International Journal of Thermal Sciences 110 (2016) 137–145

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

# Thermal characteristic of a tube fitted with porous media inserts in the single phase flow

Wenbin Tu [a,*], Yun Wang [a], Yong Tang [b]

[a] School of Mechanical Engineering, Jiangsu University, Zhenjiang 212013, People's Republic of China
[b] Key Laboratory of Surface Functional Structure Manufacturing of Guangdong Higher Education Institutes, South China University of Technology, Guangzhou 510640, People's Republic of China

ARTICLE INFO

*Article history:*
Received 11 November 2015
Received in revised form
29 June 2016
Accepted 29 June 2016

*Keywords:*
Metal porous media
Enhancement
Inserts

ABSTRACT

In this paper, the heat transfer rate and the pressure drop of metal porous media inserts are analyzed in the single phase. The testing range of the Reynolds number is between 3654 and 14617. Tap water is used as the working fluid. The effect of particle size and particle shape on the heat transfer performance is studied. The results show that an optimal value existed among the testing samples for dendritic particle. The best heat transfer rate is resulted by the sample D-125 instead of by the sample D-25 with the small particle size, which is approximately 2.2–3.0 times as that of the smooth tube. This is mainly because the velocity at the inlet of inserts increases greatly and the fluid mixing intensity at the annular is also high. Two factors work together to bring about a best heat transfer coefficient. The friction factor increases with the decrease in the particle size. The best Performance Evaluation Criterion (PEC) value is resulted by sample D-125, which is about 1.26–1.71. The particle shape also has an impact on the heat transfer rate. The heat transfer coefficient of the spherical particle is higher than that of dendritic particle. However, the higher heat transfer rate is paid at the cost of high flow resistance. This high flow resistance finally deteriorates the heat transfer performance. As a result, the best heat transfer performance is achieved by the dendrictic particle, which brings a high heat transfer rate as well as a low flow resistance. Therefore, the PEC values have to be taken into consideration in the design of heat exchanger.


## 1. Introduction

Bergles [1] classified the heat transfer enhancement technology into two types, one is called as passive, which require no directly application of external power, and another is called as active, which require external power. Passive techniques usually include the external surface, inserts, vortex generator, etc and active techniques normally include mechanical vibration, electric fields, magnetic fields, jet impingement, etc [2–4]. Among the passive techniques, inserts are normally adopted to enhance the flow in the circular tube. Compared with other enhancement techniques, inserts have the advantage of low cost, easy maintenance, rapid installation, which enables them to draw great attention to the researchers [5].

The twisted-tape inserts are extensively used in the design of heat exchangers, which usually produce the swirl flow or the secondary flow to improve fluid mixing, therefore, a high heat transfer rate will be obtained. Paisarn Naphon [6] developed predicting correlations for the twisted tape insert. The majority of the data fell within ±15%, ±10% of the proposed correlations for heat transfer coefficient and friction factor, respectively. Eiamsa-ard [7] investigated the effect of twisted ratios and space ratios on the heat transfer performance. Bas and Ozceyhan [8] experimentally investigated the effect of twist ratio and clearance ratio on flow resistance and heat transfer rate with a twisted tape swirl generator inserted. The results showed that it can result in a good heat transfer rate as well as give a less contamination, compared with the attached one. The researcher found that an increase in the heat transfer rate inevitably brings an increase in the flow resistance. It becomes a challenge task to get a high heat transfer coefficient with a limited flow resistance increase. Great effort is made to avoid unnecessary flow disturbing in the attempting to increase the heat transfer coefficient. The researchers found that it was possible to achieve an outstanding heat transfer with reasonable pressure drop by modifying twisted tapes with appropriate geometries. A variety of twisted tapes with modifying geometries such as centrally hollow narrow twisted tapes [9], serrated twisted tape [10], twin

* Corresponding author.
*E-mail address:* 13912145@qq.com (W. Tu).

http://dx.doi.org/10.1016/j.ijthermalsci.2016.06.035
1290-0729/

twisted tapes [11] were developed. The modified edges or center of twisted tapes will induce stronger turbulence intensity in the vicinity of the tube wall or the core of the tube, which will greatly increase the heat transfer performance [12]. However, the friction factor is relatively low for their special geometer structure. The other method concerned by the researchers is to change the temperature profile instead of to reduce the thickness of the thermal boundary layer. This method will greatly decrease the flow resistance without sacrificing the heat transfer rate [13]. Guo [5] investigated the heat performance of conical-strip inserts and conical-ring inserts. The results show that conical-strip insert is only 53–56% of that for conical-ring inserts. The thermo-hydraulic performance factor can be enhanced by 36–61% by using conical-ring inserts. Eiamsa-ard [14] and You [15] analyze the heat performance of a louvered strip insert. The results showed that the louvered strip insert brought a good thermo-hydraulic performance in the turbulent flow regime. Moreover, some researchers go further to develop some inserts with special geometry which is greatly different to the traditional twisted tapes. Tu et al. [16] developed a kind of insert, small pipe inserts, which can transfer more heat for the same pumping power compared with other inserts. Xing et al. [17] developed a new type of porous medium insert, mesh cylinder insert. This inserts only consist of a thin stainless wire-net, with a shape of a cylinder and its inlet was closed. The result showed that mesh cylinder inserts can achieve a good heat transfer performance. Changing the temperature profile and the velocity profile seems to be a good way to achieve a high heat transfer performance. Recently, many previous works adopted porous medium as inserts to enhance heat transfer. The mechanism of porous medium insert can be concluded as follows:(1) disturb the boundary layer to decrease the thermal resistance; (2) increase the intensity of turbulence to augment mixing of fluid; and (3) increase the effective thermal conductivity of fluid due to the high area density and thermal conductivity of porous media [18]. Pavel et al. [19] demonstrated that higher heat transfer rates can be achieved by using porous inserts at the expense of a reasonable pressure drop. Mao et al. [20] demonstrated that higher heat transfer rates can be achieved by using porous inserts at the expense of a reasonable pressure drop. Huang et al. [21]found that the heat transfer rate of the tube with porous inserts is about 1.6–5.5 times larger than the smooth tube. Inserting a porous medium at the core of the tube is proved to be an effective way for heat transfer enhancement.

In this paper, we develop a new type of insert, porous media cylinder inserts, which has the shape of the cylinder with a thickness of 2 mm and its inlet is closed by the same porous media. This structure is expected to increase the velocity at the inlet and improve the mixing intensity at the annular region. In addition, it is also expected to exert a small effect on the core flow, bringing about a low flow resistance. An experimental set-up will be conducted to investigate the thermal characteristic of porous media inserts. The effect of particle size and particle shape on the heat transfer performance will be carefully analyzed.

## 2. Experimental set-up

The schematic of the experimental setup in this study is shown in Fig. 1. The setup mainly consists of a test section, a cooling water loop and a hot water loop. The test section was made of two concentric tubes in which hot water flowed through the inner tube and cold water flowed in counter flow through annulus. The length of the test section was 1300 mm. The inner and outer tube diameters are 18 and 38 mm, respectively. The inner tube is copper (1300 mm long, 2 mm thick) and the outer tube is Plexiglas (1300 mm long and 5 mm thick). Hot water was heated by a hot water tank (HH-W600; HengFeng Electronics Manufacturing Inc, JiangSu Province, China) and the water temperature was heated to a constant temperature of 70 °C controlled by a PID controller inside the water tank. Tap water went through the cooling circuit and its temperature is maintained at ~30 °C. The water flow rate was measured by using a rotameter with an accuracy of ±1%. The inlet and outlet temperature of the water was measured by four T-type thermocouples (Omeron Inc.). Eight T-type thermocouples are located in the tube wall to measure the local temperature. All the thermocouples were calibrated before testing with an accuracy of ±0.1 °C. The pressure of test tube was measured by a pressure transmitter (P/N:DP1300-DP5E22B1N, Senex Inc.) with an accuracy of ±0.5%. All of the temperature and pressure data were recorded by using a data logger (Agilent Data Acquisition Unit 34970 A). The test section and the pipeline are wrapped with a layer of insulation glass wool to minimize heat loss in the radial direction.

The permeability testing system is shown in Fig. 2. It only consists of a water loop. Deionizer Water is pumped through the test section from a water tank by a magnetic gear pump (MG204WB, Nanjing Auric Inc). The flow rate is measured by using two rotameters (LZB-3WB: 10–100 ml/min; LZB-6WB: 60–600 ml/min, Yuyao Inc, Zhejiang province, China) with an accuracy of ±0.1%. The pressure difference of the test section is measured by a pressure transmitter (Senex, DP1300-DP5E22B1N) with an accuracy of ±0.5%. The pressure is recorded by using a data logger (Agilent Data Acquisition Unit 34970 A).

## 3. Sample prepare

Commercial copper powder usually has two different shapes, one is spherical, and another is dendritic shown in Fig. 3. Porous media made by this two different powder will be greatly different in the heat and mass transfer. Therefore, both of them were used as the testing sample.

Fig. 4 shows the schematic of the test section, where the test sample is composed of five parts each contains a shape of a cylinder with a diameter of 10 mm, a thickness of 2 mm, and a length of 150 mm. The cylinder parts are shown in Fig. 5. These five porous cylinders are mounted on a stainless steel rod with a length of 1000 mm by the elastic rubber element. The whole inserts are fixed in the tube by some self-made metal clips. Five groups of samples made by different particle were tested in this study. Three of them are made by spherical copper powder; the other two are made by dendritic copper powder. The Parameters of testing sample of porous media inserts were shown in Table 1. Solid state sintering was used to manufacture the testing samples. The porous media samples were sintered at 900 ± 10 °C with the sintering time of 60 min in a vacuum sintering furnace. Fig. 6 shows the picture of samples for permeability test. The permeability samples were block in the shape with the size of 20 × 20 × 2 mm. Sample of A is made of dendritic cooper powder with particle size larger than 150 μm, B is made of dendritic cooper powder with particle size of 100 μm-125 μm and C is made of dendritic cooper powder with particle size smaller than 25 μm. Sample of D is made of spherical cooper powder with particle size of 100 μm-125 μm. All samples were sintered for one hour in the vacuum sintering furnace.

## 4. Data processing

The data processing are as follows:

The heat transfer rate absorbed by the cold water in the annulus, $Q_C$ is calculated from

$$Q_c = \dot{m}_c c_p (t_{c,o} - t_{c,i}) \tag{1}$$