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# Performance analysis of a combined evaporator condenser for sorption cycles

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## 1. Summary

Capillary-assisted low-pressure evaporators (CALPEs) are used in closed-cycle sorption systems including heat pumps, heat transformers, desalination, and thermal energy storage systems. A common type of these evaporators is an extension of fin-and-tube heat exchangers, where fin spacing is small enough (~200 μm) to utilize capillary flow to eliminate the need for a pump in the evaporator chamber. Using the same heat exchanger as both evaporator and condenser is highly desirable, if possible, as it reduces the complexity, weight and cost of sorption systems. Experimental, analytical, and numerical results are available only for a limited range of geometries and operating conditions of CALPEs. More importantly, the performance of CALPEs as condensers has not been thoroughly investigated. In this study, a porous copper coated heat exchanger, originally designed as a CALPE is tested as a *combined evaporator and condenser* (CEC) under a range of operating conditions to assess its CEC performance.

## 2. Introduction

A capillary-assisted low-pressure evaporator (CALPE) features small fin spacing of (~200 μm) and works in low pressures, typically under 5 kPa, see Fig. 1. The surface tension of the refrigerant causes upward movement along the grooves on the outside surface of the evaporator. Thermal spray coating of copper particles on the surface of the heat exchanger provides further surface enhancement. Seiler et al. [1] studied the impact of driving force with varying filling levels. They reported surface properties and the capillary driving force to have a notable influence on thin-film evaporation. They reported a 10-fold increase in heat transfer coefficient for coated tubes as compared to uncoated tubes. Thimmaiah et al. [2, 3] developed and tested a CALPE and reported that the internal single-phase heat transfer coefficient, i.e., the internal convective heat transfer coefficient of the heat transfer fluid (HTF), was the bottleneck of CALPE with tube diameters of 19.05 mm. Moreover, they found out that increasing the HTF mass flow rate by 6.1 times only increased the cooling power by 20% in a 40 fin-per-inch 19.05 mm diameter commercially-available tubes.

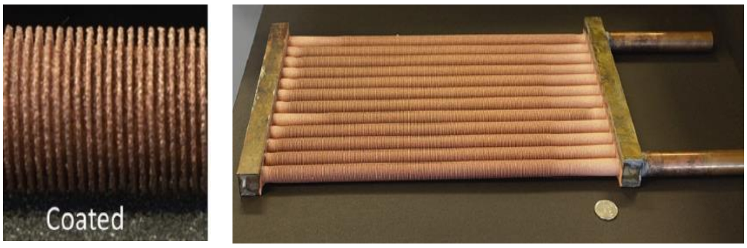


Fig. 1: Porous copper coated Capillary-assisted low-pressure evaporator (CALPE).

Although the performance of capillary-assisted tubes as evaporators has been investigated, there is a lack in literature in accessing their performance, limitation, and design criteria when it comes to condensation. This is highly desirable since combining the evaporator and condenser (CEC) in sorption has the potential to significantly reduce the overall mass, complexity, and cost and paves the way for compact designs. In this study, performance of an existing CALPE as condenser is investigated to provide insight to design efficient CECs.

Table 1: Geometry details of heat exchanger tube used in this study

| Tube name | OD (mm) | Fin height (mm) | Inside surface area ($m^2/m$) | Outside surface area ($m^2/m$) | Root wall thickness (mm) |
|---|---|---|---|---|---|
| **GEWA** | 12.7 | 1.5 | 0.024 | 0.124 | 0.8 |

## 3. Experimental Study

A porous copper coated CALPE is made by spray coating on GEWA®-K-2615 tubes (Wieland Thermal Solutions) with 9.7 mm inner diameter with 26 fins per inch which has an overall volume of 35×20×1.5 $cm^3$. Table 1 provides details of the tubes. As shown in Fig. 2, temperature control systems (TCS) provided a constant temperature HTF for the experiments. Tests were started with the evaporator submerged in water (flooded evaporator) and ended when the evaporator chamber was dry. Operating pressure was the saturation pressure at set temperature and ranged between 1 and 2 kPa for the tests. First, the performance of the spray coated CAPLE as an evaporator was investigated at different HTF flowrates with HTF inlet temperatures between 10 and 15 °C. The flow rate was varied between 2.5 and 5.5 liters per min (LPM). The aluminum evaporator chamber was triple coated with a protective polymer to prevent corrosion and a 0.4 mm Teflon sheet prevented direct the contact between the copper evaporator and the chamber walls.

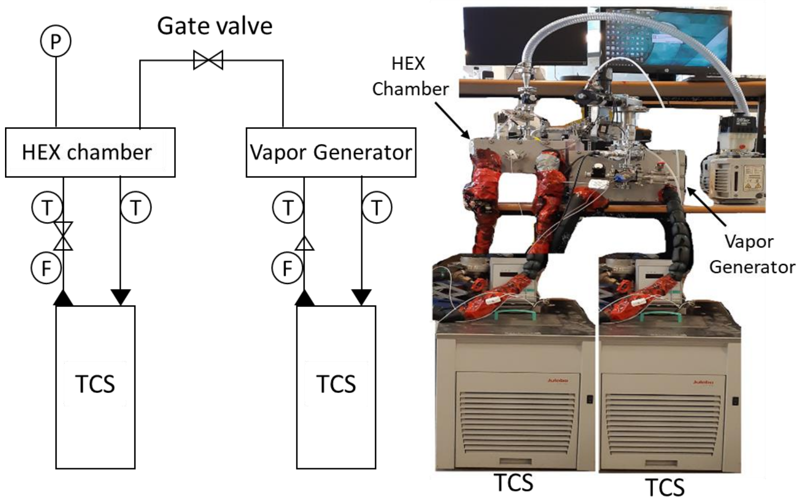


Fig. 2: CEC test-bed components

To test the CALPE as a condenser, the test-bed shown in Fig. 2 was used. Two vacuum chambers were connected with a short hose and a pneumatic valve. The bigger chamber worked as vapor generator/vapor collector alternatively. It was designed intentionally large so it would not create a bottleneck and affect the performance of the condenser. The smaller chamber was used for testing the heat exchanger used in this study. For each test, the heat exchanger was installed in the chamber and it was sealed and vacuumed. Prior to start of the experiments, two TCS were run for at least an hour to ensure steady-state condition was achieved. Three operating temperature sets were chosen. In the first run, the HTF temperature in the small chamber was set to 0 °C and the large chamber to 10 °C. This would make the heat exchanger in the small chamber to act as a condenser. Next, the temperatures were reversed, and the heat exchanger acted as an evaporator at 10 °C with the large chamber at 0 °C. For the second run, the same procedure was repeated but with temperatures set at 0 and 15 ℃. The third run was with temperatures 0 and 20 ℃. When the temperature control systems reached steady-state, the valve between the two chambers was opened, allowing the water vapor to move from the evaporation chamber to condensation chamber. The test was finished when all the water (1.3 L) had moved to the condenser chamber.

PT100 RTD temperature sensors acquired from Omega with a ±0.15 ℃ accuracy were used to measure the HTF inlet and outlet temperature. T-type thermocouples from Omega, with a ±0.5 ℃ accuracy, were used to monitor temperatures inside the evaporator chamber. absolute pressure sensors [PX309, Omegadyne] with an accuracy of 0.08% were used and calibrated before each test. A flowmeter [OM015S, Flowmec]was used with an accuracy of ± 0.7 %. The uncertainty of the measured cooling power was 9% in our tests.

## 4. Results and discussion

Figure 3 (a) shows the measured evolution of cooling power over time. At the beginning of the experiments, the evaporator is flooded, and the dominant heat transfer mechanism is natural convection due to the difference between the saturation and the tubes' temperature. As the water level decreases, the capillary action starts to affect the heat transfer and increases the cooling power significantly due to the addition of thin film evaporation, which accompanies the natural convection mechanism. This trend continues until the evaporator is dry. As seen in Fig. 3 (left) the outlet temperature of the HTF drops steadily which indicates the cooling effect. Figure 3 (right) summarizes the results for six experimental conditions. For HTF temperature of 15 ℃ and flowrate ranging from 2.5 to 5.5 LPM, cooling power of up to 825 W has been measured. The corresponding HTF temperature drop across the evaporator was between 3.7 and 2.2 ℃ for the flowrate of 2.5 and 5.5 LPM, respectively. Figure 3 (right) shows the cooling power for HTF of 10 ℃. A maximum of 625 W has been observed at the highest flowrate of 5.5 LPM. The HTF temperature change in this case ranged from 2.6 to 1.5 ℃. The highest power density for this evaporator was 320 W/kg and 0.79 MW/m$^3$ at 5.5 LPM of HTF at 15 ℃ and 240 W/kg (0.58 MW/m$^3$) for HTF at 10 ℃.

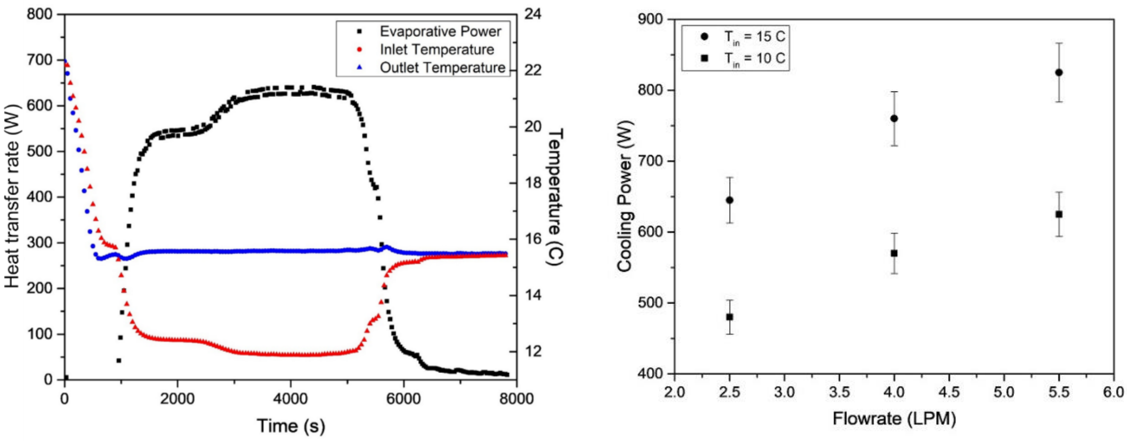


Fig. 3: left) Evaporator cooling power, inlet, and outlet temperature of HTF over time for flowrate of 2.5 LPM, right) Cooling power vs flow rate of HTF.

Since predictably of the higher HTF flowrate gave the highest cooling power, the CEC experiments were performed at 5.5 LPM of HTF flowrate. Figure 4 shows the performance of the spray coated CLAPE as a CEC. The left figure in Fig. 4 summarizes the results for three different temperature difference between the chambers and demonstrates the maximum performance of CLAPE as an evaporator and a condenser. For temperature difference of 10 ℃, the HTF running through the spray coated heat exchanger was set to 0 ℃ and the HTF running through the vapor generator was set to 10 ℃. This leads to condensation on the small chamber. By switching the temperature setting, the smaller chamber becomes an evaporator and the larger chamber acts as an vapor collector. As shown in Fig. 4, the spray coated CALPE performed better in most parts a condenser as it did as an evaporator. For the aforementioned temperature setting, the maximum cooling power of 350 and heating power of 375 W were achieved. For temperature difference of 15 and 20 ℃, the cooling power of 700 and 1100 W (270 and 424 W/kg) and heating power of 750 and 1200 W (289 and 463 W/kg) were achieved, respectively.

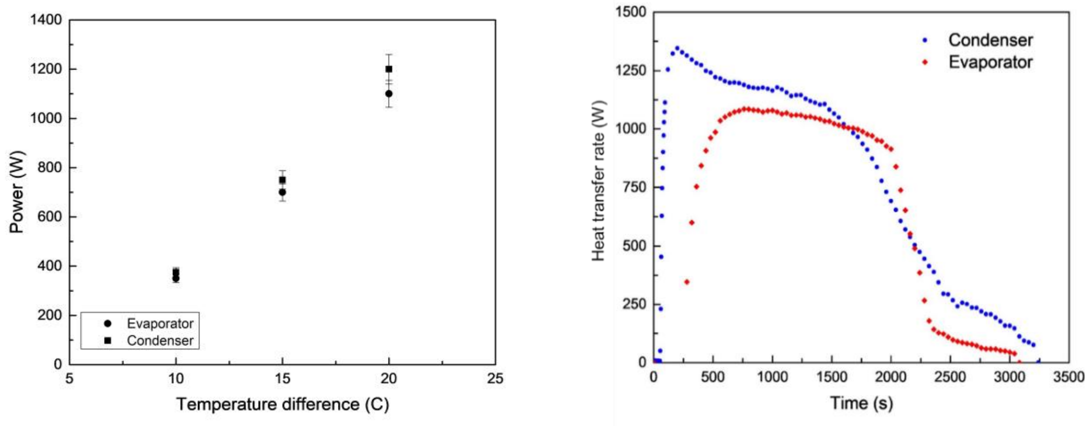


Fig. 4: Left) Cooling power versus heating power of spray coated CALPE for different temperature difference between chambers, Right) A sample real time performance of CEC

As an example, the real time performance of the spray coated heat exchanger as both evaporator and condenser is depicted in Fig. 4 (right). In conclusion, the copper spray coated heat exchanger's performance as a condenser is comparable to its performance as an evaporator. The copper spray coated evaporator performs well as a CEC and will be used in our future studies for CEC in sorption systems. In future studies, effect of different fin design and geometry will be studied as well as a complete modeling of CEC and optimization.

## References

[1] J. Seiler, F. Lanzerath, C. Jansen, A. Bardow, Applied Thermal Engineering 147 (2019) 571–578

[2] P. C. Thimmaiah, A. Sharafian, M. Rouhani, W. Huttema, M. Bahrami, Energy 122 (2017) 144-158

[3] P. C. Thimmaiah, A. Sharafian, W. Huttema, C. McCague, M. Bahrami, Applied Energy 171 (2016) 256–265