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Research Paper

Experimental study of heat transfer enhancement in the evaporator of single-effect absorption chiller using new different tube insert

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HIGHLIGHTS

- We investigate the effect of new different tube inserts on the evaporator of absorption chiller.
- Four types of tube inserts including of S, GS, TW and BT were investigated.
- Butterfly inserts have the largest increase in the performance factor compared to other types.

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ABSTRACT

In this paper, the effect of the different tube inserts with various geometry parameters on turbulent flow in the evaporator of single-effect absorption chiller has been investigated experimentally. The experiments were performed with several tube inserts including of wire coils (S1, S2), modified wire coils (GS1, GS2, GS5), modified classic (TW) and butterfly (BT) for mass flow rate from 0.167 to 0.583 kg s^{-1}. In all cases, the use of tube inserts leads to a considerable increase in heat transfer and pressure drop over the evaporator without tube insert. The highest performance factor of 1.78 was achieved for the butterfly tube inserts compared to others. In all cases and all Reynolds number, the performance factors are more than one and these techniques are favorable for heat transfer enhancement.

1. Introduction

Many efforts have been made on heat transfer enhancement in heat exchangers. During the past decade, researchers focused on many different ways to reduce the size and cost of heat exchangers [1–6]. Generally, heat transfer enhancement can be done with two techniques. These techniques can be classified into active and passive techniques. The passive techniques include coiled wire, twisted tape or other swirl flow devices inserted into a flow provide swirling flow and periodic redevelopment of the boundary layer, etc. and no additional external power is needed. In this method, the swirl induced tangential flow velocity component causes improve fluid mixing between tube core and the wall region nearby. On the other hand, the swirl induce heat transfer enhancement brings alone inevitable shear stress and pressure loss in device inserted tube. For a long time, many researches have been carried out concerning the effect of tube inserts on heat transfer and pressure drop [7–11]. Wang and Sunden [12] introduced a comparison in the thermal and hydraulic performances between twisted tape and coiled wire insert for both laminar and turbulent flow regimes. They reported that coiled wire inserts provided better overall enhancement than the twisted tape inserts. Heat transfer enhancement inside tubes with three dimensional internal extended surfaces and twisted tape inserts were studied by Liao and Xin [13]. Their experiments were carried out at different ranges of the Prandtl and Reynolds numbers. They proposed a correlation for predicting friction factor and Stanton number. Sivashanmugam and Suresh [14] investigated the heat transfer and friction factor parameters of flow in circular tube fitted with a full-length helical screw element with different twist ratios. They performed their experiments for various Reynolds numbers and the obtained experimental data were then compared with those previously reported in the literature. They reported higher performance of the helical twisted insert in comparison with the twisted tape insert. The heat exchangers of absorption chillers are one of the most important parts of it to improve efficiency. In this regard, so far researches have been done many studies. A variable effect LiBr-water absorption chiller for high-efficient solar cooling system was investigated experimentally by Xu et al. [15]. Their results showed that the COP increased from 0.69 to 1.08 under generation temperature from 95 °C to 120 °C. Li et al. [16] investigated the

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Nomenclature

A	heat transfer surface area (m^2)
C_p	specific heat capacity
D	diameter of the test tube (m)
e	wire diameter of tube insert (m)
G	mass flux ($kg\ m^{-2}\ s^{-1}$)
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
K	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length of test tube (m)
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
N_p	number of tube pass
N_t	number of test tube
ΔP	pressure drop across the test section (Pa)
Q	heat transfer rate (W)
q	heat flux ($W\ m^{-2}$)
R	thermal resistance ($m^2\ K\ W^{-1}$)
T_{in}	inlet temperature of the fluid (K)
T_{out}	outlet temperature of the fluid (K)
T_{wi}	inside surface temperature of the wall (K)
T_{sat}	saturation temperature of shell side (K)
L_c	length of big section of modified wire coil (m)
l_c	length of small section of modified wire coil (m)
p	wire coil and modified wire coil pitch (m)
w	classic tube insert width
pp	proportion of modified coil pitch [$pp = (p/e)_{Lc}/(p/e)_{lc}$]

Dimensionless groups

f	friction factor
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number

Greek symbol

θ	tube insert angle (degree)
μ	dynamic viscosity (Pa s)
ρ	fluid density ($kg\ m^{-3}$)
η	thermal performance factor

Subscripts

a	augmented tube
b	based on bulk temperature
cu	copper tube
i	tube inside
in	tune inlet
o	tube outside
out	tube outlet
s	smooth tube
sat	saturation
t	tube insert
w	based on wall temperature

performance of a solar powered LiBr-water absorption cooling system. They reported that the chiller's maximum instantaneous refrigeration coefficient (chiller efficiency) could be up to 0.6. The influence of the operation condition on the performance of a chemisorption chiller driven by hot water between 65 °C and 80 °C was experimentally assessed by Gomes de Oliveira and Joao Generoso [17]. Their results showed that the utilization of mass recovery simultaneously to heat recovery improved the COP and cooling power up to 11.7% and 15.4% respectively, when compared to the values obtained when only heat recovery was employed. The performance analysis of small capacity chillers by different modeling methods was carried out by Labus et al. [18]. A comparative evaluation of different modeling methods for predicting the absorption chiller as well as statistical indicators and tests which might assist in selection of the most appropriate model were presented. Their results showed that highly accurate empirical models can be developed by using only the variables of external water circuits as model input parameters. Martinez et al. [19] investigated the development and experimental validation of a simulation model to reproduce the performance of a 17.6 kW LiBr-water absorption chiller. Heat transfer areas and coefficients of each heat exchanger, the circulating solution flow rate and the properties of the LiBr-water solution have been considered. Once a model was created and the real data used to validate the obtained results. An empirical study on evaporation heat transfer characteristic and flow pattern visualization in tubes with coiled wire inserts was studied by Shafaee et al. [20]. They reported that use of coiled wires increase the flow boiling heat transfer coefficients up to maximum value of 124% above the plain tube values with wire coiled. Chen et al. [21] presented experimental and analytical study on air-cooled single effect LiBr-H_2O absorption chiller driven by eventuated glass tube solar collector for cooling application in residential buildings. The air-cooled single effect absorption chiller was fabricated and tested under a broad range of a steady-state condition. Their results showed that the studied absorption chiller cam meet about 65% of total cooling load of the building with an average COP_{th} of about 0.61. Lubis et al. [22] explored solar-assisted single-double-effect absorption chiller for use in Asian tropical climates. They focused on single-double-effect absorption chiller machine that was installed in Indonesia. Their results yielded a coefficient of performance between 1.4 and 3.3, and a gas reduction ratio from 7 to 58% when compared to a double-effect absorption chiller driven by gas. The effect of different coiled wire geometry on pressure drop during condensation of R-134 a vapor inside a horizontal tube was experimentally investigated by Akhavan-Behabadi et al. [23]. They developed a new correlation based on the experimental data for predicting the pressure loss in coiled wire inserted tube. In another experimental study, Akhavan-Behabadi et al. [24] presented the result of the increasing heat transfer enhancement and pressure drop during flow boiling of R-134a in a coiled wire inserted horizontal evaporator. Agrawal et al. [25] experimentally studied the heat transfer enhancement by using coiled wire inserted during force convection condensation of R-22 inside a horizontal tube.

Even though, extensive researches have been done regarding heat transfer improvement in heat exchangers using tube inserts, but these techniques can used in many processes to improve heat transfer as one of the most important techniques and reduce energy consumption and emissions. Although, the study has not been done on the effect of tube inserts on the evaporator performance in single effect absorption chiller as yet, in this paper the experimental investigation has been done to determine the impact of new tube inserts on the evaporator performance in single effect absorption chiller.

2. Experimental set-up

A schematic of chiller thermodynamics cycle and a photograph for setup of single-effect absorption chiller are shown in Fig. 1. This set-up consists of evaporator (1), absorber (2), generator (3), condenser (4), solution heat exchanger (5), water boiler (6), cooling tower (7), vacuum pump (8), solution pump (9), refrigerant pump (10), hot water pump (11), chilled water pump (12)