Applied Thermal Engineering 133 (2018) 276–282

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Experimental studies of heat transfer of air in a double-pipe helical heat exchanger

Davood Majidi, Hashem Alighardashi, Fatola Farhadi*

Department of Chemical and Petroleum Engineering, Sharif University of Technology, Azadi Avenue, Tehran 11365/8639, Iran

HIGHLIGHTS

- Double-pipe helical heat exchanger with copper fin in the annulus is studied.
- Overall heat transfer coefficient of the double-pipe helical HEX is investigated.
- Hydraulic diameter is replaced by equivalent one for OHTC calculation.
- A correlation for the OHTC is suggested and validated against experimental results.
- The effect of the hot and cold mass flow rates on OHTC is studied.

ARTICLE INFO

Keywords:
Heat exchanger
Helical coil
Double-pipe
Heat transfer coefficient of air

ABSTRACT

The overall heat transfer coefficient (OHTC) of air in a double-pipe helical heat exchanger is studied and experimentally investigated. In order to increase the rate of heat transfer in the annulus section, a copper-wire fin is soldered on the outside area of the internal tube. The literature correlations' results are presented against the experimental data by changing mass flow rate and temperature, and consequently changing the Reynolds number. Further, a new method is suggested to obtain the heat transfer coefficients of double-pipe helical heat exchangers for the internal tube and the annulus section by combining two of the previously proposed approaches and making subsequent corrections, e.g. using equivalent diameter instead of hydraulic diameter. Moreover, the influence of the hot and cold mass flow rates on the OHTC, as well as the effect of the installed fin on the heat transfer coefficient of the annulus section are investigated. Finally, obtained results show the strength of the suggested correlation and the enhancement in the OHTC due to the presence of the fin in the annulus.

1. Introduction

Helical coil heat exchangers have been widely used in industrial applications due to their compactness, low cost, and high efficiency in heat transfer [1–3]. Numerous studies have been illustrated the superior performance of helically coiled tubes compared to straight tubes in heat transfer systems [4–8]. The flow and the convective heat transfer in helically coiled tubes are complicated compared to straight tubes, owing to the development of secondary flows associated with the curvature of the tube which leads to high turbulence and improvement in the heat transfer [1,4].

Several studies have been experimentally and theoretically investigated helically coiled tubes features; Rennie and Raghavan experimentally and numerically investigated heat transfer in a double-pipe helical heat exchanger, showing that increasing the Dean number in the tube or annulus results in augmentation in the OHTC [4]:

$$De = \frac{\rho V}{\mu}\left(\frac{d_{o,i}^2-d_{i,o}^2}{d_{o,i}+d_{i,o}}\right)\left(\frac{d_{o,i}-d_{i,o}}{D/2}\right)^{1/2} \tag{1}$$

In another study, they discussed that flow conditions in the annulus have a significant influence on the OHTC [9]. Wongwises and Polsongkram experimentally worked on the condensation heat transfer of HFC-134a in a helical double-pipe heat exchanger and concluded that the average heat transfer coefficient increases with increasing average vapor quality and mass flux [10]. Seban and McLaughlin put effort on heat transfer in coil tubes; they illustrated that in the large diameter of coils, the results of OHTC were quite similar to the straight tubes [11].

In double-pipe heat exchanger studies in order to obtain the heat transfer coefficient in the annulus area, the equivalent diameter must be considered instead of the hydraulic diameter, since the mutual heat

* Corresponding author.
E-mail address: farhadi@sharif.edu (F. Farhadi).

https://doi.org/10.1016/j.applthermaleng.2018.01.057
Received 26 October 2017; Received in revised form 21 December 2017; Accepted 16 January 2018
Available online 20 February 2018

Nomenclature

A	surface area [m^2]
C_p	specific heat [J kg^{-1} °C^{-1}]
d	diameter [m]
d_f	fin diameter [m]
D	coil diameter [m]
D_{eq}	equivalent diameter [m]
De	Dean number
D_H	hydraulic equivalent diameter [m]
F	volumetric flow rate [m^3 s^{-1}]
k	thermal conductivity [W/m °C]
L	characteristic length
$LMTD$	log-mean temperature difference [°C]
Nu	Nusselt number
Pr	Prandtl number
Q	heat transfer rate [kW]
Re	Reynolds number
T	temperature [°C]
U	overall heat transfer coefficient (OHTC) [W/m^2 °C]

Greek letter

ρ	density [kg m^{-3}]

Subscripts

ave	average
c	cold, coil
h	hot
i	in, inside
o	out, outside
S	straight

transfer area is only the inner surface of the annulus section. Even some of the research studies with Nano fluids in double-pipes ignored the replacement of equivalent diameter instead of hydraulic diameter for the annulus calculation [1,12].

In most of the previous heat transfer studies, constant wall temperature is used as a boundary condition, since thermal boundary conditions affect the Nusselt number for fully developed flow in straight tubes. Further, changing the inlet temperature or inlet flow rate changes the Nusselt number, and accordingly has an effect on the heat transfer coefficient [13,14].

In the present study, experimental and theoretical heat transfer of air in a double-pipe helical heat exchanger is investigated. In order to illustrate the efficacy of this study, the obtained results are compared with the previously proposed correlations. The OHTC is calculated based on the inner surface of the tube, since there is a possibility of heat loss from the external tube wall although the heat exchanger is properly insulated. Hence, using outer tube area to calculate the OHTC may result in biased results.

Heat transfer of gas flows is associated with complexities compared to liquids because of their restrictions for measuring the proper discharge pressure to the atmosphere in an experimental setup. Other restrictions of working with gas flows include but not limited to the compressibility of them, their temperature and pressure dependence to physical properties, as well as their volumetric flow rate measurement dependence to proper correction.

The innovation of the present study is the use of a copper fin in the annulus section (Fig. 1) to enhance the OHTC. It should be emphasized that, in today's highly competitive world market, increasing the heat transfer rate, even a small amount, by implementing an economical fin in a heat exchanger can result in a considerable improvement in the process efficiency and economy. Moreover, as already mentioned, the annulus heat transfer coefficient is expressed as a function of equivalent diameter, not hydraulic diameter. Several experiments are performed to demonstrate the effectiveness of the fin in the annulus section besides illustrating the privilege of equivalent diameter in the heat transfer.

2. Experimental setup

The setup for the current study is a double-pipe helical heat exchanger, dimensions of which is shown in Table 1. The test setup consists of a double-pipe helical heat exchanger, the cooling and heating loops, and the relevant instrumentation. Two independent cooling and heating loops (Fig. 2) are considered to provide controlled inlet temperatures and a wide range of feed temperature gradient entering to the heat exchanger. The provided air by the compressor is divided into two streams; one of which is directed to the cooling loop to decrease the air temperature to the set point, and the other one is sent to the heating loop. The hot and cold water baths with controlled temperature are used to provide the desired temperature for the heating and cooling loops. The cold and hot stream temperatures are regulated by a PID controller at the desired temperature within the range of 10 °C to 20 °C and 30 °C to 50 °C, respectively. After regulating the gas flow temperature, the hot and cold streams are sent to the heat exchanger, in a counter-flow configuration with the cold stream in the annulus section and the hot stream in the internal tube (Fig. 3).

The mass flow rates of both streams are in the range of 1–8 kg h^{-1}. By doing so, the effect of the hot and cold mass flow rate on the OHTC is obtained under similar conditions. A 1 mm diameter copper wire is wound and soldered as a spiral fin around the outer wall of the inner tube within the annulus space. The wire fin has a pitch of 4 cm and left a 1 mm gap for air flow in the remaining free space of the annulus (Fig. 1).

In order to minimize the heat exchanger heat loss to the environment, the coil is insulated by 10 mm aluminum wrapped glass wool. The specifications of the instrumentations, rotameter, thermometer, and pressure sensors, are presented in Table 2.

3. Theory and methods

The main purpose of this work is to obtain the heat transfer coefficients for a wide range of Reynolds number for the inner tube and the annulus. The energy balance between the hot and the cold streams, Q,

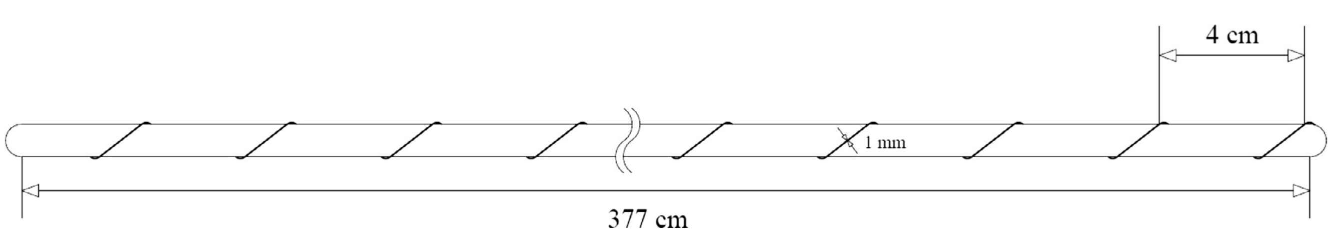

Fig. 1. Schematic of soldered wire fin in the annulus of the double-pipe helical heat exchanger.