Experimental Study of Porous Metals in Heat Exchangers

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Abstract. Use of porous materials in heat exchangers makes them more efficient in a smaller form-factor. Heat exchangers based on porous materials have uses in various industries, e.g. in power engineering. The latter currently relies on steam-to-water heat exchangers that load the environment. One promising way to make heat exchangers more eco-friendly is to use porous materials. An experimental setup was made to study heat transfer in porous materials. The setup enabled the research team to find the degree of cooling the hot coolant (water) passing through a porous heat exchanger. For comparison, experiments also involved a second heat exchanger (tubular, non-porous). The paper presents the installation diagram and the experiment methodology. It also reports the processed experimental data, draws conclusions, and suggests further experimentation.

1. Introduction

Next-gen porous heat conductors made of powdered aluminum, copper, or other materials, can be used to make efficient heat exchangers in a small form factor. What distinguishes the design of such exchangers is that their channels or intertube space are filled with metals of varying porosity. Such heat exchangers can differ in purpose and serve as the basis for refrigerators, heat pumps, or steam-turbine condensers. [1-11] Porous metals greatly increase heat output.

This paper compares the heat transfer efficiency of two coolants: hot (water) and cold (Freon).

There are different proposed designs for heat exchangers where the coolant undergoes phase transition. One proposal is to attach a triple layer of metal of varying porosity to the heat-exchange surface. Another method is to pass the phase-transitioning hot coolant through porous metal to enlarge the heat transfer surface for more efficient heat transfer. Some heat exchangers have porous gills of varying angle of inclination. Notably, heat exchangers are either expensive, or require difficult cleaning from the sediments that gradually accumulate in operation. [12–21].

The research team’s university has created a copper heat exchanger containing 19 copper tubes to transport hot coolant. The tubes themselves carry 4 cylindrical inserts of a mean porosity of 0.4739. The inserts are cylinders of porous aluminum, each is 50 mm high and 49 mm in diameter. Each insert has 19 holes of a diameter of 6 mm. [22]

For efficiency comparison, they’ve made another heat exchanger with no porous inserts.

The goal hereof is to experimentally compare the intensity of heat transfer in two water-gas heat exchangers where the coolant undergoes phase transition. One exchanger uses porous metal, the other one doesn’t. The next step is to process and analyze the experimental data. The final objective is to conclude on the feasibility of porous-metal heat exchangers.
2. Experimental Results and Analysis
The experimental setup consists of two circuits. The first circuit carries water and is equipped with a pump, a water boiler, and an instrumentation complex that features 3-second resolution of water temperature and flow tracking. The second circuit is an evaporator that transports R404a Freon.

![Diagram of the Freon circuit.](image)

1 is a condenser; 2 is a thermomanometer; 3 is a compressor; 4 is a vaporizer; 5 is a temperature sensor; 6 is a throttle.

Figure 1. Diagram of the Freon circuit.

The Freon circuit in Figure 1 is equipped with temperature sensors as well as with the inlet/outlet Freon pressure sensors; it also features a compressor.

Experiments have been carried out using each of the two heat exchangers at four water flow rates. During the experiments, the research team measured the water temperature as well as the Freon temperature at the inlet and at the outlet. Water flow was metered by a special instrument. To prevent random error, temperature readings were recorded 10 times for each different flow rate. This produced an array of data for indirect heat transfer intensity estimation.

The task was to compare the two heat exchangers in terms of heat transfer coefficient. As the Freon flow rate was not recorded, it was found analytically using the heat balance equation.[23]

\[
Q = M_w \cdot c_{pmw} \cdot (t_1 - t_2) = M_{fp} \cdot \tau_{fp} = kH \Theta_m
\]  

(1)

where \(M_w\) is the water flow rate, kg/s; \(M_{fp}\) is the Freon flow rate, kg/s; \(c_{pmw}\) is the isobaric mass heat capacity of water; \(\tau_{fp}\) is the Freon vaporization temperature; \(t_1\) and \(t_2\) is the water temperature before and after the vaporizer; \(k\) is the heat transfer coefficient, W/(m²·K); \(H\) is the heat transfer surface area; \(\Theta_m\) is the mean temperature coefficient.

The equation (1) was used to find the heat transfer coefficient.

\[
k = \frac{M_w c_{pmw} (t_1 - t_2)}{H \Theta_m}
\]

(2)

The inputs for the formula (2) were taken from the experimental measurements. The data processing output is visualized below.
As seen in Figure 2, the heat transfer coefficient was found to be higher in the porous-metal exchanger for the same flow rates.

Further measurements were designed to find how significantly water would be cooled in steady-state operation. To that end, water was heated to 40ºC; the Freon circuit was then switched on to cool the water for 30 minutes. The measurements were recorded as soon as Freon and water temperatures stabilized. The experiment was run multiple times for each heat exchanger. Water was found to only cool to a specific value. The water temperature drop was designated as Δt. The results yielded by the two heat exchangers are plotted below.

As can be seen in Figure 3, the porous heat exchanger lowered the water temperature more significantly: 30ºC against the 15ºC reduction in the non-porous exchanger. Thus, porosity was found to intensify heat transfer.

Water temperature was also plotted as a function of location in the heat exchanger. The solid line in the graph below shows water temperature evolution in the porous heat exchanger; the dashed line is for the non-porous device.
Figure 4. Water temperature as a function of location in the heat exchanger. Apparently, the porous counterpart was more efficient at cooling.

3. Conclusions
The research has produced the following findings:
1. The heat transfer coefficient was found to be higher in the porous-metal exchanger for the same flow rates.
2. The porous heat exchanger lowered the water temperature more significantly.
3. The laboratory setup can now be used to make a porous heat exchanger for real-world application in power engineering.

4. References
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