An Innovative Technology for Enhancement of Heat Transfer : 3D Lattice Metal Frame Porous Media

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研究成果の概要（和文）：輸送パラメーターの実験のセットアップを確立し、実験を行った。3D金属フレーム構造における強制対流熱伝達の体積平均熱輸送パラメーター（透過性、慣性係数、界面熱伝達係数、熱分散）は、細孔スケールの方程式を解くことによって数値的に決定される。この研究の独創性のポイントの1つは、サーマルカメラを使用して、サンプル内部の固体温度を測定することである。流体温度と固体温度の両方、およびチャネル内の速度についても測定を行い、数値研究と比較したところ、それらの間に良好な一致が観察された。この良好な一致に基づいて、LMFのさまざまな形状の数値研究を行うことにより、熱輸送パラメータ相互の比較が可能となる。

研究成果の学術的意義や社会的意義
Although metal foam is used for enhancement of heat transfer, the shape of the metal foam can not be optimized. This is study is a fundamental study for the use of Lattice Metal Frames which are good alternative for the metal foam. It can provide high heat transfer rate with minimum pressure drop.

研究成果の概要（英文）：The heat transport experimental setup was established and experiments were conducted. Furthermore, the volume-averaged transport parameters (which are permeability, inertia coefficient, interfacial heat transfer coefficient, longitudinal and transverse thermal dispersion) of periodic 3D Lattice Metal Frame structure for forced convection heat transfer are determined numerically by solving pore scale equations. One of the originality points of this study is to measure solid temperature inside of the sample by using Thermal Camera and special glass in the experiments.Both the fluid and solid temperature and also velocities in the channel are measured and compared with numerical studies and good agreement between them were observed. Based on this good agreement, numerical studies for different shapes of LMF has done and transport parameters are compared with each others. The study continues for the optimization of the shape of the Lattice Metal Frame.

研究分野：Convective Heat Transfer

キーワード：Forced Convection　Heat enhancement　Porous Media　Lattice Metal Frame

１．研究開始当初の背景

Heat transfer enhancement is one hot topic in heat transfer. Many active and passive methods have been studied and worked. The most common passive method for enhancing heat transfer is the use of fin. Fins extend heat transfer area causing enchantment of heat transfer. Recently, the use of porous media (especially open cell metal foams) becomes popular for enhancement of heat transfer. Open cell metal foams increase the stagnant thermal conductivity, mixing the fluid and enhances heat transfer area. However, the high-pressure drop for the application of metal foam is a severe problem. By improving manufacturing technology, especially by developing of Metal Laser Printer, the use of 3D Lattice Metal Frame becomes popular. Laser Metal Printer can design a porous structure with a high heat transfer enhancement rate and low-pressure drop. By other words, it is possible to design a structure and optimize the shape of the structure which is the big advantage of the 3D Lattice Metal Frame (LMF) comparing to the open cell metal foams.

２．研究の目的

This study aims to find the volume average transport properties (permeability, inertia coefficient, interfacial heat transfer coefficient and thermal dispersion in flow and transverse directions) of different shapes 3D LMF such as Simple Cube, Side Center Cube, Body Center Cube and Face Center Cube, numerically. For the validation of the numerical results experimental setup aimed to be established. The experimental study was performed for simple cube 3D LMF and the experimental results and numerical results are compared to be sure of the numerical results. Later, optimization of the shape of the 3D LMF by using pore scale study and then calculation of the volume average transport parameters are possible.

３．研究の方法

The study investigated thermal transport parameters such as permeability, inertia coefficient, interfacial heat transfer coefficient, thermal dispersion in a 3D Cubic LMF both theoretically and experimentally. An experimental setup is established to find the temperature and velocity distribution in the 3D Cubic lattice metal frame. Then, the volume average governing equations for the 3D LMF are solved by using the transport parameters obtained from the pore scale analysis. An experimental study was performed to validate the simulation results. The Figure of the experimental setup is shown in Figure 1 and the picture of the studied experimental sample is shown in Figure 2. Experimental studies were done for 3D cubic Lattice Metal Frame and each cell is connected with circular rods.

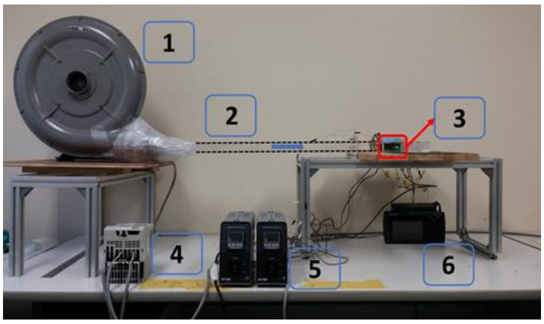


Figure 1. The Picture of Experimental Setup 1-Blower, 2- Air Channel, 3-Porous Media, 4- Voltage Transducer, 5- Heater Sources, 6- Data Logger

Figure 2. The Picture of the studied 3D cubic LMF sample

The solid inside temperature of the sample was measured by using thermal camera. By using a software, the temperature could be measured. The special glass was used in the experiment, since the temperature behind the normal glass or acrylic glass cannot be seen by thermal camera.

For the numerical study, the transport parameters which are permeability, thermal diffusivity, heat transfer coefficient and inertia coefficient are found from the solution of the pore scale equations. The governing equations for the pore scale are conservation of mass, momentum and energy equations. The domain for the pore scale results are shown in Figure 3. After obtaining the volume average parameters, Then the volume average equations are solved and the volume average temperature, velocity and pressure are found. The obtained values are compared with the experimental results.

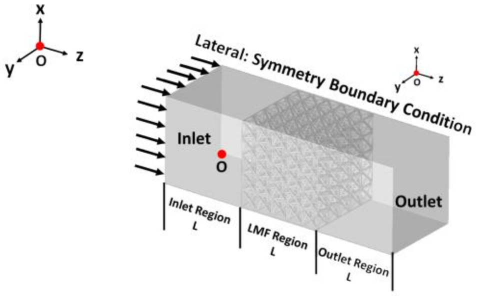
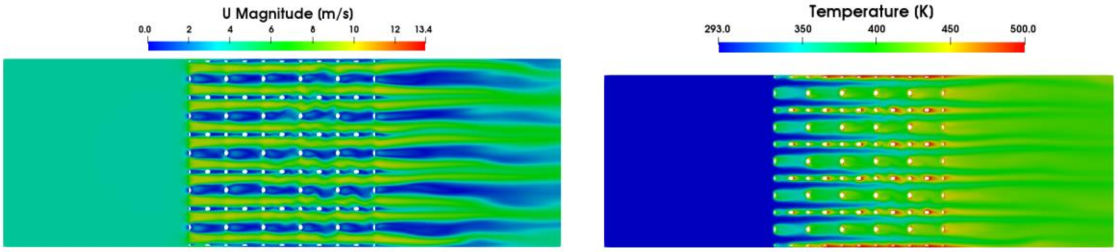


Figure 3. The considered domain with dummy inlet and outlet regions, and boundary conditions (O indicates the origin point)

４．研究成果

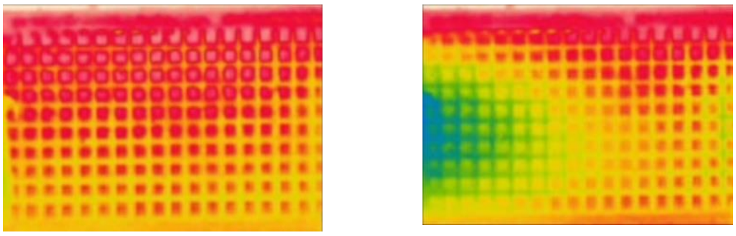
One of the obtained pore scale results for Face Centered Cubic structure is shown in Figure 4. The velocity and temperature distribution for a Simple Cube 3D LMF when Re = 529 can be seen clearly. There is oscillation of velocity around the rods and the effect of the convection for the temperature distribution can be seen from the figure. Air enters to the 3D LMF at the ambient temperature and its temperature increases and leave the channel at the uniform temperature at the outlet.



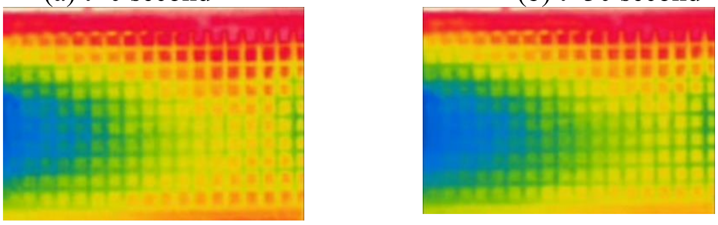
(a) (b)

Figure 4. The pore scale results for Face Centered Cubic structure when Reynolds number is 529 at the middle section parallel to flow, (a) velocity, (b) temperature

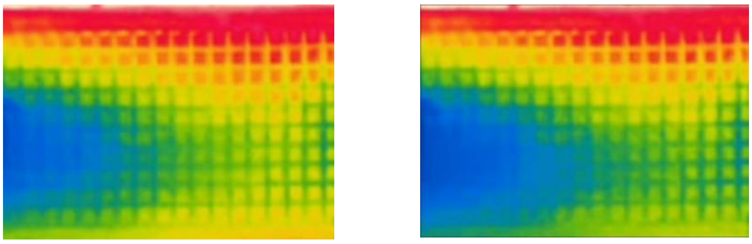
As it was mentioned before, the solid temperatures were measured by using thermal camera. Figure 5 shows the solid temperature distribution of the inside of the sample depending on different time steps. These pictures were taken by thermal camera.



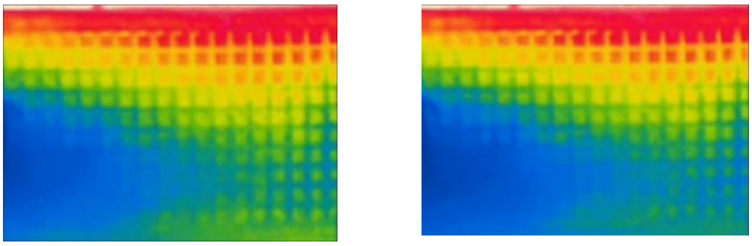
(a) t=0 second (b) t=30 second



(c) t=60 second (d) t=90 second



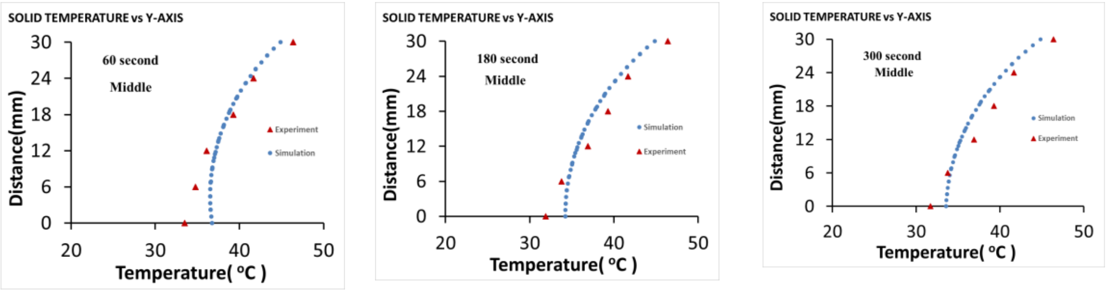
(e) t=120 second (f) t=180 second



(g) t=240 second (h) t=300 second

Figure 5. Solid temperature distribution measurement inside of the sample (3D cubic LMF) by using thermal camera depending for the different time steps

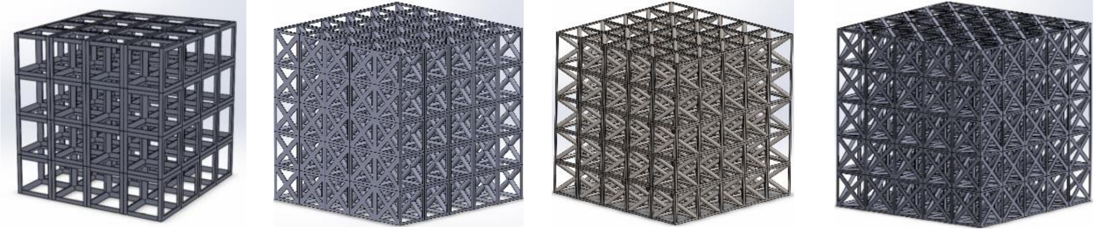
The solid temperatures obtained by thermal camera are compared with results of the volume average temperature. These comparisons were done at three sections of the channel. The comparison is shown in Figure 6. As it can be seen a good agreement between them can be observed between the volume average results and experimental results showing that all transport parameters were found from the pore scale analysis numerically are correct.



(a) (b) (c)

Figure 6. Comparison of the solid temperature at the middle section between simulation and experiment

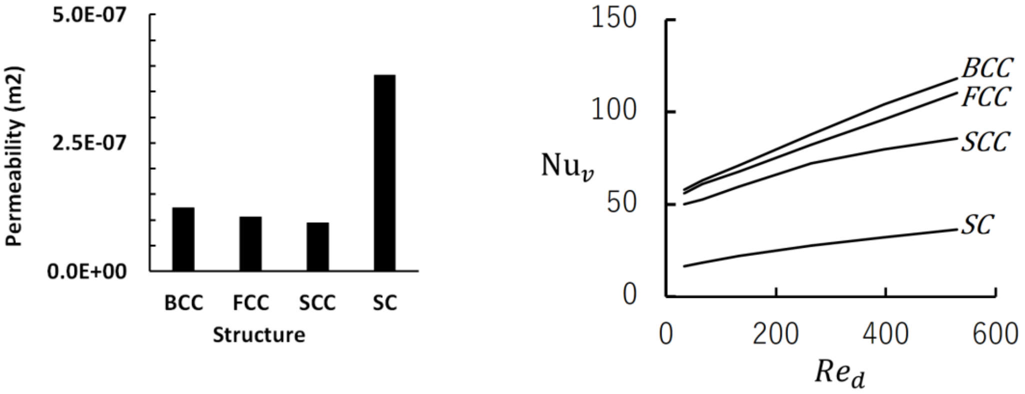
Based on the good agreement between the numerical and experimental results, further numerical works have been done. The computational studies were performed for different 3D Lattice Metal Frame structures as Simple Cube, Side Center Cube, Body Center Cube and Face Center Cube. The shapes of these structures are shown in Figure 7.



(a) (b) (c) (d)

Figure 7. The topology of the studied 3D LMF, (a) Simple cube, (b) Side center cube, (c) Body center cube, (d) Face center cube

The comparison of the different transport parameters for the porous media was done and the advantages and disadvantages of the studied structures are discussed. Figure 8 shows a sample of the results for the permeability and interfacial heat transfer coefficient. As it can be seen, simple cubic structure has very high permeability compared with the other studied structure. Fluid can flow in the structure with very low pressure drop however this structure does not mix the fluid and almost a straight forward flow was observed. This causes that heat transfer between the solid and fluid decreases and that is why the interfacial heat transfer coefficient for the simple Cube is the smallest one in Figure 8.



(a) (b)

Figure 8. Fluid flow results for the studied structures, (a) permeability, (b) interfacial volumetric Nusselt number

One of the original points of this study is to measure solid temperature inside of the sample by using Thermal Camera and special glass in the experiments. Both the fluid and solid temperature and also velocities in the channel are measured and compared with numerical studies and good agreement between them were observed. The study should continue for the optimization of the shape of the Lattice Metal Frame. The next steps of the stud will be numerical studies for the parametric shapes of lattice metal frame, since the good agreement of the numerical and experimental studies proved the accuracy of the numerical method.

５．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計1件（うち招待講演　0件／うち国際学会　0件）

１．発表者名 Guray Caket, Hasan Celik, M. Mobedi, F. Kuwahara
２．発表標題 A NUMERICAL AND EXPERIMENTAL STUDY ON DETERMINATION OF INTERFACIAL HEAT TRANSFER COEFFICIENT AND THERMAL DISPERSION OF A 3D CUBIC LATTICE METAL FRAME
３．学会等名 The 7th Asian Symposium on Computational Heat Transfer and Fluid Flow,Tokyo, Japan 2019
４．発表年 2019年

〔図書〕　計1件

１．著者名 Celik H., Mobedi M., Nakayama A.,	**４．発行年** 2019年
２．出版社 CRC Press	**５．総ページ数** 381
３．書名 Pore Scale Analysis in Forced Convection Heat Transfer in Porous Media (Edited by Mahmoudi Y., Hooman K., Vafai K., Convective Heat Transfer in Porous)	

〔産業財産権〕

〔その他〕

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６．研究組織

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