200 m were used. The heat pipes have a mesh-wick structure and are filled with aluminum oxide nanoparticles at mass concentrations of 5 and 10%. The results showed that the heat pipes are more efficient at a concentration of 5%.

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