Convection Heat Transfer in Porous Media with Evaporation and Condensation Processes

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Abstract: This study aimed at derivation of a new formula to calculate the mean values of the heat transfer coefficients of phase change fluid flow. The fluid flow considered encountered convection heat flux inside rigid tubes filled with porous media. Analytical method was used to obtain the following form: An analytical method using the exponent method of non-dimensional analysis was used to reach a general form of a relation combining heat transfer with Brinkman number and Weber number. Two different correlations were formulated, one for the evaporation process and the other for the condensation process. Different constants of equation 10 will produce the different forms. The values of the constants depend on the fluid under experimentation. As a case study, carbon dioxide was used. The formulae obtained can be used to calculate the mean heat transfer coefficient \( \tilde{h} \) and heat flux. Heat flux is the catalyst for phase change. Enhancement in heat transfer by increasing heat flux was due to the existence of porous media inside the tube. Better heat exchanger design as well as better condensers and evaporators will result, due to this arrangement, in porous media inside rigid tubes.

Keywords: Porous Media, Heat Transfer, Two Phase Flow, Change of Phase, Refrigeration, Carbon Dioxide.

1. INTRODUCTION

Heat transfer and fluid flow inside tubes have many applications, such as: heat exchangers, condensers, evaporators and boilers. Using porous media inside tubes enhances heat flux and increases heat transfer coefficients. 

Convection heat transfer for a phase change flow inside tubes was studied in the literature. Mini- and micro-tubes were used. Many correlations for mean Nusselt number \( \tilde{N}_{\text{Nu}} \) and mean heat transfer coefficient \( \tilde{h} \) were obtained. Both \( \tilde{N}_{\text{Nu}} \) and \( \tilde{h} \) were calculated using the analytical correlation or using the experimental results for the purpose of comparison. References \cite{5-8} are good examples for literature work in this field.

Reference \cite{4} discussed flow and convection heat transfer in porous media for single phase fluid. Reference \cite{9} argued about the suitability of using a superposition formula of pool boiling, \( h_b \) and single liquid flow formula, \( h_l \) to get the flow form, \( h_r \) in the form:

\[
h_r = h_b + h_l \tag{1}
\]

Numerical solutions were implemented for cylindrical and annular configurations. References \cite{8-9} studied experimentally phase change processes for flow inside porous tubes. The first work used water and steam flow, while the second one used carbon dioxide (CO\(_2\)) in the super critical region. Results of both works were tabulated and exhibited in suitable figures.

Reference \cite{11} investigated CO\(_2\) phase change flow inside tubes filled with porous media. The author used dimensional analysis for the mean value of the Nusselt number, \( N_{\text{Nu}} \), for:

\[
N_{\text{Nu}} = 1.27 \times 10^{-4} \left[ \left( Re_{\text{CO}_2} \right)^{0.2574} \tilde{h}_{\text{sf}} \left( Pr \right)^{0.253} \right] (\frac{L}{D})^{0.037} (Da) \tag{2}
\]

Condensation:

\[
N_{\text{Nu}} = 1.8 \times 10^{09} \left[ \left( Re_{\text{CO}_2} \right)^{0.2574} \tilde{h}_{\text{sf}} \left( Pr \right)^{0.253} \right] (\frac{L}{D})^{0.037} (Da) \tag{3}
\]

Porosity in his work ranged from 39% up to 45%. Methods were used to formulate a correlation equation for the mean value of convection heat transfer coefficient of flow in porous media inside tubes. Experimental results of CO\(_2\) flow were obtained.

2. ANALYTICAL STUDY

The variables affecting the convection heat flux in the processes under consideration were gathered in one equation.

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