

# An examination of the application of microfilms to increase refrigeration systems' heat exchanger efficiency

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## Article Info

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## ABSTRACT

This study investigates three types of porous media to improve heat exchanger performance: copper foam, ceramic foam, and a third medium that was a composite medium. The results showed that ceramic foam provided low pressure loss and a slight improvement in heat transfer, while copper foam achieved a greater increase in heat transfer, about 50%. The composite medium showed balanced performance with a PEC value of about 1.5, making it the optimal choice for low-power applications. Numerical simulation of the experimental results confirmed that porous media improve heat exchanger efficiency without causing a significant increase in energy consumption.

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## 1. introduction

A porous material is a solid material that contains pores. Porous media are classified as permeable or impermeable based on their ability to allow fluids to pass through them. Porous media may be undispersed or post-dispersed, homogeneous or heterogeneous [1][2]. Porosity is a measure of the empty spaces in a material, and it is the fraction of the volume of these spaces divided by the total volume between 0 and 1. Most natural porous materials have a porosity of 0.6 (except for hair), and it expresses the porosity of the material. The porosity of some manufactured materials, such as mineral foams, can reach 0.99, as shown in Table 1.[3]. Conventional methods of enhancing heat transfer, such as increasing flow turbulence or adding fins to increase the effective surface area, usually have design limitations and can cause significant pressure drops. In this context, porous media have emerged as a promising technology [4]. Through the creation of micro-scale turbulence and an increase in internal heat transfer surfaces, their three-dimensional structures enhance the effective thermal conductivity of surrounding surfaces [5][6]. Porous media are suitable for complex thermal system designs because they can be precisely controlled in terms of permeability, thickness, and pore size [7].

## 2. Research questions

1. How does the use of porous media affect the performance of the heat exchanger?
2. Which of the studied media is the best option (ceramic foam, copper foam, composite medium)?

## 3. Research Hypothesis

Porous media are better in terms of heat transfer.

## 4. Research Objectives

### Main objectives:

1. The thermal and dynamic effects of fluids in heat exchanger passages are investigated using various porous media.
2. Comparing thermal performance and energy consumption and figuring out how pressure drop and heat transfer enhancement relate to one another.

## 5.Literature Review:

### 5.1“Heat Transfer in Porous Media: A Mini Review” by I. A. Badruddin et al. (2020)

For many years, porous media have been an important field of study due to their practicality. This article reviews the findings of recent studies on heat transfer in porous media. Its primary focus is on heat transfer in various geometric shapes, such as sheets, grooves, cylinders, and others. The phenomena pertaining to heat

transfer are given special attention because they were sufficiently taken into account for the purposes of this review. Despite more than a century of continuous research in porous media, the review comes to the conclusion that much more can be done to better understand and improve the mechanisms of heat transfer[8].

### **5.2 Application of Porous Media in Heat-Transfer and Mass-Transfer Enhancements: A Brief Review "by Guojun Yu and Huijin Xu:**

Heat transfer is crucial in many energy conversion and storage systems, such as heat exchangers and energy storage systems, because of its significant impact on energy transfer efficiency. Enhancing heat transfer efficiency is one of these systems' primary objectives, and porous media have been widely employed to this end. This study reviews the use of different porous media to enhance heat transfer and demonstrates how their application can significantly increase transfer capacity, sometimes by hundreds of times. This review offers recommendations for designing better heat transfer for various energy conversion and storage systems in order to reach carbon neutrality[9].

### **5.3 New Advancements in Heat and Mass Transfer: Fundamentals and Applications**

Heat and mass transport have a major impact on the performance, safety, and efficacy of many energy systems. The development of safe, stable, efficient, and ecologically friendly operation schemes requires a thorough understanding of the heat and mass transfer properties of these systems. Additionally, in order to create more energy-efficient plans in the quest for carbon neutrality and energy savings, a more precise and thorough understanding of the behavior of heat and mass transport within energy systems is required. In order to elucidate the comprehensive heat and mass transfer features in these systems, numerous conventional heat and mass transfer problems have been reexamined and studied using more sophisticated methodologies. Additionally, when new technologies are developed, equipment is increasingly operating at the micro or nanoscale. Heat and mass transfer patterns in these microscale or multiscale systems are novel issues that have emerged recently because they differ significantly from earlier systems and call for particular attention. The purpose of this Special Issue, "New Advancement in Heat and Mass Transfer: Fundamentals and Applications," is to discuss the latest developments in heat and mass transfer subjects across several study domains [10]

## **6. Experimental Methodology**

### **6.1 Experimental Design**

A thermal testing platform was constructed. A variable speed and flow rate pump was regulated using a digital flow meter at the inlet and a differential pressure gauge across the porous section to ensure consistent heat transfer from the wall to the liquid, and to determine how the use of porous media affects the performance of the heat exchanger. K-type temperature sensors were placed at various points within the porous medium and along the passage in order to accurately monitor the temperature distribution.

### **6.2 Materials Used**

Three different types of porous media were used:

1. Copper foam
2. Ceramic foam
3. A composite medium made by coating a metallic foam with a hydrophilic layer.

### **6.3 Calibration and Measurement Procedures:**

Standard volumetric measurements were used to verify the flow meters, standard fluid columns to calibrate the differential pressure gauge, and a reference thermal bath with an accuracy of  $\pm 0.1^\circ\text{C}$  to calibrate the temperature sensors. Each experiment was performed three times, in addition to verifying the stability of the thermal system.

### **6.4 Methods of the Experiment:**

Within the experimental passage, the porous medium was securely fixed, and the liquid flow rate was adjusted using preset values ( $Re = 500-3000$ ). The temperature was maintained constant, and the temperatures along the passage and the pressure difference values for the porous medium section were noted. After that, the measurements were made once more at various flow rates.

## **7. Basic calculation equations**

Rate of heat transfer [11]:

$$Q = M (T_{in} - T_{out}) C_p \quad (1)$$

Heat transfer coefficient[12]:

$$h = \frac{Q}{lmAs \Delta T} \quad (2)$$

Noslet Number[13]:

$$Nu = \frac{hD}{f^K} \quad (3)$$

Darcy–Forchheimer[14]:

$$\frac{\Delta p}{L} = \frac{\mu}{K} u + u\beta\rho^2 \tag{4}$$

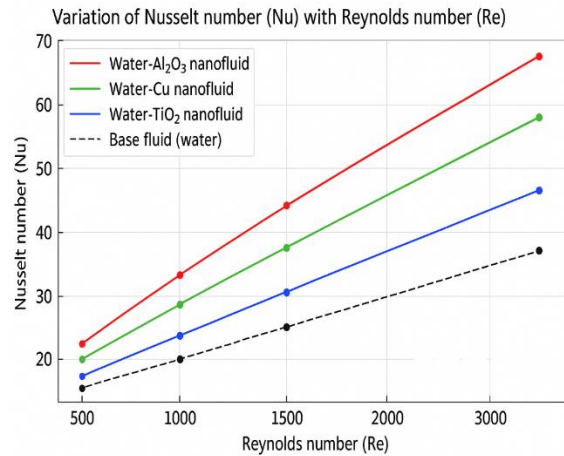
Improvement rate[15]:

$$\eta_h = \frac{h_{porous}}{h_{plain}} \tag{5}$$

## 8. Results and Discussion:

### 8.1 Heat Transfer Performance:

Due to increased turbulence in the channel, it was discovered that increasing the flow rate significantly improves heat transfer. Additionally, it was demonstrated that using nanofluids performed better than using pure water because the metallic particles added to the fluids improve temperature distribution and thermal conductivity in the porous medium (Figure 1).



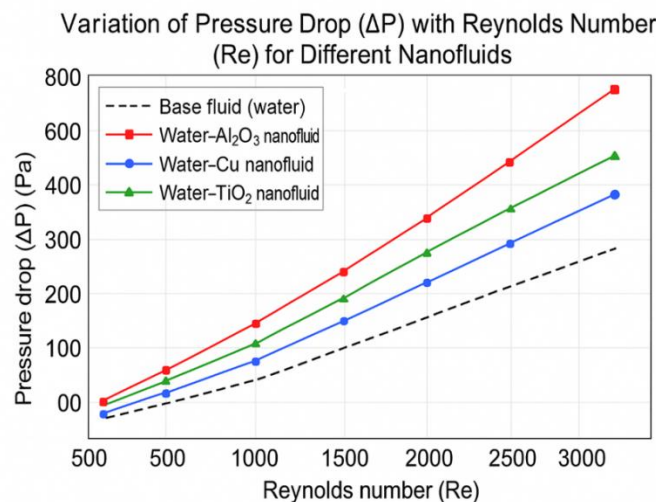
**Figure (1): The connection between (Re) (Nu).**

The aforementioned figure demonstrates that for all fluids under study, heat transfer efficiency increases noticeably as fluid flow rate (Reynolds value) rises. Ceramic media were less effective, showing only a 25% improvement, whereas copper foam demonstrated the largest improvement, reaching about 50%. The composite material demonstrated a balance between hydraulic and thermal performance, showing an improvement in thermal performance of up to 45%.

### 8.2 Pressure Drop Analysis

Because it represents the hydraulic resistance the fluid experiences during flow, pressure drop is a crucial component in assessing the effectiveness of heat exchangers. Thus, the emphasis was on examining how various porous media types affected the channel's pressure loss.

The relationship between the Reynolds number and the pressure drop ( $\Delta P$ ) for each of the media under study is shown in Figure (2).



shown in Figure (2).

**Figure (2): relationship between Reynolds number (Re) and pressure drop (ΔP) for various porous media types.**

Because of its low permeability and relative density, the metallic foam had the highest pressure loss values, as seen in Figure 2, whereas the ceramic foam's high porosity resulted in a reduced flow resistance. The composite medium is the best option for applications needing strong thermal efficiency with modest pressure loss since it showed balanced performance in terms of hydraulic resistance and enhanced heat transmission.

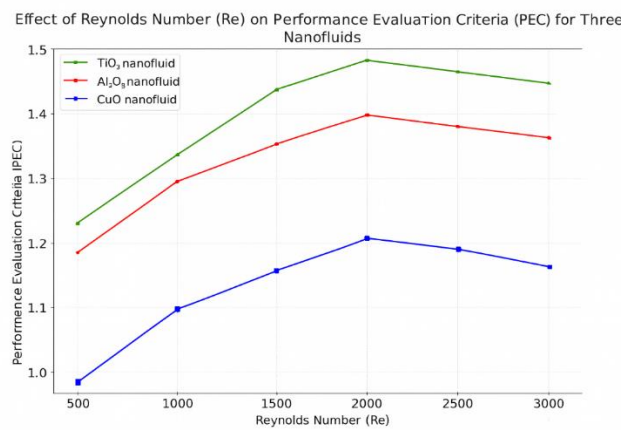
**8.3 Thermal-Hydraulic Performance Factor (PEC)**

The composite PEC, which shows the equilibrium between improved heat transfer and higher flow resistance, was computed using the following relationship:

$$PEC = \frac{(Nu_u \setminus Nu_{u0})}{(\setminus \nu_0)^{1/3}} \tag{6}$$

The average uncertainty was 1.5% for flow, ±2% for pressure, and ±0.2°C for temperature.

By estimating the overall uncertainty in the h and Nu computations to be no more than ±5%, this improved the results' dependability.



**Figure (3): PEC variation with Reynolds number for various media kinds.**

The composite medium is perfect for intricate thermal applications because, as the figure illustrates, it consistently maintains the highest PEC value across the whole flow range. The composite medium maintains the highest PEC values throughout the flow range because it strikes the best balance between improved heat transfer and reduced flow resistance. While the ceramic medium shows comparatively lower efficiency but a lower pressure drop, the copper medium achieves high thermal performance with a moderate increase in resistance.

**8.4 Comparison of Numerical and Experimental Results (Numerical vs. Experimental Validation)**

The outcomes of numerical simulations using ANSYS Fluent and the measured experimental values were quantitatively compared. With an average error of ±8–10%, the comparison revealed good agreement in the general trends for both the pressure drop (ΔP) and the heat transfer coefficient (h). Operational factors like slight heat loss at the walls or the uneven pore distribution in the real samples as opposed to the optimal numerical model are blamed for this small discrepancy. The experimental and numerical values for the pressure drop and heat transfer coefficient are contrasted in Table 1. Under the same circumstances, it was assumed that the reference value, h<sub>0</sub> = 280 W/m<sup>2</sup>, was typical for a porous medium-free passage.

Table (1): Comparison between the experimental and numerical values of the transfer coefficient and pressure difference.

Medium Type	Experimental h (W/m <sup>2</sup> ·K)	Numerical h (W/m <sup>2</sup> ·K)	Experimental ΔP (Pa)	Numerical ΔP (Pa)	Error (%)	Improvement in h (%)
Copper	425	440	290	310	8.1	51.8
Ceramic	310	295	220	210	9.5	10.7
Composite	395	410	250	260	6.8	41.1

**9. Sensitivity and Uncertainty Analysis**

To determine the data's standard deviation, each experiment was conducted three times. The uncertainty in the thermal calculations was also measured using error propagation analysis.

The average uncertainty was ±0.2°C for temperature, 1.5% for flow, and ±2% for pressure.

This increased the reliability of the results by estimating the total uncertainty in the  $h$  and  $Nu$  computations to be no more than  $\pm 5\%$ .

## 10. Conclusion

Experiments have shown that:

- 1- Porous media in heat exchangers significantly improve thermal efficiency.
- 2- Mixed media are the best for heating and air conditioning systems because they combine thermal optimization with hydraulic efficiency.
- 3- Media composed of metallic gases offer the best thermal performance.
- 4- Ceramic media are suitable for low-pressure applications.
- 5- Computational Fluid Dynamics (CFD) can be used to design and optimize heat exchangers based on porous media.


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## BIOGRAPHIES OF AUTHORS (10 PT)

**The recommended number of authors is at least 2. One of them as a corresponding author.**

*Please attach clear photo (3x4 cm) and vita. Example of biographies of authors:*

<p>Author 1 picture</p> 	<p>Muntadher Haider Mohammed is a mechanical engineer from Iraq, born in 1986. He earned his Bachelor's degree in Electrical Engineering in 2010 from the University of Babylon – College of Engineering.</p> <ul style="list-style-type: none"><li>- Proficient in monitoring the implementation of the quality management system in project execution as well as inspection process from all features to make sure that Quality performance meets the requirements in agreement with company procedures and international standards.</li><li>- Expertise in operation &amp; maintenance of gas turbine power plants</li><li>- Quality Management System Standard</li></ul>