THERMAL ANALYSIS FOR HIGH TEMPERATURE SOUND ABSORBING APPARATUS OF POROUS METALS

Bo Zhang
Ningxia University, School of Mechanical Engineering, Yinchuan, Ningxia, China
Universiti Malaysia Pahang, Faculty of Mechanical Engineering, Pahang, Malaysia
email: zhangb@nxu.edu.cn

Junzhe Zhang
Ningxia University, School of Mechanical Engineering, Yinchuan, Ningxia, China

Mohd Ruzaimi Mat Rejab
Universiti Malaysia Pahang, Faculty of Mechanical Engineering, Pahang, Malaysia

At present, sound absorption properties of porous metals at high temperature, as well as involving in multi-physical fields such as high Mach number airflow and different temperature gradients are still focused on. Due to strong- nonlinearities included in above cases, it is relatively difficult to do effective thermal and acoustic simulations. This paper put forward a 3D simulation model with the help of thermal analysis module of COMSOL MULTIPHYSICS. In addition, a realistic steady state heat transfer apparatus is established in order to produce some valid experimental data for the improvement of the 3D simulation model. After that, other analysis and numerical experiments for coupling acoustic fields may be performed to explore the sound absorbing properties of porous metal at high temperatures quantitatively.
Keywords: Simulation model, heat transfer apparatus, sound absorbing capacity

1. Introduction

Porous metal materials have some attractive advantages such as good absorption capacity of shock energy, excellent sound absorption, lightweight, and thermal exchange properties. Therefore, they have potential applications in many important fields, such as aviation industry, deep sea engineering, biomedical engineering, and mechanical engineering [1]. More and more authors have paid more attention to the research on the properties of porous metal materials, in particular on materials' multifunctional characteristics [2, 3]. In this paper, through the analysis and summary of the relevant basic theories, a 3D simulation model was built by using COMSOL. In this work, we revised and improved the previous experimental apparatus for studying sound absorbing properties under high temperature conditions by means of performing numerical calculation, analysis and the exact measurements, making the simulated results more reliable. It should be noticed that a simulation tool COMSOL is used in this work to analyse the heat transfer and airflow inside tube of the apparatus. By performing many thermal tests for the apparatus at different heating temperatures, the developed simulation model was constantly improved and the reliable simulation results come out accordingly. In this way, we eventually verify the accuracy of the model and its rationality for future applications.

2. Simulation models

2.1 Geometric Model

In this subsection, a 3D geometric model is firstly built up by using COMSOL- owned geometric modelling tool, in accordance with the realistic scale of the apparatus under consideration; see Fig. 1.

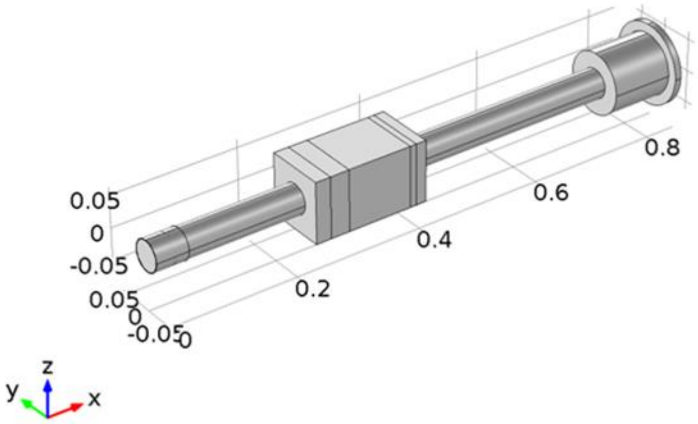

Figure 1: Geometric model in COMSOL for the apparatus.

2.2 Physical Model

Following the geometric modelling, the corresponding physical model is put forward in this subsection. The establishment of the physical model needs to match the requirements of ambient experimental environment by means of valid parameters setting. Considering model extending for future use and its potential applications, we employ a porous media heat transfer module of COMSOL in simulation. The purpose is to facilitate the test of the heat transfer of the apparatus and the experimental measurement of sound absorbing capacity of porous specimen and also to study the sound absorption performance of other porous composites under the condition of high temperatures. Because that in COMSOL, there is no solid heat transfer module embedded in the heat transfer module only for porous media. Therefore, we have to separately add solid heat transfer and fluid heat transfer module. In the establishment of physical model, the convective heat flux and external natural convective exchanges are considered at the same time. In addition, the length of the contact surface is set to be 1 meter, ambient pressure is considered to be standard atmospheric pressure, and the room temperature is 25 ℃,which is measured in lab. Also we think the external wall of apparatus radiates heat outwards to ambient environment, so the options for the streamline diffusion and the crosswind diffusion in COMSOL are switched on. Meanwhile, the refractive index of transparent medium is selected to be 1. The radiation resolution is set to be 256, the option for wavelength dependence of radiation is kept constant, the surface emissivity is 0.35, and the radiation direction is normal to the surface of solid tube of the apparatus, as shown in Fig. 2.

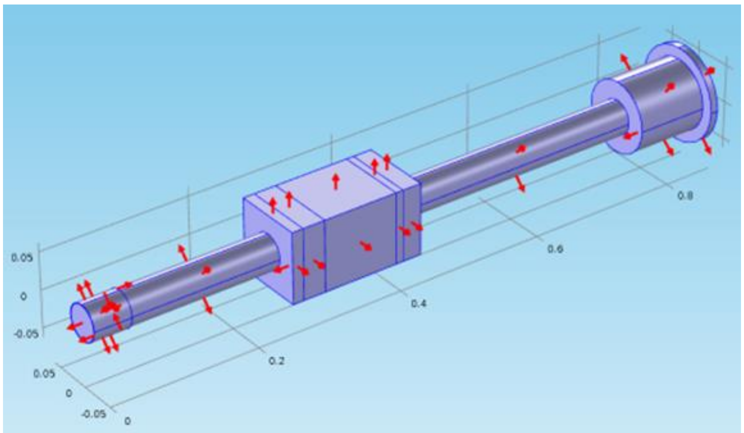

Figure 2: The directions of heat radiation on the external surface of tube of the apparatus.

After establishing the physical model, one may turn it into a corresponding finite element model. The mesh parameters involved for model are listed in Table 1.

Table 1: The mesh parameters for simulation model

Unit information	Values	Unit information	Values
Mass of minimum unit (Kg)	7.23×10^{-4}	Maximum cell size (m)	0.0692
Mass of average unit (Kg)	0.6904	Minimum cell size (m)	0.00865
Number of tetrahedral units	25562	Curvature factor	0.5
Number of triangle units	7784	Resolution for narrow area	0.6
Number of edge units	1276	The maximum growing rate	1.45
Number of vertex units	120	Predefined size	Refining

3. Numerical calculations

In numerical calculations for heat transfer of this apparatus, an energy conservation equation for solid embedded in COMSOL tool must satisfy, as follows:

$$\rho c_p \mathbf{u}.\nabla.(T_2) = \nabla.(k.\nabla T_2) + \mathrm{Q} \quad (1)$$

In Eq. (1), ρ is the density of solid material, c_p is the specific heat capacity at constant pressure, u is the particle velocity, k is the thermal conductivity, T_2 is the temperature variable, and Q is the heat flow rate of heat source. It is noted that the three components u_x, u_y, u_z of velocity vector $\boldsymbol{u}$ are regarded as zero and also no any heat source is included in COMSOL simulation, i.e., here Q=0. For hot air inside apparatus, the similar energy conservation equation must satisfy also, as follows.

$$\rho c_p \mathbf{u}.\nabla.(T_2) = \nabla.(k.\nabla T_2) + Q + Q_{vd} + Q_\rho \quad (2)$$

In Eq. (2), ρ, c_p, u, k, T_2, and Q have the same meaning as defined in Eq. (1). Besides, Q_{vd} stands for the viscous dissipation rate and Q_ρ for the pressure work per second.

As for the convective heat exchange between the whole apparatus and airflow of outside tube, we can use the following formula to describe:

$$\mathrm{q_0 = h.(T_{ext} - T_2)} \quad (3)$$

$$\mathrm{h = h(L, P_A, T_{ext})} \quad (4)$$

In Eqs. (3)- (4), the symbol q_0 stands for the thermal flux, and h for the heat exchange coefficient; for air, h is from 5 to 25 with the unit W/ (m^2.K). In addition, P_A stands for the standard atmospheric pressure, T_{ext} for the external temperature, and L for the length of contact surface.

Pertaining to heat radiation to ambient, in this work, only the radiation from the external surface of the apparatus is taken into account and the involved control equation for heat radiation is given as

$$-\mathrm{n}.(k\nabla T_2) = \varepsilon\sigma(T_{amb}^4 - T_2^4) \quad (5)$$

where, n is the refractive index of air, k the thermal conductivity, T_2 the temperature in the solution domain, T the ambient temperature, ε the surface emissivity (usually, ε=0.35), and σ the Boltzmann constant.

4. Results and conclusions

In this work, in order to eventually obtain the sound absorbing performance of porous metallic specimen at high temperatures, we selected two microphones(MPA416 series products) to collect acoustic signals during acoustic measurements; note that the working temperature for two microphones is from 10 ℃ to 50 ℃. Hence, it should be pointed out that the working area of two microphones must be in normal ranges of working temperatures above-mentioned. To meet this requirement, we have to cool the air inside apparatus and tube wall neighbouring above working area for microphones, i.e., keeping the temperatures in this area less than 50℃. And enhanced cooling water pipes and some slices of insulation materials are designed and employed for the safety of microphones in this apparatus. According to the above design idea, an improved high temperature sound absorbing apparatus of porous metals are implemented, as shown in Fig.3:

Figure 3: High temperature sound absorbing apparatus of porous metals.

To verify the accuracy of the heat transfer model, the temperatures at 15 positions on the external surface of this apparatus must be separately measured under the conditions that the heater temperature is adjusted to be 100 ℃, 200 ℃, 300 ℃, and 400 ℃ ,respectively. Moreover, the distributions of all testing points are shown in Fig. 4 below.

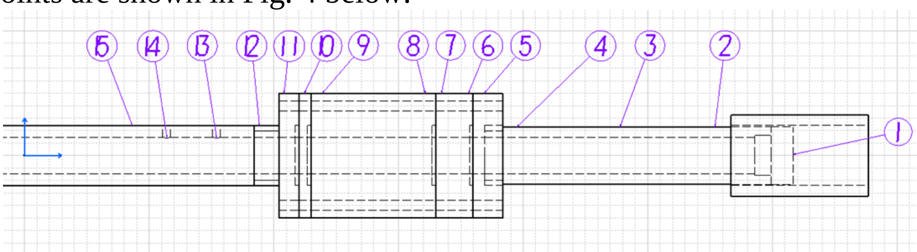

Figure 4: Testing points at 15 positions on the external surface of apparatus.

To obtain above distribution of temperatures, we measured the actual temperature at 15 positions on the surface of tube for heat source with four given temperatures, 100, 200, 300,and 400℃. The measured distributions of temperatures are plotted in Figs. 5-8.

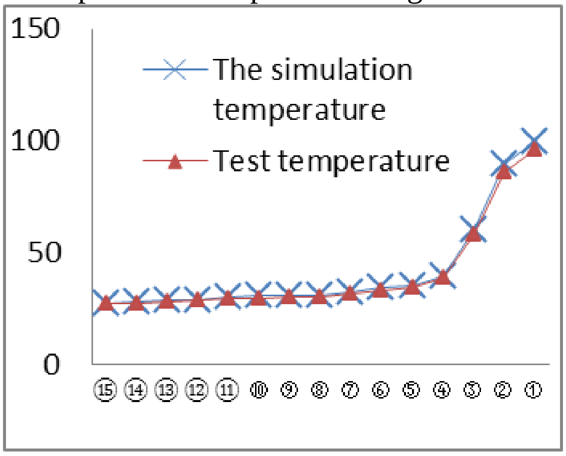

Figure 5: The temperature distribution for the heater of 100℃.

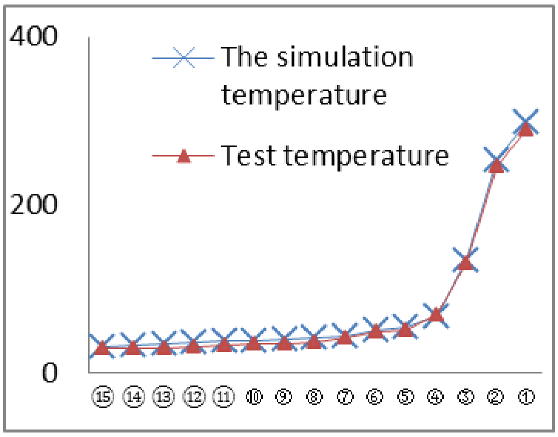

Figure 6: The temperature distribution for the heater of 200℃.

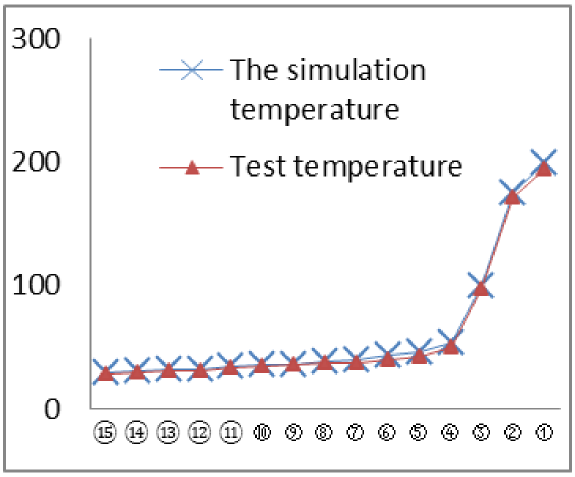

Figure 7: The temperature distribution for the heater of 300℃.

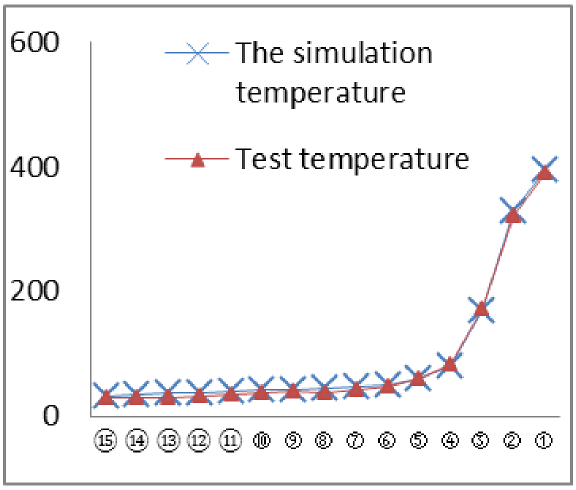

Figure 8: The temperature distribution for the heater of 400℃.

In conclusions, the simulation model for studying the sound absorption performance of porous metal material in a high temperature apparatus was established by using "porous media heat transfer" module and “pressure acoustics and frequency domain" module in COMSOL Multiphysics. The thermal properties of whole apparatus in Multiphysics field was analysed by means of coupling physical fields modulus of COMSOL. In addition, for the theoretical modelling of porous metals, the classical Johnson-Champoux-Allard acoustic model is employed [4]. And the several conclusions are briefly drawn as follows:

(1) The simulation model established by COMSOL Multiphysics can explore the temperature distribution of this presented apparatus and sound absorption performance of porous materials.

(2) In the simulation model, it can be seen that the temperature distribution inside this apparatus has an important effect on the sound absorption performance of the porous metal material and the calculated and measured results are in consistent with the actual physical phenomena.

The work in this paper provides a reference for the subsequent study of the sound absorption performance of porous metal materials in the presence of temperature gradient, making the simulation model more reliable and accurate.

.

5. Acknowledgement

The authors gratefully acknowledge support for this work from the Project of National Natural Science Foundation of China (grant No.51365046).

REFERENCES

1 Zhang B, Chen T, Feng K, Chen H. Sound Absorption Properties of Sintered Fibrous Metals under High Temperature Conditions. *Journal of Xi'an Jiao tong University*, **42**(11), 1327-1331, (2008).

2 Rademarker E, Idzenga S, Huisman H, Nijboer R. A new facility for hog steam acoustic liner testing, *Proceeding of 10th International Congress on Sound and Vibration*; Stockholm, Sweden, 7-10 July, (2003).

3 Wu J, Hu Z, Zhou H. Sound Absorbing Property of Porous Metal Materials with High Temperature and High Sound Pressure by Turbulence Analogy. *Journal of Applied Physics,* **113**(194905), 1-7, (2013).

4 Allard J.F. *Propagation of Sound in Porous Media, Modelling Sound Absorbing Materials*. Elsevier Applied Science, New York (1993).