International Journal of Thermal Sciences 121 (2017) 390–397

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Heat transfer coefficients for evaporator with nested helical coils

N. Demesa [a, *], A. Huicochea [b, **], J.A. Hernandez [b], J. Siqueiros [c]

[a] Posgrado del Centro de Investigación en Ingeniería y Ciencias Aplicadas (CIICAp), Universidad Autónoma del Estado de Morelos (UAEM), Av. Universidad No. 1001, Col Chamilpa, CP. 62209, Cuernavaca, Morelos, Mexico
[b] CIICAp, UAEM, Mexico
[c] Consejo Estatal de Ciencia y Tecnología, Secretaria de Innovación, Ciencia y Tecnología, La Ronda No. 13, Col. Acapantzingo, Cuernavaca, Morelos, C.P. 62440, Mexico

ARTICLE INFO

Article history:
Received 21 July 2016
Received in revised form
17 July 2017
Accepted 2 August 2017

Keywords:
Evaporator
Heat exchanger
Heat transfer coefficients
Heat pump by absorption
Nested helical coils
Concentric multi-coils
Absorption heat transformer

ABSTRACT

The evaporation processes at low temperatures are essential for the factories and thermal systems as the heat pumps by absorption. This paper shows the design, building and characterization about an evaporator of 2 kW with a steam generation at 323.15 K. Its geometry consists in three nested helical coils with different diameters. Every coil is connected in series and the heat interchange is given by means of pool boiling. The heat transfer coefficients are indicated considering different operating conditions. The sizing method was validated taking into account the theoretical and experimental overall heat transfer coefficient of 659.8 W/m^2 K. The evaporator efficiency was up to 83% taking into account a steam of 7.1×10^{-4} kg/s with a heat source at 334.35 K and 0.11 kg/s.

1. Introduction

The helical tube geometry is used in many situations as an alternative to enhance the uniform heating and the heat transfer speed for the Heat Exchanger (HE). The flow development and the heat transfer in the helical coils are more complex with respect to the straight tubes, due to the presence of inertial and centrifuge forces, which are determined by wending diameter, space between turns, tube diameter, between other [1]. Therefore, the design and building of the HE with helical coils represent a great challenge. Several theoretical and experimental studies have been developed to understand these phenomena [2–7]. Some advantages are: their coefficients of heat transfer are higher [8], spaces saving, better efficiency, costs reduction for building and maintenance [9]. However, these can operate at a maximum pressure of 68.94 MPa, while the operating temperature is limited by the materials and the corrosion rate [10]. The HE's with helical geometry are used for heat recovering processes, air conditionings, refrigeration systems, chemical and nuclear reactors, medical equipments, chemical and food processing [2,11,12]. There are many configurations about the helical HE, where the basic design is a coiled tube inside a shell [13–16]. Different correlations based on the experience have been proposed to determine the Nusselt number and local heat transfer coefficients for specific operating parameters [1–9,11,12,15–24]. Hardik et al. [17] studied the curvature effects ($13.1 < D_{HEL}/D_{EXT} < 67$) and the turbulence ($300 < Re < 19{,}000$) for the heat transfer in a helical coil with water. A curvature increment increases the Nusselt number up to 25 and 35%. Shokouhmand et al. [23] analyzed three helical coils with different geometry. The overall heat transfer coefficient is improved from 0 to 40%, when the heat interchange is given at countercurrent. The nanofluids improve the heat transfer for a vertical and horizontal helical coil because the secondary flows and thermal conductivity increase. The increment of Nusselt number is between 37 and 49% with respect to the H_2O [24].

The local heat transfer coefficients in helical tubes are higher than straight tubes (1.16–1.43 times) due to turbulence and vorticity by curves [8]. Also, the helical tubes used for a condensation process, improves the average heat transfer coefficients up to 13.8% with respect to straight tubes [25]. Nevertheless, the

---

* Corresponding author.
** Corresponding author.
E-mail addresses: francisco.demesa@uaem.mx (N. Demesa), huico_chea@uaem.mx (A. Huicochea).

http://dx.doi.org/10.1016/j.ijthermalsci.2017.08.002
1290-0729/© 2017 Elsevier Masson SAS. All rights reserved.

Nomenclature

A	Heat transfer area [m^2]
C	Coil
Cp	Specific heat capacity [kJ/kg K]
D	Diameter [m]
G	Acceleration of gravity [9.81 m/s^2]
h	Specific enthalpy [kJ/kg]
H	Height [m]
$LMTD$	Logarithmic mean temperature difference [K]
$\dot{m}$	Mass flow rate [kg/s]
N	Coil turns
Nu	Nusselt number [−]
P	Pressure [Pa]
Pr	Prandtl number [−]
$\dot{Q}$	Heat transfer rate [W]
Re	Reynolds number [−]
T	Temperature [K]
U	Overall heat transfer coefficient [W/m^2 K]
V	Volume [m^3]

Greek letters

ε	Efficiency [−]
λ	Thermal conductivity [W/m K]
α	Local convective heat transfer coefficient [W/m^2 K]
υ	Kinematic viscosity [m^2/s]
ρ	Density [kg/m^3]

Subscripts

AMB	Environment
CON	Condensed
COO	Cooling
EVA	Evaporator
EXT	External
F	Film
FG	Vaporization
GEN	Generated
GLO	Global
HEL	Helical
HS	Heat source
INT	Internal
IN	Inlet
LIQ	Liquid phase
NUC	Nucleation
OUT	Outlet
PBO	Pool Boiling
SAT	Saturation
SHE	Shell
T	Turn
TOT	Total
VAP	Steam
W	Wall

information about the design of HE's with nested helical coils and the heat transfer phenomenon for the evaporation process at low pressure are limited. The heat interchanges for the food, no metallic and textile processes are executed from 303.15 to 313.15 K [26].

The Absorption Heat Transformer (AHT) mainly operates by using HE's (generator, condenser, evaporator and absorber) at different temperatures and pressures. Its main aim is to upgrade the energy at a higher temperature with respect to the heat source, which can be waste, geothermic or solar heat. This equipment is also known as an absorption heat pump type II, because the evaporation temperature is higher than the condensation temperature. The evaporator is an essential component for the absorption process, because the liquid refrigerant (which comes from the condenser), is evaporated to mix with the strong binary mixture (which comes from generator) in the absorber, to have a useful heat at high temperature and a weak working solution, which returns to the generator in order to begin the cycle again. The steam can reach temperatures from 303.15 to 363.15 K, while the useful heat in the absorber can be between 323.15 and 423.15 K [27–30]. Also, several configurations for steam mechanical compression heat pumps have been proposed, where the refrigerant is evaporated between 298.15 and 308.15 K [31]. For a Rankine organic cycle, the evaporator can be activated from 303.15 K according to the refrigerant [32–34].

The bibliographic review indicated above, shows the relevance and limitation about nested helical coils evaporators. This paper describes a theoretical and experimental study for an evaporator of 2 kW, which is operated as pool boiling at a water evaporation temperature of 323.15 K. The local and overall heat transfer coefficients are discussed considering several operating parameters, besides new parameters on thermal capacity and sizing are proposed.

2. Design for evaporator

The thermodynamic data were obtained using a model established previously [35–39] and a simulator for a single stage *AHT* at $T_{EVA} = 323.15$ K and $T_{CON} = 299.15$ K. The design is based on the *LMTD* method with the operating parameters indicated in Table 1.

The proposal is to use nested helical coils inside a shell with two sections, where the evaporator is in the bottom and the condenser is down in order to ease both processes as shown in Fig. 2. The stainless steel 316L is used for the building because the useful life is prolonged when the corrosive agents are present. Every coil is made with tubing of ½”. The water is used as refrigerant, which circulates outside the tubing, while the simulated heat source is supplied inside the tubing.

2.1. Pool boiling

Due to the inclination angle (almost 2°) for every turn and the ratio between coil to external diameters of the tube, all coils can be considered as an arrangement of horizontal tubes for the external section [40]. Therefore, the heat transfer for a helical coil

Table 1
Design data for the evaporator.

	Hot water	Cold water (condensed/steam)
ε [−]	0.8	
T_{IN} [K]	333.15	299.15
T_{OUT} [K]	327.05	323.15
$\dot{m}$ [kg/s]	0.0983	0.0008
p [kPa]	85.9	12.4