Effects of rotation angle and metal foam on natural convection of nanofluids in a cavity under an adjustable magnetic field

Cong Qi [a, b, c *], Jinghua Tang [a, b], Zi Ding [a, b], Yuying Yan [c], Leixin Guo [a, b], Yifeng Ma [a, b]

[a] Jiangsu Province Engineering Laboratory of High Efficient Energy Storage Technology and Equipments, China University of Mining and Technology, Xuzhou 221116, China

[b] School of Electrical and Power Engineering, China University of Mining and Technology, Xuzhou 221116, China

[c] Fluids & Thermal Engineering Research Group, Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, UK

Abstract: To investigate the natural convection heat transfer of Fe_3O_4-water nanofluids in a rectangular cavity under an adjustable magnetic field, two experimental systems are established. Meanwhile, several factors, such as nanoparticle mass fractions (ω=0%, 0.1%, 0.3%, 0.5%), magnetic field directions (horizontal and vertical), magnetic field intensities (B=0.0T, 0.01T, 0.02T), rotation angles of the cavity (α=0°, 45°, 90°, 135°), and PPI of Cu metal foam (PPI=0, 5, 15) are taken into consideration to research the natural convection of Fe_3O_4-water nanofluids in a rectangular cavity. With the increasing nanoparticle mass fraction, Nusselt number firstly rises but then falls, and the maximum value of which appears at a nanoparticle mass fraction ω=0.3%. Horizontal magnetic field is not significant to the thermal performance enhancement, but vertical magnetic field shows an opposite trend and makes a positive contribution to the thermal performance. The cavity with a rotation angle α=90° shows the highest thermal performance. Nusselt number of the cavity filled with metal foam can be improved obviously compared with that without metal foam. But the increasing PPI of metal foam is disadvantageous to heat transfer

*Correspondence author.
E-mail: qicong@cumt.edu.cn (C. Qi); tangjh@cumt.edu.cn (J. Tang); edu_dingzi@163.com (Z. Ding); yuying.yan@nottingham.ac.uk (Y. Yan); guoleixin@cumt.edu.cn (L. Guo); myf@cumt.edu.cn (Y. Ma)

performance.

Key words: Nanofluids; Natural convection; Magnetic field; Metal foam

Nomenclature

A	cross-sectional area, m^2
c_p	specific heat of nanofluids, $J\cdot kg^{-1}\cdot K^{-1}$
E	heat transfer enhancemental ratio
h	convective heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$
I	electric current, A
l	width of cavity, m
Nu	Nusselt number of nanofluids
q_m	mass flow rate, $kg\cdot s^{-1}$
Q	heating power, W
Q_{loss}	heat loss, W
Q'_{net}	effective heat absorption for nanofluids, W
Q''_{net}	effective heat absorption for water, W
Q_{net}	average effective heat absorption, W
T_C	inside surface (cold side) temperature of left cavity, K
T^*_C	outside surface (cold side) temperature of right cavity, K
T'_C	inside surface (cold side) temperature of right cavity, K
T^*_H	outside surface (hot side) temperature of left cavity, K
T_H	inside surface (hot side) temperature of left cavity, K
T_{in}	inlet temperatures, K
T_m	average temperature of nanofluids, K
T_{out}	outlet temperatures, K
U	voltage, V

Greek symbols

α	rotation angle, °
ω	nanoparticle mass fraction, %
δ	wall thickness of cavity, m
λ_w	thermal conductivity of cavity, $W\cdot m^{-1}\cdot K^{-1}$
λ_f	thermal conductivity of nanofluids, $W\cdot m^{-1}\cdot K^{-1}$

Subscripts

C	cold side
f	fluid
H	hot side
w	wall

1 Introduction

Since the conception of nanofluids was put forward, many scholars have prepared many kinds of nanofluids and researched their thermophysical parameters and thermal performance [1, 2]. It is found that nanofluids are far superior to common fluids in terms of heat conduction. Therefore, nanofluids have been used in various fields, for example, photothermal conversion [3, 4], thermal management of electronics [5, 6, 7], phase change heat transfer [8, 9, 10, 11], heat storage unit with fins [12, 13], tubes with combined turbulator [14], forced convection in heat exchanger system including external thread tubes with built-in twisted belt [15， 16], tubes with double twisted tapes [17], triangle tubes with built-in twisted belt [18], double tube heat exchanger with tape insert material [19], a cylindrical enclosure [20], porous media [21, 22, 23], helically corrugated tube [24], and micro-channel heat sink [25, 26]. Some reviews on the other applications of nanofluids can be also obtained from Babar et al. [27].

For natural convection, many investigations have been carried out by scientists because of its safety and quietness. Sheikholeslami et al. have done a variety of researches on natural convection of nanofluids. Such as, natural convection of nanofluids in a porous enclosure with applied electric field [28], a porous media with applied electric field based on CVFEM [29], a circular enclosure with melting surface under magnetic field [30], a porous enclosure using non-equilibrium model [31], a permeable medium via Darcy law [32], a porous enclosure considering the thermal radiation and Coulomb force [33], a permeable media under external magnetic source [34], a porous complex shaped cavity based on thermal radiation [35], a permeable medium by an innovative computer method [36], and a circular cavity under the variable magnetic forces [37]. Izadi et al. analyzed the natural convection in a porous gap under a variable magnetic field [38], and the natural convection in a porous medium filled with multi-walled carbon nanotube-Fe_3O_4/water magnetic hybrid nanofluids [39]. Not only are the effect of Hartmann number on the thermal performance discussed in above references, but as well as Darcy number and Rayleigh number. From above references, the relationship between thermal performance and Darcy number, Hartmann number, Rayleigh number can be discovered, which shows that Hartmann number can reduce the heat transfer rate, but Darcy and Rayleigh number are beneficial to the improvement of temperature gradient.

Pordanjani et al. [40] analyzed the entropy generation of nanofluids' natural convection in an inclined square cavity under a magnetic field. Results indicated that thermal performance can be improved by the increase of magnetic field angle from 0 ° to 45 °. Pordanjani et al. [41] designed an enclosure with sinusoidal wall temperature distribution and investigated the natural convection of nanofluids under magnetic field. Results showed that Nusselt number is proportional to magnetic field angle and Rayleigh number, but deteriorates with the increase of aspect ratio and Hartmann number.

Izadi et al. used LBM to explore the natural convection of a T-shaped enclosure [42] and ⊥ shaped cavity [43] which is full of nanofluids, between two eccentric cylinders filled with porous material based on Buongiorno's two phase model [44], inside a porous enclosure with undulant-wall by LTNE and two-phase model [45], inside a porous enclosure under variable magnetic fields [46], and in a C-shaped cavity by LBM [47]. Xu et al. [48] also applied LBM to study the effects of porous foam on the natural convection transport of nanofluids in a cavity. The results of above studies presented that the thermal performance can be improved by augmenting the heat source aspect ratio, Rayleigh number, porosity and magnetic strength while deteriorates with Lewis number.

Safaei et al. simulated the natural convection of a shallow cavity full of nanofluids while taking thermal radiation into consideration [49], an incinerator with a hot block [50], and cavities with different aspect ratios [51]. Zhou et al. not only numerically explored the natural convection of liquid-metal nanofluids in a cavity [52], around a bubble in a cavity [53], but also researched the surface tension driven convection in a rectangular cavity [54]. Results showed that Rayleigh number, Grashof number, emissivity, height and width of heater can all improve the heat transfer, while Hartmann number can worsen it.

Mehryan et al. [55] explored the natural convection of nanofluids in a square enclosure under a periodic magnetic field. Results revealed that the period of magnetic field can argument the heat transfer and entropy generation. Sheremet et al. researched the natural convection of a baffled U-shaped cavity full of nanofluids [56], an inclined cavity with time-periodic temperature boundary [57], an open cavity including multiple porous layers [58], an open cavity containing a heat-generating element [59, 60] and an open triangular cavity considering the Brownian diffusion [61]. Selimefendigil et al. discussed the natural convection of nanofluids in various cavities, such as, a three-dimensional cavity containing two adiabatic inner rotating cylinders [62], a cavity filled with CNT-water nanofluids [63], a 3D trapezoidal cavity [64], a lid-driven trapezoidal cavity [65], and a cubic enclosure including an inner rotating cylinder [66]. Mohebbi et al. [67] introduced the natural convection in a Γ-shaped enclosure full of nanofluids. Sajjadi et al. [68] and Mohebbi et al. [69] analyzed the natural convection of nanofluids in a porous media. Above studies analyzed the effect of boundary temperature oscillating frequency, Rayleigh number, nanoparticle concentration, porous medium on heat transfer, all of which can be instrumental in enhancing heat transfer. Qi et al. [70, 71] used LBM to simulate the influence of nanoparticle size on natural convection. The mechanism for heat transfer enhancement is revealed that the Brown force is the main factor in contrast to other forces.

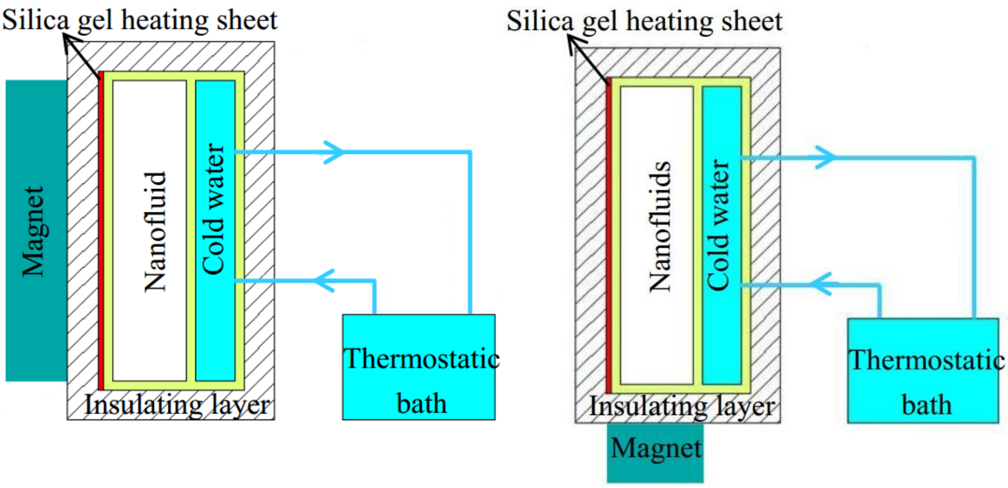
Above references mainly discussed the various shape cavities filled with nanofluids. However, effects of rotation angle on the natural convection of nanofluids under different magnetic field directions and intensities are less investigated, and the influence of metal foam PPI under different magnetic field directions and intensities are also less investigated. Hence, the purpose of this study is to experimentally reveal the effects of rotation angle and metal foam on natural convection of nanofluids in a cavity under an adjustable magnetic field direction and intensity.

2 Method

2.1 Experimental system

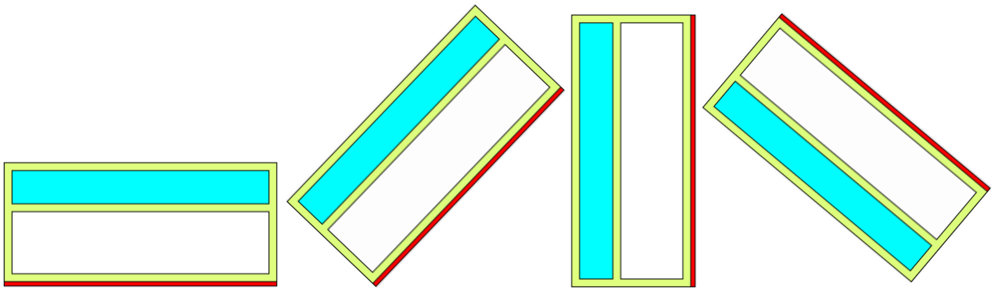
2.1.1 Effect of rotation angles

An experiment is designed to study the natural convection performance of a rectangular cavity filled with Fe_3O_4-water nanofluids under different magnetic fields. Fe_3O_4 nanofluids belong to magnetofluid, and the influence of magnetic fields on magnetofluid is larger than other nanofluids. In addition, compared with other base liquids, water is cheaper and easier to obtain. Hence, water and Fe_3O_4 are chosen as the base fluid and nanoparticles in this experiment. Considering the Fe_3O_4-water nanofluids are mainly affected by the Lorentz force under the induced magnetic field, different magnetic field intensities are considered and B is employed to refer to the magnetic field intensity of the induced magnetic field. Hence, Effects of several factors, such as nanoparticle mass fractions (ω=0%, 0.1%, 0.3%, 0.5%), magnetic field directions (horizontal (rightward) and vertical (downward)), magnetic field intensities (B=0.01T, 0.02T) and rotation angles (α=0°, 45°, 90°, 135°), on the thermal performance are analyzed. The schematic diagram of natural convection system without metal foam is demonstrated in Fig. 1. The size of the left cavity is 100 mm (length) × 100 mm (height) × 25mm (width), which is filled with nanofluids. The material of the cavity is made of copper, and the thickness of the copper is 5mm. The cold water flows through the right small cavity to keep the right wall (cold side) of the left cavity at a low constant temperature. A silica gel heating sheet (Q=15W) is used to provide a high constant temperature for the left wall (hot side) of the left cavity. A magnet attached to the left and bottom wall is applied to supply a horizontal magnetic field and vertical magnetic field respectively, and Gauss meter (CH-15, errors: ±1G) is used to measure the magnetic intensity. Insulation, the material of which is composed of silicic acid rock wool and foam sponge, is adopted to reduce the heat loss. A thermostatic bath (DC-2030, errors: ±0.02℃) is employed to offer the low constant temperature water. The temperature of import and export of the cold fluid and outside surface temperature of the left cavity can be measured by the thermocouples (T type, range: 0~200℃). Then, data will be collected by a data acquisition instrument (34970, channels: 22). The details of the different rotation



(a) (b)

Fig. 1. Schematic diagram of free convection system without metal foam, (a) horizontal (rightward) magnetic field, (b) vertical (downward) magnetic field



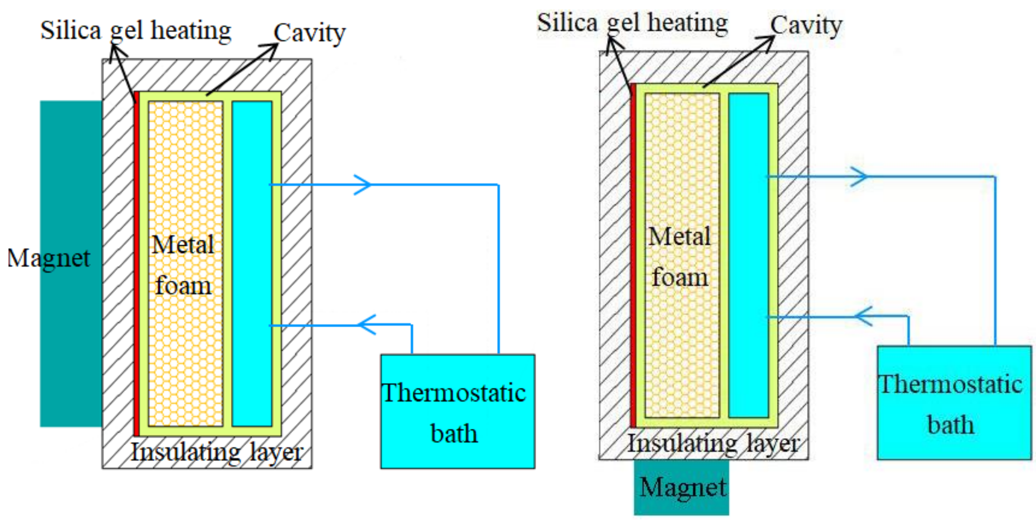
(a) (b) (c) (d)

Fig. 2. Details of the different rotation angles, (a) α=0°, (b) α=45°, (c) α=90°, (d) α=135°

angles (α=0°, 45°, 90°, 135°) are presented in Fig. 2.

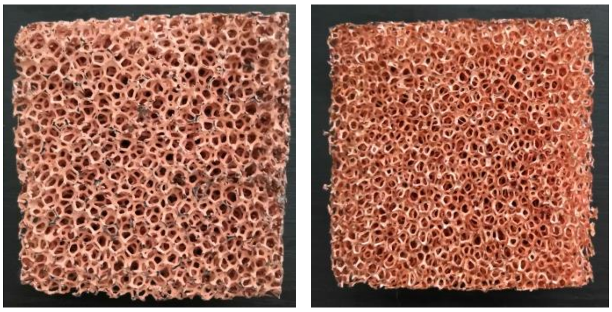
2.1.2 Effect of metal foam

Based on the corresponding rotation angle for the highest thermal performance of section "2.1.1 Effect of rotation angles ", Cu metal foam is filled in the cavity with the best rotation angle to augment the heat transfer. And the effects of nanoparticle mass fractions (ω=0%, 0.1%, 0.3%, 0.5%), magnetic field directions (horizontal and vertical) and magnetic field intensities (B=0.01T, 0.02T), the influence of PPI (PPI=5, 15) on the natural convection are also investigated. Fig. 3 presents the schematic diagram of natural convection system with metal foam. The detail of Cu metal foam with different PPI (PPI=5, 15) are given in Fig. 4. And their structural parameters are presented in Table 1.



(a) (b)

Fig. 3. Schematic diagram of free convection system with metal foam, (a) horizontal (rightward) magnetic field, (b) vertical (downward) magnetic field



(a) (b)

Fig. 4. Metal foam with different PPI, (a) PPI=5, (b) PPI=15

Table 1 Structural parameters of metal foam

NO	PPI	Porosity	Bore diameter (mm)
1	5	94.08%	0.81
2	15	94.08%	0.57

2.2 Data processing

Calculation of the volume fraction of nanofluids is as follows:

$$\varphi = \frac{1}{(1/\omega)\left(\rho_{np}/\rho_{nf}\right)} \tag{1}$$

Heating power of DC power is as follows:

$$Q = UI \tag{2}$$

Effective heat absorption of hot fluid (nanofluids) is as follows:

$$Q_{net}^{'} = Q - Q_{loss} \tag{3}$$

where, the Q_{loss} is measured by a heat flow meter.

Effective heat absorption can be also calculated from the cold fluid (water):

$$Q_{net}^{''} = c_p q_m (T_{out} - T_{in}) \tag{4}$$

Average effective heat absorption is chosen in the experiment:

$$Q_{net} = \frac{Q_{net}^{'} + Q_{net}^{''}}{2} \tag{5}$$

Outside surface (hot side) temperature of the left cavity is calculated by the following formula:

$$T_{\mathrm{H}}^{*} = \frac{(T_1 + T_2 + \cdots + T_6)}{6} \tag{6}$$

Inside surface (hot side) temperature of the left cavity is calculated by the following formula:

$$T_{\mathrm{H}} = T_{\mathrm{H}}^{*} - \frac{Q_{\mathrm{net}}\delta}{A\lambda_w} \tag{7}$$

Also, outside surface (cold side) temperature of the right cavity is calculated by the following formula:

$$T_C^{*} = \frac{(T_7 + T_8 + \cdots + T_{12})}{6} \tag{8}$$

Inside surface (cold side) temperature of the right cavity is as follows:

$$T_{\mathrm{C}}^{'} = T_C^{*} - \frac{Q_{net}\delta}{A\lambda_w} \tag{9}$$

The temperature of cold water in the right cavity is constant, and the temperature of cold water is the same with the inner surface temperature on both sides of the right cavity respectively. Hence, the inside surface (cold side) temperature of the left cavity can be obtained from the following form:

$$T_{\mathrm{C}} = T_C^{*} - \frac{2Q_{net}\delta}{A\lambda_w} \tag{10}$$

Qualitative temperature of the nanofluids in the left cavity is as follows:

$$T_m = \frac{T_H + T_C}{2} \tag{11}$$

Calculation of convective heat transfer coefficient is as follows:

$$h = \frac{Q_{\mathrm{net}}}{A(T_{\mathrm{H}} - T_{\mathrm{C}})} \tag{12}$$

Nusselt number is defined as:

$$Nu = \frac{h \cdot l}{\lambda_f} \tag{13}$$

Heat transfer enhancement ratio is calculated by following formula:

$$E = \frac{Nu - Nu_{(0.0\%+\text{PPI}=0)}}{Nu_{(0.0\%+\text{PPI}=0)}} \tag{14}$$

2.3 Uncertainty analysis

Error transfer formula for Nusselt number can be obtained from [72]:

$$\frac{\Delta Nu}{Nu} = \left|\frac{\partial \ln Nu}{\partial h}\right|\Delta h + \left|\frac{\partial \ln Nu}{\partial W}\right|\Delta W + \left|\frac{\partial \ln Nu}{\partial \lambda_\text{f}}\right|\Delta \lambda_\text{f} = \frac{\Delta h}{h} + \frac{\Delta W}{W} + \frac{\Delta \lambda_\text{f}}{\lambda_\text{f}} \tag{15}$$

The errors of the Nusselt number can be calculated from equation (15) and it is only 6.34% in this experiment, which guarantees the dependability of the experimental system.

2.4 Experimental verification

Experimental verification cannot be neglected to ensure the accuracy of this experiment. The results of water in the cavity are compared with that of other reference [73], and it is illustrated in Fig. 5. It can be found that they are close to

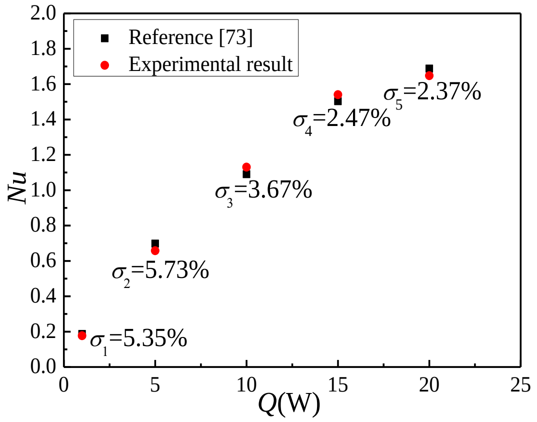


Fig. 5. Comparison of Nusselt numbers between experimental data and literature values [73]

each other, and the max error is only 5.73%, which explains that the experimental set has a high accuracy.

3 Results and discussions

3.1 Effect of rotation angles

For the cavity without metal foam, relationships between rotation angles and Nusselt number under different magnetic field directions and intensity are researched, whose results are showed in Fig. 6. In Fig. 6, nanofluids with mass fractions of 0.1%, 0.3% and 0.5% correspond to nanofluids with volume concentration of 0.019%, 0.058% and 0.097%, respectively. If the concentration is too low, the heat transfer can hardly be enhanced. However, the agglomeration trend of nanoparticles will increase with the increasing concentration of nanoparticles, which will result in the weakening of the stability of nanofluids. To ensure the stability and high thermal conductivity of nanofluids, nanofluids with volume concentration of 0.019%, 0.058% and 0.097% are selected. And results indicate that Nusselt number rises with the nanoparticle mass fraction firstly and then falls. The critical nanoparticle mass fraction ω=0.3% can be got due to its highest Nusselt number. As we know, there are three important factors (heat conductivity, viscosity, Brownian motion of nanoparticles) playing the largest role on heat transfer enhancement. A thermal conductivity measuring instrument (model: DRE-III, accuracy: ±2-3%) is applied to obtain the thermal conductivity and a viscosity meter (model: NDJ-8S, accuracy: ±2%) is used to measure the viscosity in this experiment. The detail results can be found in our previous published paper [74]. As the increasing of nanoparticles concentration, the heat transfer performance of nanofluids will be enhanced not only because of its higher thermal conductivity caused by nanoparticles, but also due to the large turbulivity induced by the Brownian motion of nanoparticles. However, as the concentration of nanoparticles increases, viscosity also increases, which can cause a reduction in heat transfer performance. When nanoparticle mass fraction is lower than ω=0.3%, high heat conductivity and Brownian motion are major roles on Nusselt number. However, when nanoparticle mass fraction is larger than ω=0.3%, the viscosity becomes to play a more crucial role instead of the heat conductivity and Brownian motion of nanoparticles. So the mass fraction of nanoparticles ω=0.3% becomes the corresponding critical concentration of nanoparticles with the highest Nusselt number.

Another important conclusion is obtained that the cavity with a rotation angle α=90° shows the best thermal performance, followed by α=45° and α=0°, and the cavity with a rotation angle α=135° behaves the worst thermal performance. Fig. 7 presents the influence of rotation angles on the relative heat transfer enhancement ratio compared with the worst working condition. It is found that Nusselt number enhancement ratio is proportional to rotation angle (from α=0° to α=90°), and the enhancement ratio of cavity with α=90° can reach 11.29% at best. For the cavity with α=135°, the hot side locates in the top and the cold side locates in the bottom. Fluid near the top hot side is heated and moves upward, but fluid near the bottom cold side is cooled and moves downward, and the top and bottom walls prevent the flow. Hence, natural convection becomes weak, and heat conduction plays a major role in this condition. Therefore, the cavity with α=135° shows the worst thermal performance. For cavity with α=0°, the hot side locates in the bottom and cold side locates in the top. Fluid near the bottom is heated and flows upward and fluid near

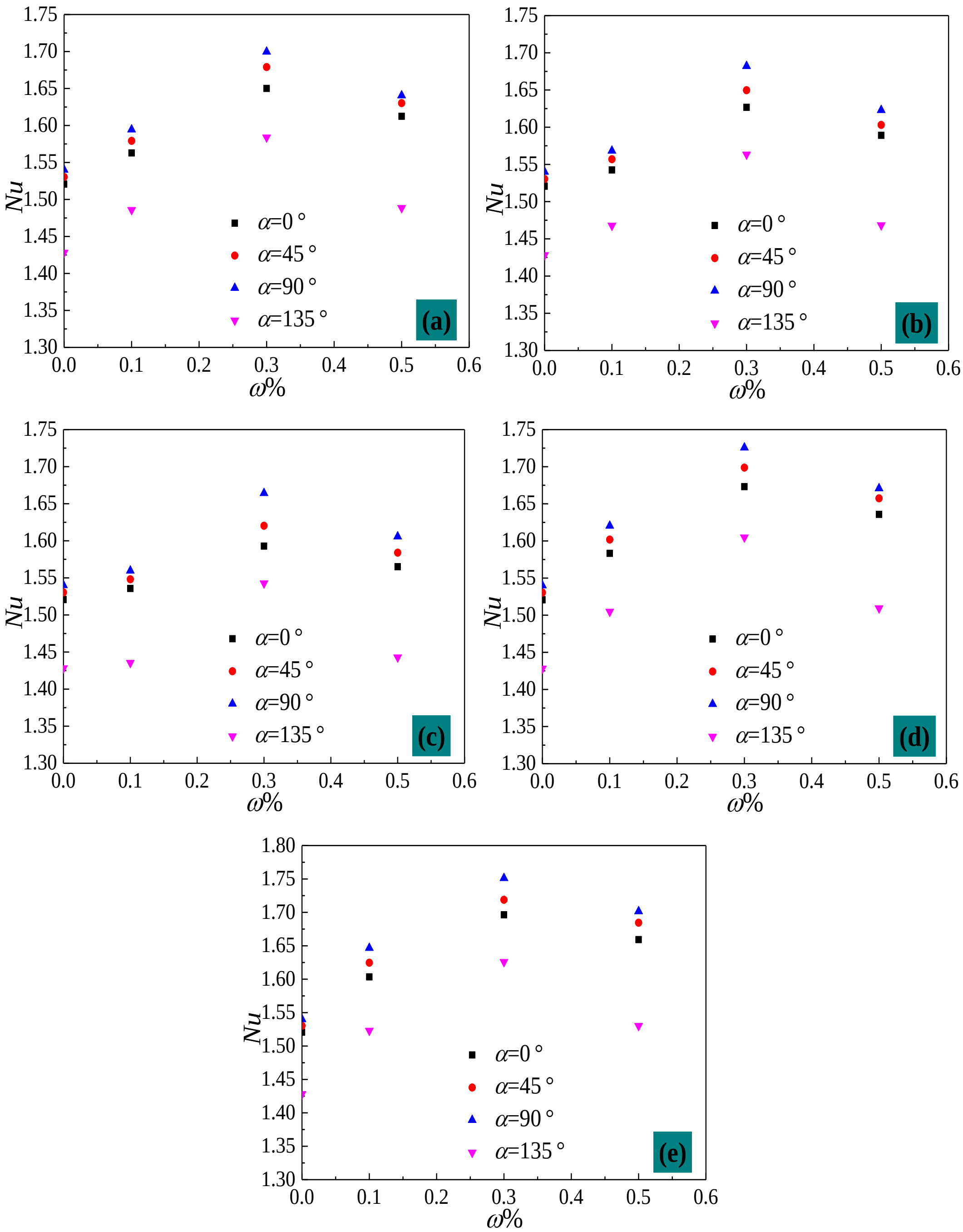


Fig. 6. Effects of rotation angles on Nusselt number under different magnetic fields, (a) no magnetic field, (b) horizontal magnetic field with *B*=0.01T, (c) horizontal magnetic field with *B*=0.02T, (d) vertical magnetic field with *B*=0.01T, (e) vertical magnetic field with *B*=0.02T

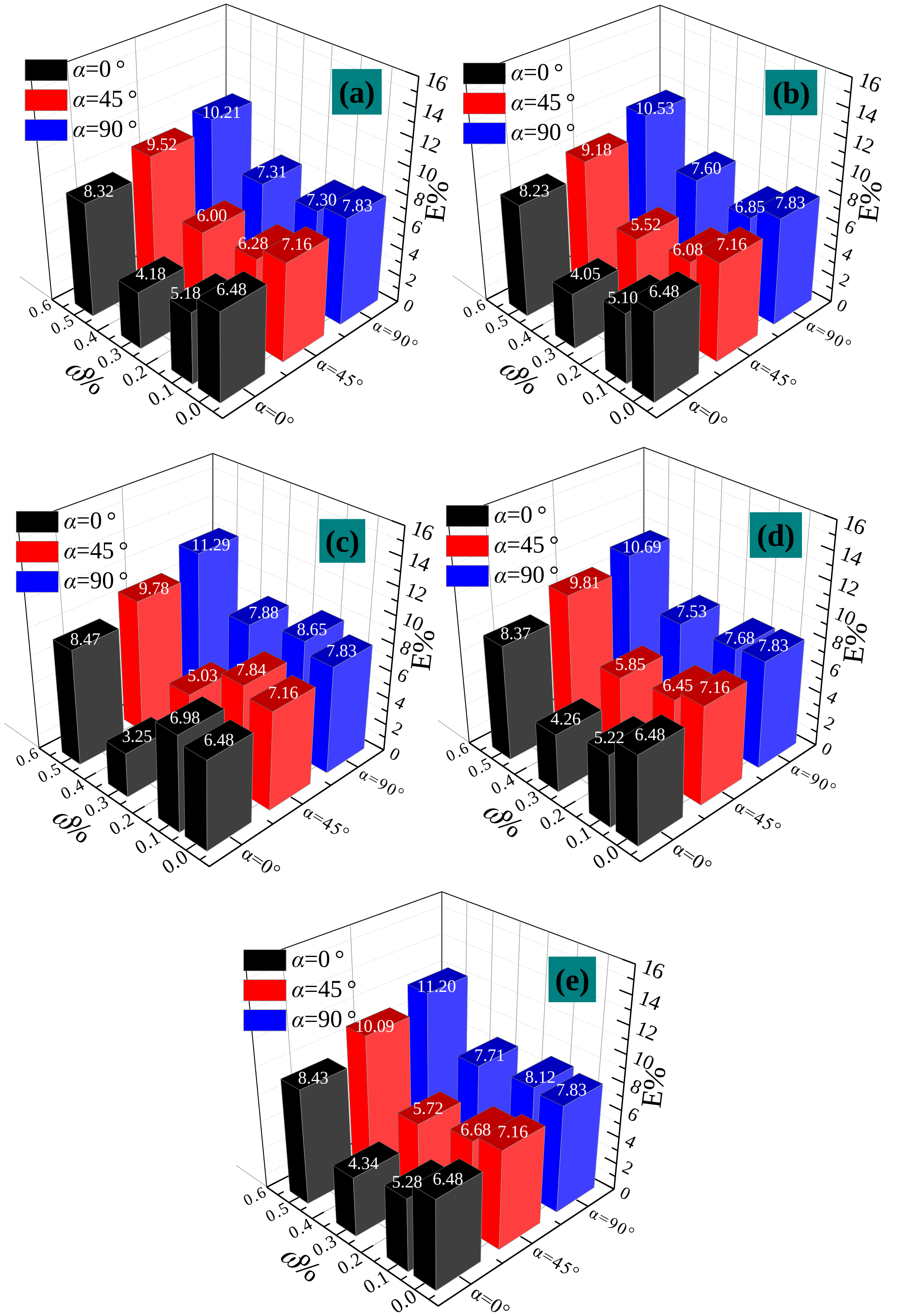


Fig. 7. Effects of rotation angles on Nusselt number enhancement ratio compared with that with α=135 °at the same condition, (a) no magnetic field, (b) horizontal magnetic field with B=0.01T, (c) horizontal magnetic field with B=0.02T, (d) vertical magnetic field with B=0.01T, (e) vertical magnetic field with B=0.02T

the top is cooled and flows downward. Besides, hot and cold fluids flow in opposite directions, which is also disadvantageous to the increase of natural convection. Hence, the thermal performance of cavity with α=0° is much lower than that with α=90° but is better than the cavity with α=135° which is mainly heat conduction. The cavity with a rotation angle α=45° is between α=90° and α=0°, and its thermal performance is also between them.

3.2 Effect of PPI

From the results in above section, it can be obtained that the cavity with a rotation angle α=90° reveals the best thermal performance. So as to improve the natural convection further, Cu metal foam is filled in the cavity with a rotation angle α=90°. The experimental system can be found in Fig. 3. Effects of PPI (PPI=5, 15) of Cu metal foam on Nusselt number under different direction and intensity magnetic fields are given in Fig. 8. Results indicate that metal foam is significant in the heat transfer of cavity, the maximum value of Nusselt number can be got when PPI=5 and ω=0.3%. In porous media, there are two main heat transfer models including convection heat transfer and heat conduction. For metal foam with PPI=5, convection heat transfer dominates the major role in heat transfer. As the increase from PPI=5 to PPI=15, the flow of fluid is blocked and the heat transfer is weakened, so convection heat transfer begins to deteriorate badly although the role of heat conduction increases. As the increase of nanoparticle mass fraction from ω=0.0% to ω=0.3%, convection is improved due to the high thermal conductivity of nanoparticles. However, as the increase of nanoparticle mass fraction from ω=0.3%

to ω=0.5%, there is a large increase in viscosity which causes a deterioration in heat transfer. Effects of PPI on Nusselt number enhancement ratio are presented in Fig. 9. It shows that Nusselt number of cavity with PPI=5 and PPI=15 metal foam without magnetic field can be improved by 5.81% and 3.41% at best when compared with the data without metal foam respectively. Cavity with PPI=5, PPI=15 metal foam can improve the heat transfer by 5.60%, 4.47% under horizontal magnetic field and 5.36%, 2.97% under vertical magnetic field at best compared with the cavity without metal foam respectively. As we know, there are two important factors affecting the thermal performance, one is the high heat conductivity of metal foam which can enhance the whole heat conductivity of the cavity, and another is the porous shape which can increases the disturbance in the cavity. From Table 1, it is found that the porosities of these two metal foams are the same, which means that the amount of metal foam is the same. Hence, the two kinds of metal foam make the same contribution to the whole heat conductivity enhancement of the whole cavity. However, convection heat transfer is more intense as the increasing pore size (decreasing PPI) at the same porosity. Compared with the cavity with PPI=15 metal foam, convective heat transfer occupies a larger proportion in the cavity with PPI=5 metal foam. Therefore, Nusselt number is inversely proportional to PPI.

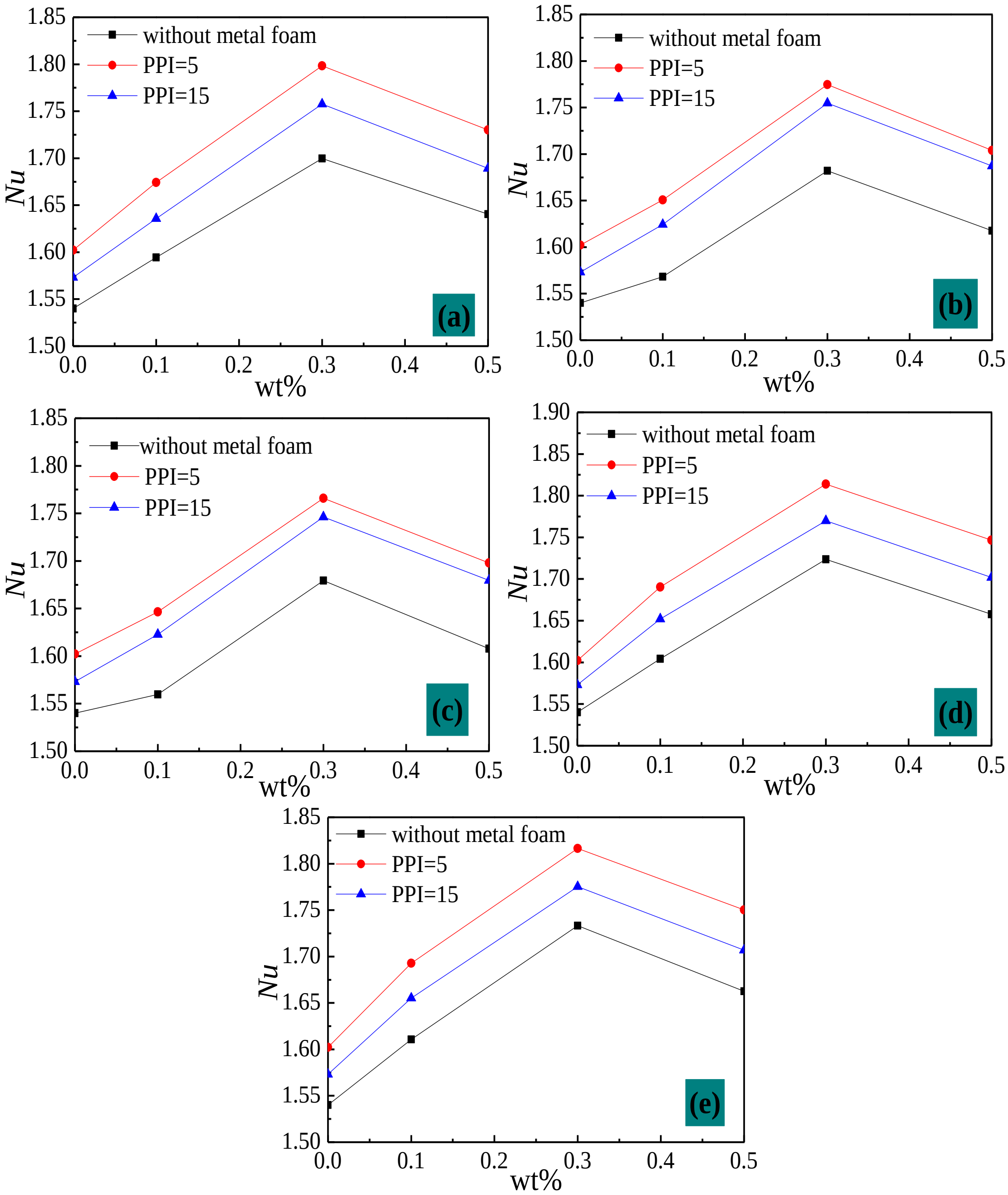


Fig. 8. Effects of PPI on Nusselt number under different magnetic fields, (a) no magnetic field, (b) horizontal magnetic field with *B*=0.01T, (c) horizontal magnetic field with *B*=0.02T, (d) vertical magnetic field with *B*=0.01T, (e) vertical magnetic field with *B*=0.02T

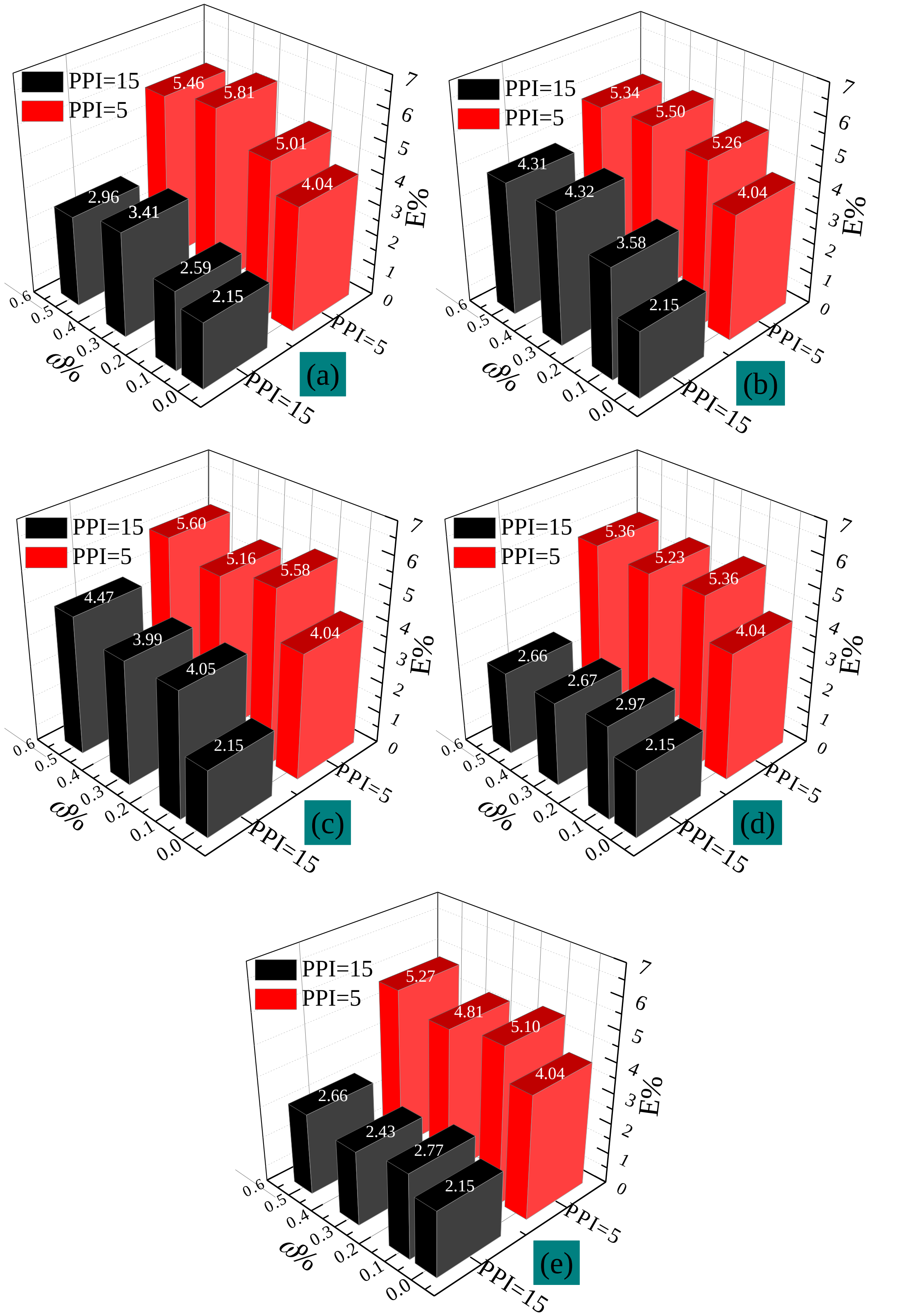


Fig. 9. Effects of PPI on Nusselt number enhancement ratio compared with that without metal foam at the same condition, (a) no magnetic field, (b) horizontal magnetic field with *B*=0.01T, (c) horizontal magnetic field with *B*=0.02T, (d) vertical magnetic field with *B*=0.01T, (e) vertical magnetic field with *B*=0.02T

3.3 Effect of magnetic fields

Also, effects of magnetic field direction and intensity on Nusselt number at different PPI are discussed, which are shown in Fig. 10. Results indicate that horizontal magnetic field can reduce the natural convection of nanofluids in the cavity, but vertical magnetic field can improve the natural convection. Higher horizontal magnetic field intensity can cause smaller Nusselt number, and higher vertical magnetic field intensity can cause larger Nusselt number.

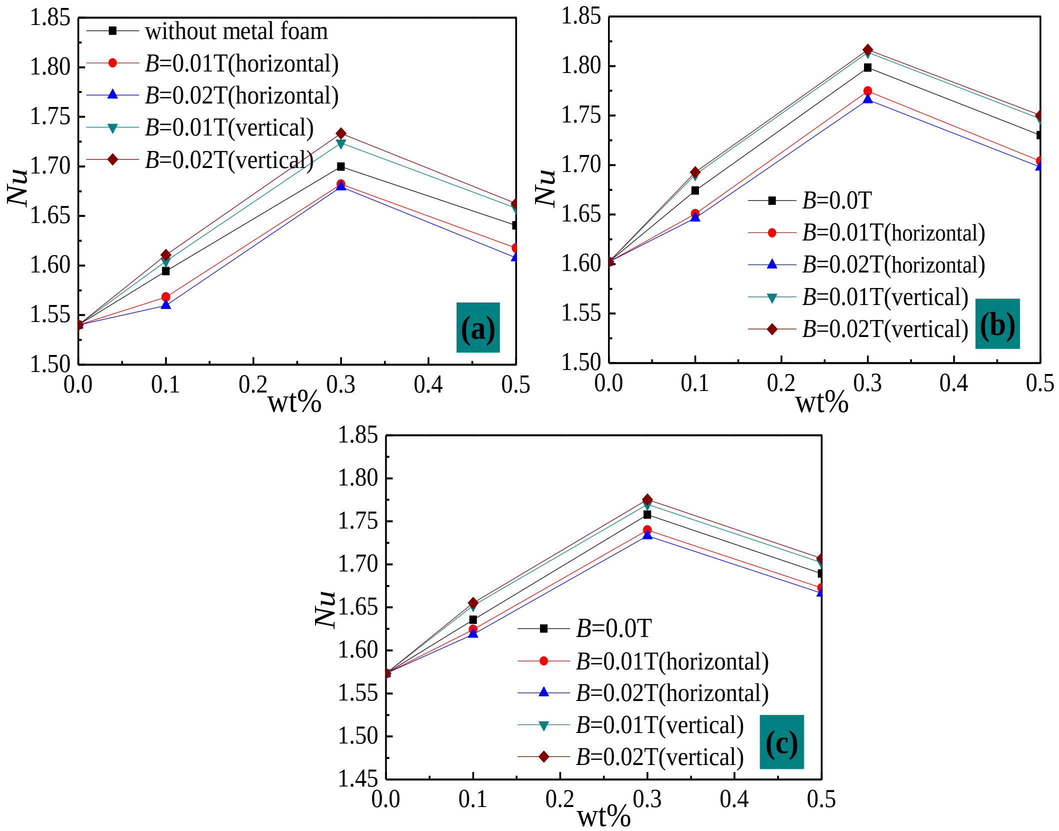


Fig. 10. Effects of magnetic field on Nusselt number at different PPI, (a) without metal foam, (b) PPI=5, (c) PPI=15

Effects of magnetic field on Nusselt number enhancement ratio are presented in Fig. 11. Results display that horizontal magnetic field can reduce the natural convection without metal foam by 2.18% at best, and vertical magnetic field can enhance the natural convection without metal foam by 1.97% at best. Also, results

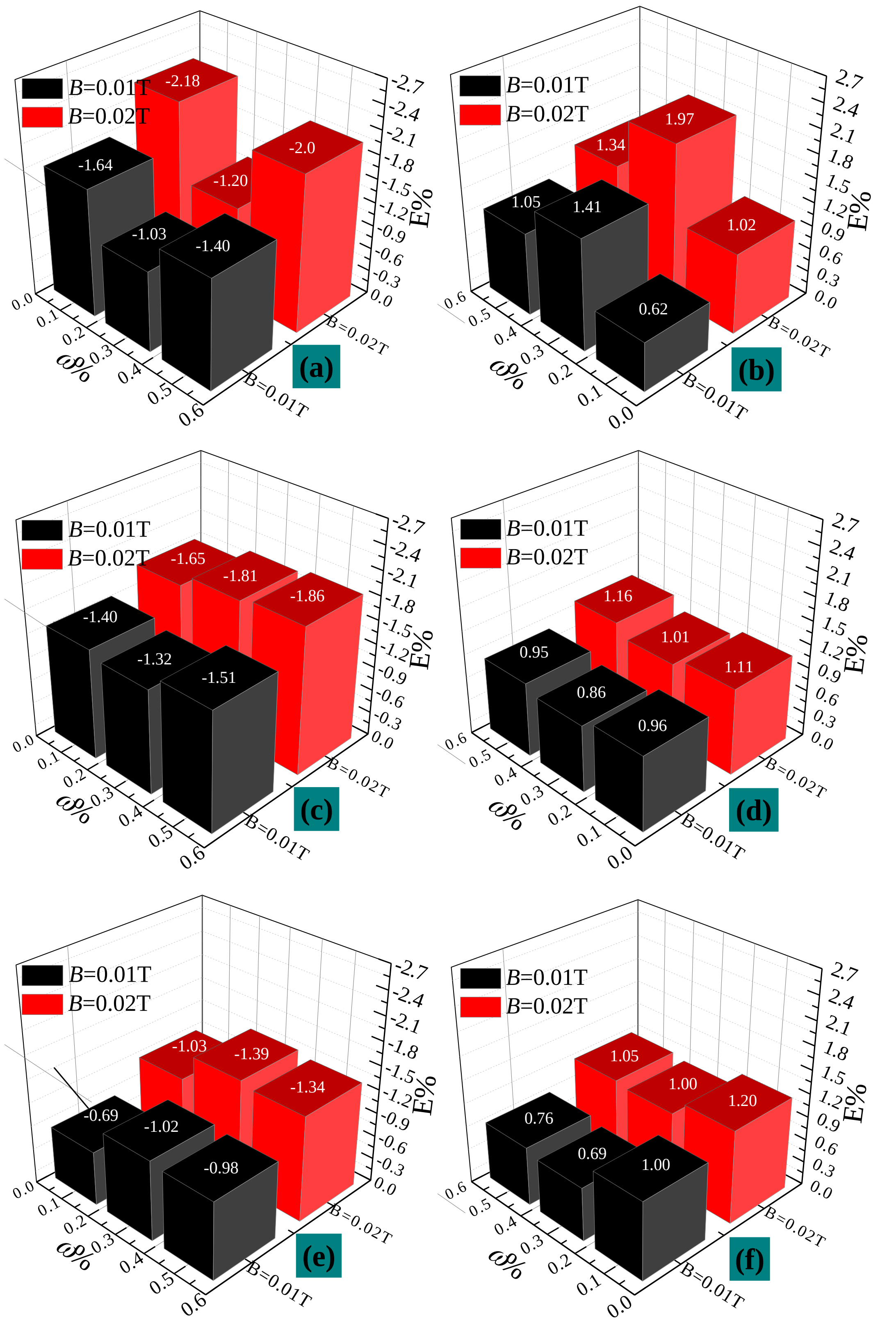


Fig. 11. Effects of magnetic field on Nusselt number enhancement ratio compared with that without magnetic field, without metal foam: (a) horizontal magnetic field, (b) vertical magnetic field, PPI=5: (c) horizontal magnetic field, (d) vertical magnetic field, PPI=15: (e) horizontal magnetic field, (f) vertical magnetic field

show that horizontal magnetic field can reduce the natural convection with metal foam by 1.86% at best, and vertical magnetic field can enhance the natural convection with metal foam by 1.20% at best. The resultant force direction of horizontal (rightward) magnetic field force and gravity force is bottom right, which is equivalent to the physical model of hot side on top and cold side on bottom. However, above physical model is disadvantageous to natural convection but it is to the benefit of heat conduction. Hence, the horizontal (rightward) magnetic field can reduce the natural convection. For the vertical (downward) magnetic field, the resultant force direction of vertical (downward) magnetic field force and gravity force is the same with that of gravity force, which is equivalent to the physical model of larger gravity force. Larger gravity force can make positive contribution to the enhancement of natural convection. Therefore, vertical (downward) magnetic field can increase the natural convection.

4 Conclusions

An experiment system is set to study the effects of rotation angle and metal foam on natural convection of nanofluids in the cavity under an adjustable magnetic field. Relevant conclusions are obtained as follows:

(1) Cavity with a rotation angle α=90° shows the best thermal effect, followed by α=45° and α=0°, and the cavity with a rotation angle α=135° behaves the worst thermal performance. Nusselt number of cavity with α=90° is enhanced by 11.29% at highest in comparison with that with a rotation angle α=135°.

(2) Natural convection heat transfer rises with nanoparticle mass fraction (from

ω=0.0% to 0.3%) firstly but then falls (from ω=0.3% to ω=0.5%). Nanofluids with a critical nanoparticle mass fraction ω=0.3% shows the highest Nusselt number.

(3) Metal foam is significant in the heat transfer of cavity, as the increase of PPI, the Nusselt number decreases.

(4) Horizontal magnetic field can reduce the natural convection of nanofluids in the cavity, but vertical direction of it can improve the natural convection. Higher horizontal magnetic field intensity can cause smaller Nusselt number, and higher vertical magnetic field intensity can cause larger Nusselt number.

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