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Preliminary communication

LONG-TERM LIQUID TRANSFER MEASUREMENTS OF FALLING FILM HEAT AT HORIZONTAL TUBE BUNDLE

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This paper presents the current research on heat transfer at a sprinkled tube bundle consisting of smooth tubes and located in a chamber inside of which a low pressure is created by an exhauster. It also monitors the changes of the heat transfer coefficient in relation to the speed of sprinkled and sprinkling liquid flow, thermal gradient and low pressure inside the chamber. This articles shows and compares extensive measurements in condensation and evaporation modes.
Key words: heat transfer coefficient, evaporation, condensation, droplet, jet.

Dugoročna mjerenja prijenosa topline padajućeg tekućeg sloja na horizontalnom cijevnom snopu. U ovom radu predstavljena su trenutna istraživanja na prijenosu topline naprskavanog cijevnog snopa koji se sastoji od glatkih cijevi smještenih u komori s potlakom stvorenim s uređajem za odvođenje dimnih plinova. Također se prate promjene koeficijenta prijenosa topline u ovisnosti od brzini naprskavanja i strujanja naprskane kapljevine, temperaturnog gradijenta i potlaka u komori. Ovaj članak pokazuje i uspoređuje opsežna mjerenja pri kondenzaciji i načina isparavanja.
Ključne riječi: koeficijent prijenosa topline, isparavanje, kondenzacija, kapljica, sapnica.

INTRODUCTION

At a horizontal tube bundle sprinkled by a liquid of a low flow rate, a thin liquid film is created that facilitates effective heat transfer. As the liquid flows, the liquid phase is promptly separated from the vapour phase which increases the heat transfer coefficient. This technology is applied for instance at sea water distillation and some experiments have been recently carried out in this field of expertise by e.g. Yang and Shen (Dalian University of Technology, China) [1]. The research of sprinkled bundles in China is conducted for the purpose of sea water desalination as some locations start to suffer from the lack of drinking water. The sprinkling modes are studied at the Victoria University in Australia in order to find ways of saving drinkable water from the point of view of irrigation water distribution. See more at [2].

The European countries and in the USA emphasize saving the primary fuel entering power-producing processes. Apart from boosting efficiency of power-producing processes and lowering energy consumption it is also possible to use the waste heat for coolness production. There are two predominant technologies of coolness production. The first method utilizes compressor cooling devices which are, however, very heavy on electric power. Absorption circulation represents their feasible alternative. Although being larger and more expensive, it consumes approximately one fifth of the electric power. The basic element of a single-stage absorption circulation consists of two exchangers operating in a low-pressure environment (the absorber and the desorber). The heat carrying agent's steam is cooled in the absorber and absorbed into an absorbent. In a simplified way, it is a sprinkled exchanger on the surface of which the water steam condensates. The primary heat is supplied to the cycle in desorber, so the heat is provided to the sprinkled liquid and water boils on the tube surface. Therefore this article is focused on the research of the heat transfer coefficient at sprinkled tube bundle, either in a condensation or evaporation mode.

HEAT TRANSFER THEORY AND MEASURING APPARATUS

At a sprinkled horizontal tube bundle with falling liquid we can observe three basic flow modes: The first phase is the Droplet mode. In this phase the liquid drops from one tube to another. The second phase is the Jet mode. In this mode the drops join into jets with as a result of an increasing flow rate. The transition between the Droplet and Jet modes is defined by at least one stable water column in among the droplets. The last phase is the Sheet mode. In this mode the flow rate is so high that the liquid creates a wall between the tubes. The transition between the Jet and Sheet modes is defined by the columns' connections and their creation of small triangular sheets. In this mode, columns and sheets exist side by side.

The derivation of equations for the researched heat transfer coefficient at the surface of sprinkled tubes was based on the definitions given in [3, 4], namely on the balance according to the law of conservation of energy, the Newton's law of heat transfer and the Fourier's law of heat conduction. A detailed description of the derivation method can be found in [5].

For the purposes of examination of heat transfer at sprinkled tube bundles a test apparatus has been constructed; see the diagram at Fig. 1. The tube bundle at which both boiling and condensation can be simulated is placed in a vessel where low pressure is created by an exhauster through an ejector. The low-pressure stand chamber is a cylindrical vessel of 1.2 m length with three apertures in which the tube bundle of the examined length 940 mm is inserted. Three closed loops are connected to the chamber. The two side loops are designed for overpressure up to 1.0 MPa and function as cooling/heating liquid conveyors. The third (middle) loop functions as sprinkling liquid conveyor. There is a pump, a governing valve, a flow rate meter and a plate exchanger attached to each loop. The plate exchanger can be connected to a boiler or gas boiler with hot water designated to heat-up the liquid or cooling water for cooling purposes. Additionally expansion vessels and safety and vent valves are fixed to the overpressure loops. In order to enable visual control the loops also include a manometer and a thermometer.

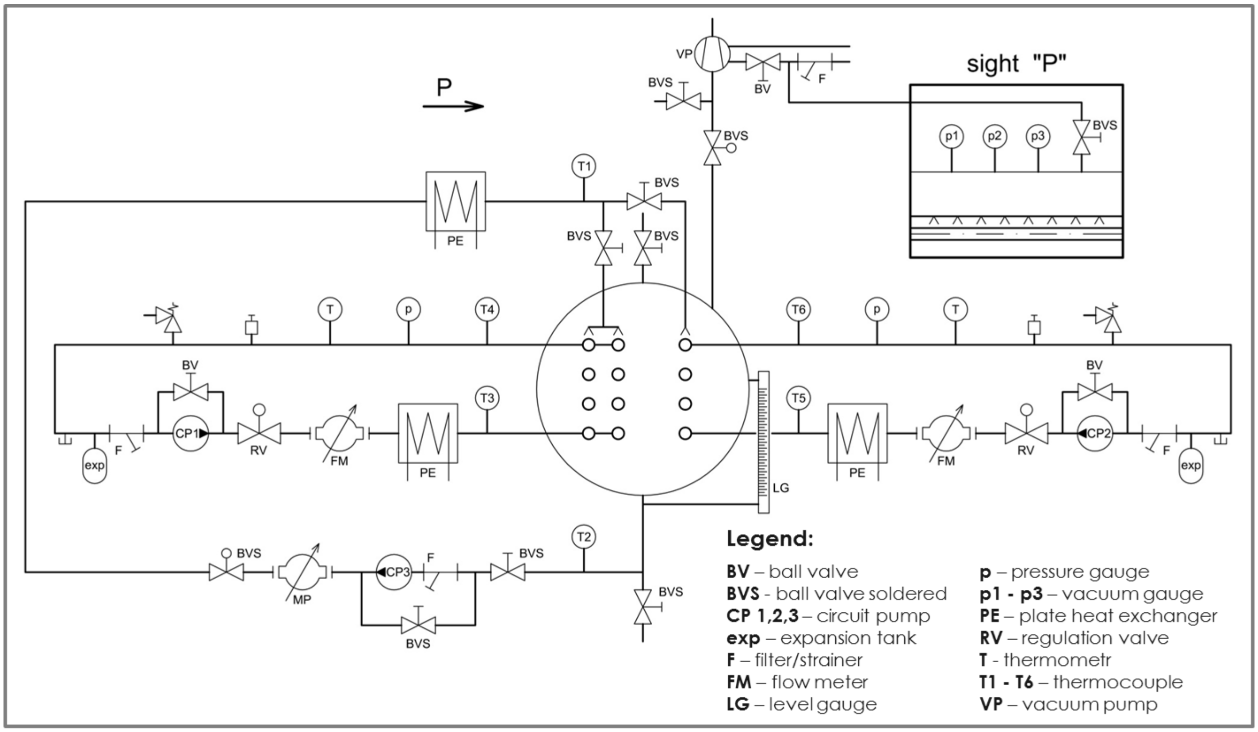

Figure 1. Test apparatus diagram
Slika 1. Shema ispitnog uređaja

The thermal status in individual loops is measured by wrapped earthed T-type thermocouples on the agents' input and output from the vessel. In order to approximate the spread of heat in the tube bundle, two thermocouples are placed inside each loop. The situation inside of the vessel is monitored by two thermocouples; the first one located directly below the surface of the liquid collected at the lower part of the chamber monitors the temperature of the sprinkling liquid and the second one monitors the inside chamber environment above the tube bundle. The fitting plate of the tube bundles is divided into two halves with apertures of various spans drilled into each of them enabling thus a high variability of the tubes' arrangement. The tube bundle consists of copper tubes of the 12 mm diameter. The distribution tube located above the tube bundle has apertures of the 1.0 mm diameter with the 9.2 mm span along the length of 940 mm.

There are three vacuum gauges measuring the low pressure. The first vacuum gauge is designed for visual control and it is a mercury meter, the second one is digital and enables measuring within the whole desired low-pressure range, but it is less accurate with lower pressure values. In order to achieve accurate measuring within the low range between 2.0 kPa and 0 Pa, the third digital vacuum gauge is used.

Electromagnetic flow meters Flomag 3000 attached to all three loops measure the flow rate. All examined quantities are scanned by measuring cards DAQ 56 either directly (thermocouples) or via transducers.

LONG-TERM MEASUREMENTS

The objective of this experiment is to evaluate the influence of the sprinkling liquid flow rate on the heat transfer coefficient at the surface of a tube bundle at various pressure levels. Both types of the experiment have been carried out at the right loop of the tube bundle where there are seven smooth tubes (including the distribution one) with the 25 mm span in two rows shifted by 10 mm. However, the calculation takes into account one row only as the flow rate inside the tubes is undivided and gradual from the bottom upwards.

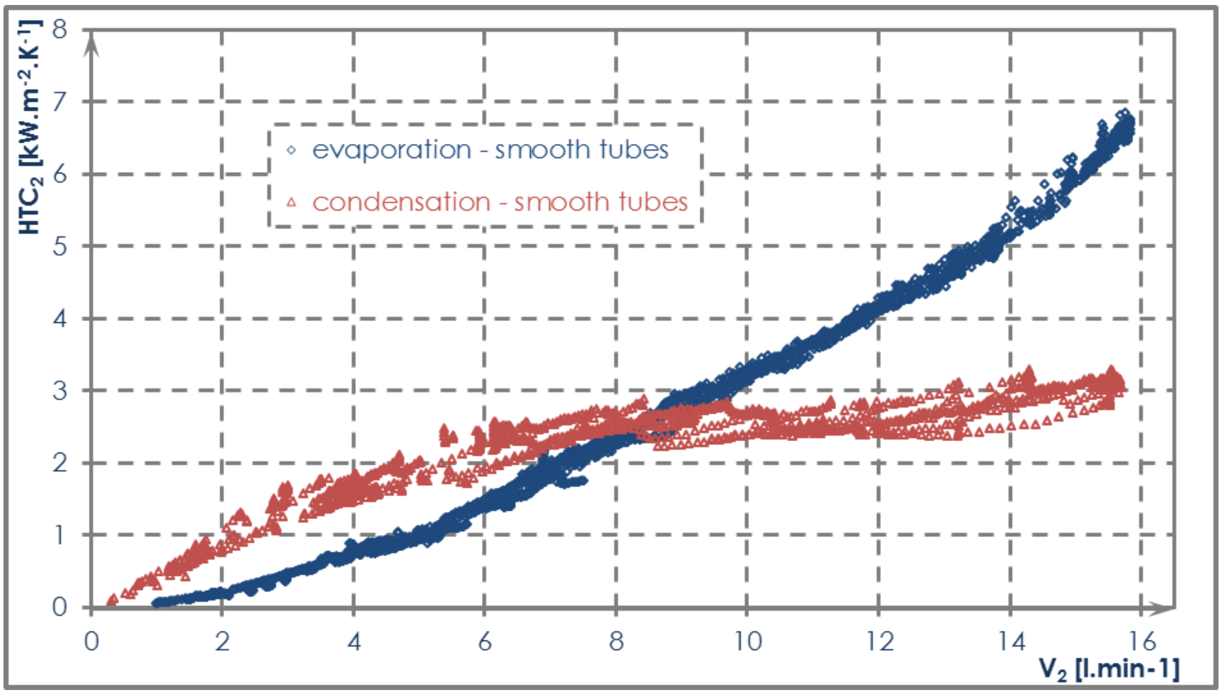

Figure 2. Dependence of heat transfer coefficient on sprinkling liquid flow rate
Slika 2. Ovisnost koeficijenta prijenosa topline o brzini strujanja naprskane kapljevine

The final examined dependence of the heat transfer coefficient at tube surface in the boiling mode is highlighted in blue points in Figure 2. In this mode hot water of the input temperature of 55.2°C flows inside the tubes with statistic deviation of a half point and the average flow rate of 13 $l.min^{-1}$ ± 0.4. The exchanger is sprinkled with a cool water of the input temperature of 29.9°C and the sprinkling liquid flow rate ranges from zero up to 16.1 $l.min^{-1}$. This mode was tested at the pressure level of 96.8 kPa (atmospheric pressure at the time of measurement) to 12.3 kPa.

The same diagram shows the waveform of the relation between the heat transfer coefficient and the sprinkling liquid flow rate in a condensation mode highlighted in red points. In this mode the tubes were sprinkled with a hot water of an average input temperature of 55.2°C ± 0.5°C and a flow rate ranging between zero and 16.1 $l.min^{-1}$. A constant flow rate of 12.9 $l.min^{-1}$ and of the input temperature of 29.8°C ±

0.4°C was still maintained inside the tubes. The pressure was changed during the measurements ranging from 10.2 kPa up to the atmospheric pressure (97.1 kPa at the time of measurement).

CONCLUSION

The reasons for our basic research and its certain necessity were outlined in the beginning of the paper. The research is justified not only by the possibility to increase the environmental comfort at various residential, commercial and industrial premises, but also for the purpose of saving water, i.e. for desalination of sea water. As the introduction implies, the arguments for the primary application of sprinkled horizontal exchangers vary throughout the individual continents' regions.

The main part of the paper was devoted to testing the influence of sprinkling liquid flow rate alteration on the heat transfer coefficient that reacted in accordance with our expectations. We tested the boiling and condensation modes with changes of the sprinkling liquid flow rate and the low pressure inside the chamber on the basis of long-term measurements and we managed to identify a distinct dependence outlining a relatively clear waveform. In case of the condensation a certain sensitivity to input temperatures is visible despite a relatively small statistic deviation. The increasing of heat transfer coefficient was not significant in under pressure.

Our further research will focus on other types of tube surfaces and their influence on the heat transfer coefficient and various admixtures both soluble and insoluble in water which affect the surface tension at decreasing pressure and we would like to identify the advantage of low pressure inside a chamber as the heat transfer coefficient reacts differently with some flow rates at tube bundle than a coefficient measured at one, two or three tubes placed horizontally one above another.

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