An Analytical and Numerical Study on Heat and Fluid Flow in Nanofluid-Saturated Porous Media

（課程博士・様式７）（Doctoral qualification by coursework,Form 7）

学 位 論 文 要 旨

Abstract of Doctoral Thesis

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論文題目：ナノ流体で満たされた多孔質体内の熱流動に関する解析的および数値的研究
Title of Thesis : An analytical and numerical study on heat and fluid flow in nanofluid-saturated porous media

論文要旨：
Abstract：

In this dissertation thesis, an extensive analytical and numerical study has been made to explore heat and fluid flow characteristics in nanofluid-saturated porous media. Nanofluids, namely, the fluids containing submicron solid particles of high thermal conductivity, have great potential as a high-energy carrier. Larger-sized particles cause numerous problems such as abrasion, clogging and high pressure loss, whereas these nanoparticles such as alumina, titania and copper oxide, available today, can be suspended stably within the fluids without settling out of suspension.

Thanks to recent advance of manufacturing technologies, metal foams are now commercially available. They naturally have high specific surface, high thermal conductivity and comparatively high permeability. Thus, the metal foams are great candidates for efficient heat exchangers, because they possess high interstitial heat transfer between the metal and passing fluid, while a pressure drop is only moderate due to a high permeability. In this study, it has been proposed to use combination of nanofluid and metal foam, namely, nanofluid-saturated metal foams, so as to achieve an innovative heat transfer enhancement.

In this study, an appropriate set of volume averaged transport equations for convection in nanofluid saturated metal foams has been derived, for the first time, exploiting a volume averaging theory. In the derivation, the interstitial heat transfer from the metal to nanofluid was assumed to take place, thus, allowing that nanofluid temperature and metal temperature differ from each other, i.e. local thermal non-equilibrium model. Microscopic transport equations, which are based on the Buongiorno model for convective heat transfer in nanofluids, were modified so as to consider the effects of nanoparticle volume fraction distributions on the continuity, momentum and energy equations. Subsequently, they were integrated within a local averaging volume, to obtain an appropriate set of governing equations in terms of volume averaged dependent variables. The various terms associated with interfacial surface integrals and spatial correlations of spatial

deviations were subsequently modeled mathematically using the volume averaged dependent variables. Their functional forms and unknown coefficients were determined by carrying out a pore scale analysis.

Both longitudinal and transverse and thermal dispersion components in a nanofluid saturated were investigated using a pore scale conduit model. Furthermore, for the first time, nanoparticle mechanical dispersion (i.e., macroscopic dispersion of nanoparticles resulting from porous matrices) was treated microscopically using the pore scale conduit model. The analysis reveals that the longitudinal particle mechanical dispersion works either to suppress or to enhance effective diffusion. It depends on the sign of the local phase temperature difference. The transverse counterpart, on the other hand, turns out to be much lower than the longitudinal one.

Moreover, heat transfer performance evaluation under equal pumping power was made analytically for the case of forced convective heat transfer in a nanofluid saturated metal foam. The analytical study clearly indicates that an unconventionally high level of the heat transfer rate (about 80 times more than the case of base fluid convection without a metal foam) is possible by combining metal foam with nanofluid.

A numerical study was also conducted by carrying out exhaustive numerical computations for nanofluid forced convection through a collection of periodically placed square metal rods subject to a constant heat flux. This collection of square metal rods subject to a constant heat flux was used as a two-dimensional numerical model of metal foam. Pore scale numerical computations were made for one structural unit by exploiting periodic boundary conditions for velocity, temperature and nanoparticle volume fraction distributions, which are assumed to be periodically fully-developed.

The numerical study provided the detailed distributions of velocity, temperature and nanoparticle volume fraction within the structural unit. These microscopic numerical results in a pore scale were integrated over the structural unit, so as to evaluate the mechanical dispersion terms, purely from the theoretical basis. The longitudinal thermal dispersion coefficients, thus obtained from the numerical computations, were compared against available experimental data and also with the analytical results based on a pore scale conduit model. An excellent agreement with the experimental data was confirmed in the numerical and analytical results, which substantiates the soundness of both numerical and analytical treatments proposed in the present study.

It has been revealed that the effect of the particle volume fraction on the thermal dispersion correlation is only minor, so that the correlations obtained for the base fluid can be used universally. On the other hand, the nanoparticle mass flux is found rather sensitive to the interstitial heat transfer rate from the metal to nanofluid, since it increases with the interstitial heat transfer rate.

As described above, specific heat transfer characteristics associated with nanofluid saturated metal foam were elucidated in this dissertation study. It clearly shows that nanofluid-saturated metal form is quite promising candidate for innovative heat transfer enhancement.

記入上の注意

１）論文要旨は、日本語２,０００字または英語８００語程度とする。

２）余白は、上３０mm、左３０mm、下及び右１５mm とする。

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１）The abstract should be about 800 words in English or 2,000 characters in Japanese.

２）Ample margins should be left, e.g., top, 30mm; bottom, 15mm; left, 30mm; right, 15mm.

３）The abstract should be typed on one side of A4 white paper (maximum 2 pages).