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Performance of a Micro Scale Integrated Thermal Management System

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1. Introduction

Electronic devices play a vital role in several applications such as computer industry and information technology, electric vehicles, avionics and renewable energy systems (wind energy, fuel cells and photovoltaic cells). The technological advances and the continuous demand on improving the performance and reducing the size of electronic devices increased the challenge in their thermal management. This means that the thermal management method could be a limiting factor in achieving more advancement in the future. Accordingly, there is a need for the development of small-scale innovative cooling systems for cooling the next generations of electronic devices.

Conducting a literature survey, one can see that, several researchers focused on flow boiling in micro channels while few researchers focused on flow condensation. Testing the microchannel evaporator and condenser in separate experimental facilities may give a certain thermal performance, which may differ when the evaporator and condenser are integrated together in a real small scale cooling system. To the best of our knowledge, there are no studies focused on the simultaneous measurements of boiling and condensation in multi-micro channels heat exchangers. Thus, the current study presents the design, commissioning and thermal performance of an integrated small scale cooling system incorporating a micro-channel evaporator and condenser. Existing models and correlations predicting the thermo-fluid performance of the evaporator and condenser were first reviewed. The final correlations used in the design of the micro heat exchangers will be discussed. The new facility can test flow boiling and condensation in micro-channels simultaneously as well as overall system performance. The system operates at atmospheric pressure and uses 3M Novec Engineering Fluid HFE-7100 as a test fluid. This fluid has a saturation temperature of 61 ^{0}C, which makes it suitable for pumped loop electronic cooling systems (sufficient temperature difference in the condensation side means small-size condenser). Figure 1 depicts a schematic of the flow loop with the integrated microchannel evaporator and condenser. The evaporator and condenser were instrumented to allow their performance to be recorded (and hence later optimized) prior to investigating the overall system performance.

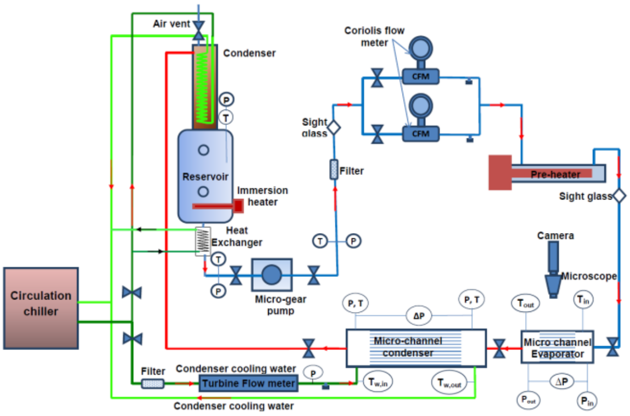
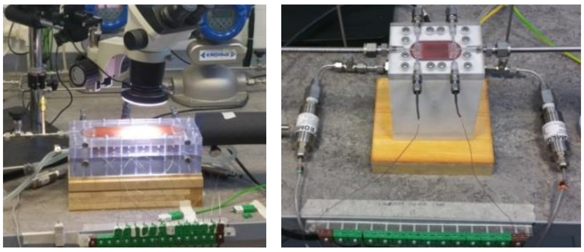


Fig. 1. Schematic drawing of the cooling system.

2. Test Sections

The evaporator consisted of 50 rectangular channels 0.3 mm wide, 1.0 mm high and 0.1 mm in fin thickness and semi-circular inlet/outlet manifolds. It was made of oxygen free copper by CNC machining with overall dimensions of 51×26 mm of which 25×20 mm is a heated footprint area. The flow enters the evaporator horizontally through a top plenum parallel to the flow then changes its direction by 90 ^{0}C before entering the channels. The inlet/outlet plenums were machined in the top transparent plate. Two different designs of symmetrical inlet/outlet plenums were investigated. The first design has a rectangular cross section and volume 0.48 cm^3 while the second has a semi-circular cross section and volume 0.8 cm^3. The condenser was made of oxygen free copper by CNC machining and consisted of 90 rectangular channels of 0.4 mm wide, 1 mm high, 0.1 mm separating wall thickness, 160 mm long and 45 mm wide. On the back side of the condenser, 24 square channels of 2 × 2 mm cross section were machined for the passage of cooling water. Since the test results of the evaporator indicated that the semi-circular plenum design achieved better flow stability, the inlet and outlet plenums of the condenser were made semi-circular. Figure 2 depicts photographs that shows the evaporator and condenser assembly. A wide range of heat and mass fluxes was examined. Flow patterns, flow instability, heat transfer and pressure drop results will be presented and discussed.

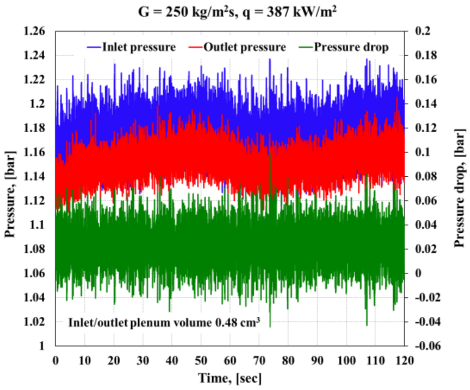


(a) condenser (b) evaporator

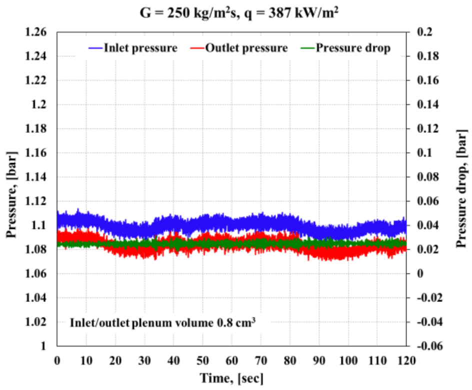
Fig. 2. Photographs of the evaporator and condenser.

3. Results

A sample of the results of the performance of the evaporator is presented in this section. Figure 3 depicts the effect of the size of the inlet/outlet plenum on the inlet/outlet pressure and pressure drop signals at the same heat flux for $G = 250\ \text{kg/m}^2\text{s}$. The data were recorded at a frequency of 1 kHz. It is obvious that the design of the inlet/outlet manifolds has a significant effect on flow instability. Increasing the volume of the manifolds by 66 % resulted in a significant decrease in the amplitude of the pressure and pressure drop signals. Flow instabilities are one of the factors that affect the design of small scale cooling systems. It is worth mentioning that flow visualization using the high speed camera indicated that flow reversal was evident in both cases of Fig. 3. In other words, this type of instability is related to the plenum size rather than bubble dynamics and flow reversal in the channels.



(a) Small size plenum



(b) Large size plenum

Fig. 3. Effect of plenum size on flow instability.

Figure 4 shows the effect of mass flux on the local heat transfer coefficient calculated based on the footprint area heat flux at thermocouple location near the channel exit for the small size plenum. The figure demonstrates that the small size plenum results in heat transfer coefficients that peak at $x \approx 0$ then decrease rapidly with vapour quality up to $x \approx 0.1$. This decrease could be due to local dryout arising from the flow mal-distribution among the channels. It is worth mentioning that, flow distribution was detected using three thermocouples inserted underneath the side channels as well as another three thermocouples underneath the middle channels. For the heat flux value presented in Fig. 3, the temperature of the side channels was 0.6 ^{0}C higher than that of the middle channels. The opposite occurred for the large size plenum where the temperature of the side channels was 0.3 ^{0}C lower than that of the middle channels. The significant decrease of the heat transfer coefficient with vapour quality is not observed for the large size plenum. After $x \approx 0.1$, the trend and magnitudes of the heat transfer coefficient were almost the same. In both cases, the heat transfer coefficient increases slightly with increasing mass flux and the effect of vapour quality becomes more pronounced as the mass flux increases.

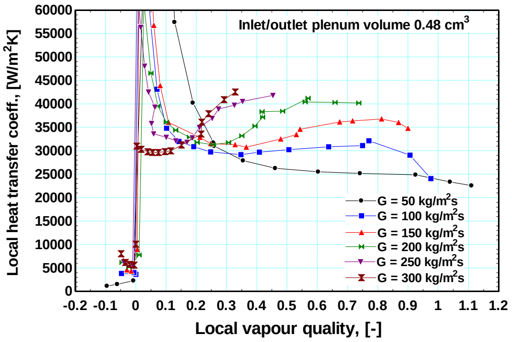


Fig. 4. Local heat transfer coefficient versus vapour quality.

Figure 5 depicts the coefficient of performance (COP) versus evaporator heat transfer rate (EHR) for different mass fluxes. The figure demonstrates that as the EHR increases the COP increases (good merit for electronics cooling systems). On the contrary, as the mass flux increases the COP decreases particularly at high thermal loads. It is obvious that the rate of increase of COP with EHR decreases significantly as the mass flux increases. The performance might get worse with further increase of mass flux. The figure also shows that the evaporator design in the current study can achieve heat transfer rate value of 382 W at COP value of 22.1. This COP value achieved in a pumped loop cooling system is much higher than that achieved with miniature vapour compression refrigeration systems, [1].

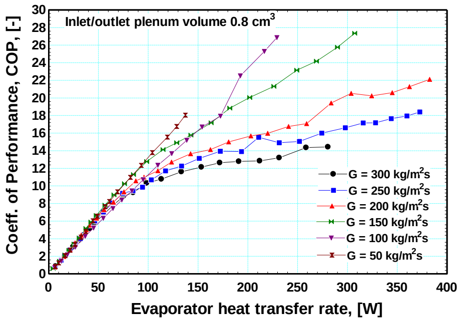


Fig. 5. COP versus evaporator heat transfer rate for different mass fluxes.

References

[1] Wu, Y-T, Ma, C-F, Zhong, X-H, Development and experimental investigation of a miniature scale refrigeration system, Energy Conversion and Management, 5(1), pp. 81 – 88, 2010.