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Improvement of Thermosyphons by Modifying the Evaporator Surface

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Abstract **-** This study presents experimental results on the modification of the evaporator surface of thermosyphons. Based on the consideration that the evaporator consists of an evaporation zone and a boiling zone, different modifications of the evaporator surface are investigated. The study has two goals – reducing the number of geysers and enhancing the thermal performance of thermosyphons. By using a silica suspension as working fluid, the actual operation of the thermosyphon is preceded by an *in situ* production step that creates a coating of the evaporation zone. This coating augments the evaporation of the falling film. Inserting a stent with a mesh-like wire structure into the boiling zone boosts the boiling. Using a coil spring instead distributes the imposed heat better and removes almost all geysering. Modifications of the type presented here extend the range of applications for thermosyphons. For example, wastewater flows with fluctuating temperatures / heat fluxes can be better utilised as regenerative energy sources. Compared to other surface modifications, *in situ* coatings and inlays in the boiling zone are cost-effective approaches.

Keywords**:** thermosyphon, evaporator, geysering, weak thermal sources

1. Introduction

Heat exchangers and other thermal equipment are of paramount importance for the energy transition. In view of the ongoing global warming, there is a growing need to utilise previously untapped reserves of waste thermal energy. Phase change probes - heat pipes, oscillating heat pipes, thermosyphons, etc. - take a prominent position among such systems.

Similar to heat pipes, thermosyphons (TS) can be seen as super heat conductors. They work passively with closed circuits of evaporation and condensation of a working fluid and are able to transfer thermal energy even at low temperature differences. In order to overcome larger distances between the evaporator and condenser, there is often an adiabatic section positioned between these two assemblies. The condensed working fluid returns to the evaporator by gravity alone. Therefore, the evaporator needs to be positioned below the condenser.

This study investigates one of the downsides of thermosyphons, the so-called geysering. Robert Bunsen (1811-1899) was probably the first who described the geysering phenomenon for natural geysers on Iceland [1]. Geysers occur when liquid is brought to boiling in narrow channels, pipes, or capillaries. In technical systems such as thermosyphons, geysering happens when they are operated at low pressure. Thermal energy is then transferred intermittently. Two phases characterise a geyser cycle. In the first phase, thermal energy is stored by overheating the working fluid. This energy is released when a vapour bubble forms and leaves the evaporator in a somewhat violent manner. Such a burst can lead to the liquid working fluid being expelled through the entire thermosyphon and even reaching the condenser.

Geysering is disadvantageous in two ways. First of all, it generates an instantaneous transfer of thermal energy. By storing thermal energy, the amount of energy transferred is reduced considerably, though temporarily. On the other hand, this energy is transported within a very short period of time when the vapour bubble departs from the evaporator. The mechanical momentum that is transferred to the thermosyphon in this way may lead to a shaking of the entire apparatus. Neither the thermal instabilities nor the mechanical loads are welcome features.

Another disadvantage of thermosyphons is their poor thermal performance when the energy supply to the evaporator is weak and the working fluid is only slightly overheated. Such a situation appears when the energy source is not very stable over time. An example of this is the wastewater system of an apartment building. Thermosyphons are suitable to exploit the thermal energy of such streams. However, the sewage flow changes in terms of mass and temperature on a daily and an annual basis. Thermosyphons usually work best at a certain operating point and would have problems with these changes.

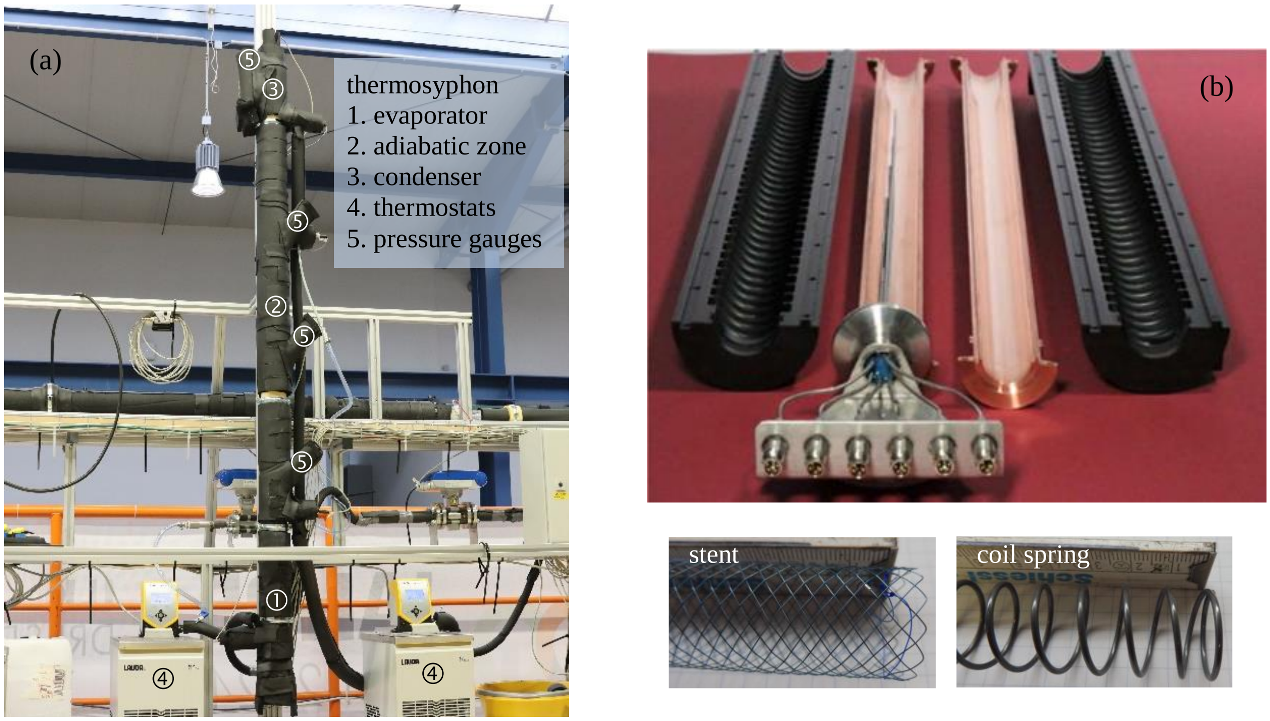

Fig. 1: Thermosyphon test rig. The insulated thermosyphon (a) consisting of the evaporator (400 mm), the adiabatic section (1,000 mm), and the condenser (400 mm). Image (b) presents the open evaporator. The black shells enclose the evaporator tube (copper) and guide the heating water flow. The temperature probe lays in the left evaporator tube half. The stent and the coil spring are inserted into the copper pipe to modify the boiling zone.

It has been known for some time that TSs operate in two different modes: *falling film evaporation* and *pool boiling* [3]. Here we argue that these modes act in parallel but that their contribution to the overall transfer of thermal energy depends on the heat imposed on the evaporator. Therefore, we distinguish between the evaporation zone and the boiling zone. Based on these considerations, this study focuses on the experimental investigation of possibilities for modifying the entire evaporator surface of a thermosyphon.

2. Material and Methods

Figure 1 displays the test rig employed for the experiments. Details of the data acquisition are described in detail elsewhere [2]. The evaporator of the TS consists of an inner copper pipe (R_a = 0.01/0.04 µm, axial / circumferential) and two outer half-shells made of polyvinyl chloride (Fig. 1a). The copper pipe and the two half-shells form a coil heat exchange through which heated water flows to temperate the working fluid inside the evaporator. The temperature distribution inside the working fluid is measured with a tailor-made probe consisting of six equidistantly positioned PT100 elements. Five pressure gauges determine the pressure along the adiabatic section and inside the condenser.

The reference measurements are carried out with deionised water. Based on previous experiments [2], the evaporation zone is altered by using a silica suspension (1.86 vol. %, d_{np} = 70 nm) as working fluid. The boiling zone is modified by inserting either a stent (Nitinol, d_{wire} = 0.2 mm, Δ_{wire} = 3 mm) or a coil spring (spring steel EN 10270-1, d_{wire} = 1.4 mm, pitch 8 mm). Both inlays have a slightly larger outer diameter than the inner diameter of the copper pipe so that they sit quite firmly in the pipe. The copper pipe is replaced after each measurement and cut in two halves to examine the inside. The amount of working fluid (80 ml) is kept constant for all experiments.

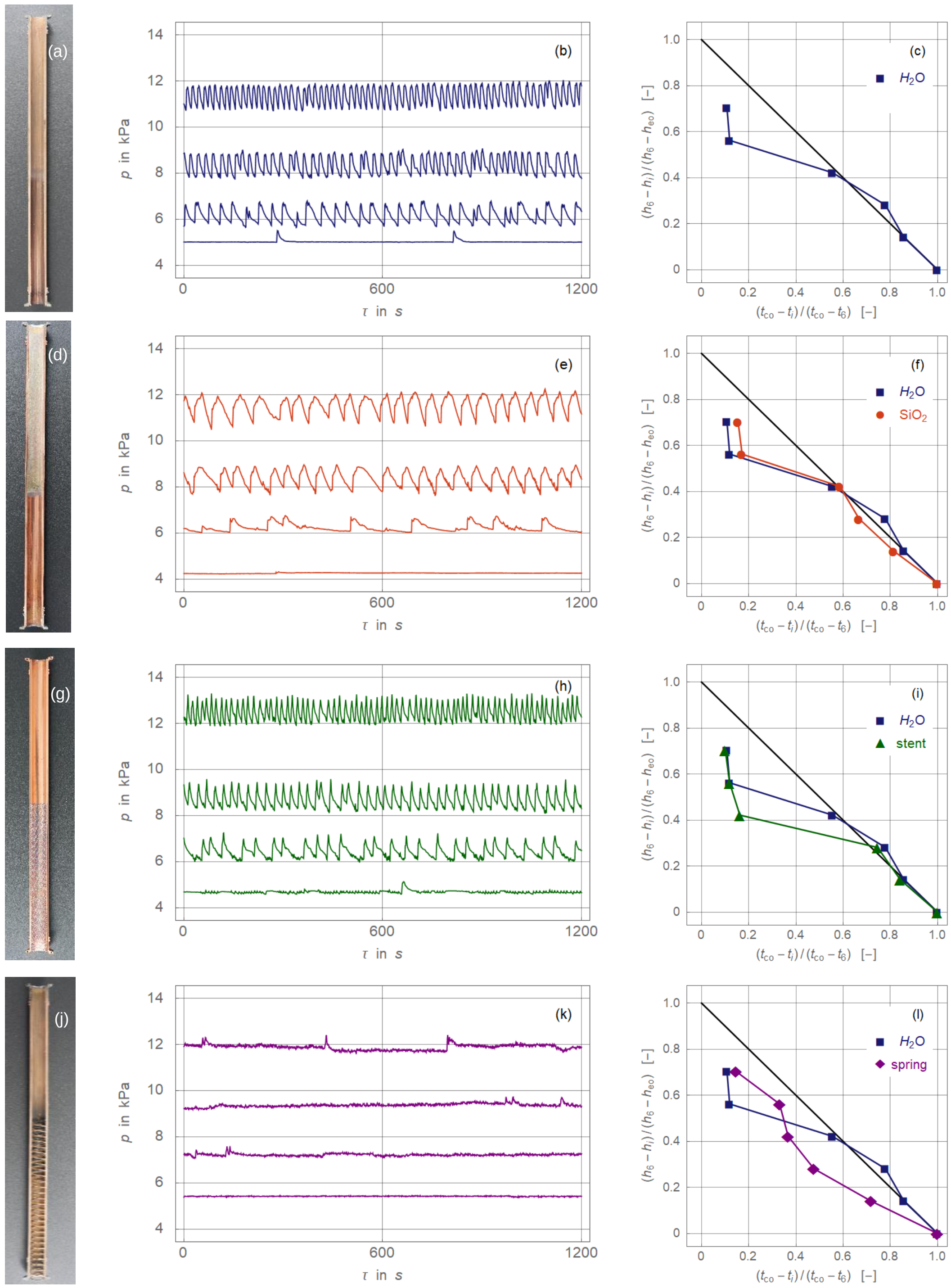

Fig. 2: Thermosyphon experimental results at t_{ci} = 15°C. The left column presents the copper tubes cut after each experimental series. The diagrams in the middle display the instantaneous pressure in the condenser for the four evaporator inlet temperatures t_{ei} = 45, 65, 75 & 85 °C (from below). The right column indicates the time averaged temperatures inside the evaporator at t_{ei} = 80 °C.

3. Experimental Results

Figure 2 presents experimental results. The left column shows images of the cut copper pipes. The centre diagrams display the pressure in the condenser region over a period of 1,200 s at four different evaporator inlet temperatures. The right plots indicate the mean temperature inside the evaporator measured t_{ei} = 80 °C using the temperature probe shown (Fig. 1 b).

The first row refers to the reference case (DI-water, no inlay). Due to the boiling process and the re-condensation of the condensate film, both evaporator zones are slightly, but differently, affected by corrosion. The geysers, whose frequency increases as the inlet temperature of the evaporator rises, are clearly identifiable. The change between the boiling and the evaporation zone (right diagram) manifests itself in a jump of the normalised temperature. The second row compiles results of the experiments with the silica suspension. Due to the violent geysers and the backflow of the working fluid after being expelled, the evaporation zone is completely covered with a coating consisting of silica particles. This enhances, especially for low overheating (4 to 16 K), the thermal performance of the thermosyphon significantly. Compared to the reference case, the frequency of the geysers is reduced, but also the shape of the geysers, without changing the mean temperatures.

The third row of Fig. 2 presents results for the stent inserted in the boiling zone. The stent is visible as the blue mesh in the lower section of the cut copper pipe. Frequency and shape of the geysers very much resemble the reference case. The average temperature of the working fluid is only identical to the reference case at the lower three measuring points. The temperature jump, which indicates the upper level of the working fluid, is below that of the reference case. Obviously more working fluid is in the gaseous phase. This finding is supported by the higher pressure for t_{ei} = 75 °C and 85 °C (centre diagram, upper curves). Over the entire range of the evaporator heat flux, a reduction in the thermal resistance is observed.

The insertion of the spring increases the heat transfer surface and distributes the heat imposed thus better through the entire working fluid. Additionally, the upper level of the working fluid is raised according to the volume of the spring. There are almost no more geysers (last row, centre diagram), which means that the transfer of thermal energy is much smoother and continuous. Which in turn leads to a lower mean temperature of the working fluid (last row, right plot).

4. Conclusion

The study presents experimental results on the modification of the evaporator surface of thermosyphons. The distinction between an evaporation zone and a boiling zone requires different measures to improve the overall heat transfer of this special type of phase change probe. By using a silica suspension as working fluid, the actual operation of the thermosyphon is preceded by an *in situ* production step that creates a coating of the evaporation zone. This coating augments the evaporation of the falling film. Inserting a stent into the boiling zone boosts the boiling. Using a coil spring instead distributes the imposed heat better and removes almost all geysering.

Modifications of the type presented here extend the range of applications for thermosyphons. Wastewater flows with fluctuating temperatures / heat fluxes can thus be utilised better as regenerative energy sources. Compared to other surface modifications, *in situ* coatings and inlays in the boiling zone are cost-effective approaches.

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