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Numerical optimization of a fin-tube gas to liquid heat exchanger

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ABSTRACT

The influence of plate fin, fin tube and protrusion parameters on heat transfer and pressure drop characteristics of a finned tube gas to liquid heat exchanger is examined in this study. The optimization of plate fin, fin tube and protrusion dimensions as well as protrusion locations on plate fin surface is performed numerically using a computational fluid dynamics (CFD) program named "Fluent". The dimensions of the plate fin of a commercially available combi boiler apparatus heat exchanger are taken as basic dimensions. As the first step, the best plate fin and fin tube geometry is determined. Secondly, the best dimensions for three different protrusions (balcony, winglet and imprint) and their most suitable locations on the plate fin surface are found. Finally, the cumulative effects of several combinations of these three protrusions on the plate fin surface are analyzed. The placement combinations of protrusions are decided according to the results obtained for the individual effect of each protrusion. The fin named as I5B2W3 is found to be the most efficient fin among the investigated cases. A comparison with a numerical and computational study is also performed to validate the numerical results of the present study.

1. Introduction

Heat exchangers, which enable the heat transfer between two flows, have a wide usage area such as power production, waste heat recovery, air conditioning, domestic heating appliances etc. One of the most important types is fin-tube gas to liquid heat exchanger. Generally, a liquid flow inside the tubes is heated or cooled by a gas flow at different temperature, which passes through the fins of the heat exchanger. The fins provide extra heat transfer area for the heat exchange between two flows. However, since the thermal resistance at the gas side is high, the heat exchange is limited. In order to increase the heat transfer performance of fin-tube heat exchangers many researchers examined the effects of geometrical parameters of plate fins and tubes. Rocha et al. [1] made a two dimensional heat transfer investigation about the ellipticity of the tubes of plate fin heat exchangers. They reported that as the tube ellipticity value is increased, the efficiency of the heat exchanger is improved. Kundu and Das [2] gave the dimensions of a plate fin which accomplish the maximum heat transfer for a constant volume in their study. Mendez et al. [3] performed a numerical and experimental investigation about the influence of the fin spacing on heat transfer and pressure drop values of a plate fin and circular tube heat exchanger. Saboya and Saboya [4] used naphthalene sublimation technique to calculate the average convective heat transfer coefficient for a plate fin and elliptic tube heat exchanger. They reported that elliptical tubes provide better overall performance than circular ones. Kim and Song [5] made naphthalene sublimation experiments for a plate fin and circular tube heat exchanger. The experiments reveal that when the tube is placed in a downstream position and when the gap between the fins is decreased, better heat transfer is accomplished. Erek et al. [6] performed a numerical study for a plate fin heat exchanger with one row tube configuration and fixed flue gas mass flow rate. They observed heat transfer enhancement when the distance between fins is decreased, when the fin tube is shifted to downstream region, when the fin height is increased, when thin fins are used and when elliptical tubes replace circular ones.

The studies given above investigated only the geometry of plate fin and tube. The fin shape is also an important parameter which can influence the heat transfer and pressure drop values of a heat exchanger. Hence, the fin shape also took the interest of many researchers. Wang et al. [7] examined 18 different fin and tube heat exchangers with wavy fin pattern in a wind tunnel. Abu Madi et al. [8] tested plate and corrugated fins experimentally. They derived correlations for Colburn j and friction factors including all variables investigated in their study. Yan and Sheen [9] compared plate, wavy

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Nomenclature

a	greater radius of fin tube ellipse, mm
A	cross sectional area, m^2
b	smaller radius of fin tube ellipse, mm
d	wave height, mm
D_h	hydraulic diameter, mm
h	balcony type protrusion height, mm
h	convection coefficient, W/m^2K
k	thermal conductivity, W/mK
l	distance, m
L	fin height, mm
L_1	fin tube location on fin, mm
L_b	balcony type protrusion length, mm
L_w	ringlet type protrusion length, mm
L_i	imprint type protrusion length, mm
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number
P	perimeter, m
Q	heat transfer rate, W
r	imprint type protrusion radius, mm
Re	Reynolds number
t	fin tube thickness, mm
T	temperature, K
V	velocity, m/s
w	winglet type protrusion width, mm

Subscripts

flue gas	for flue gas
water	for water

Greek

θ	winglet angle of attack, °
μ	dynamic viscosity, kg/ms
ρ	density, kg/m^3

and louvered fin performances by using area goodness factor and volume goodness factor in their experimental study. Lozza and Merlo [10] carried out an experimental study on the heat transfer and pressure drop performances of 15 different heat exchangers with diverse fin types. They reported that louvered fin is the best, wavy fin is the second and corrugated fin is the worst in terms of heat transfer performance. Pirompugd et al. [11] performed the tests of 18 wavy fin and tube heat exchangers in a wind tunnel for dehumidifying conditions.

Although some improvements are achieved by changing the fin and tube shapes and geometries, some more heat transfer performance enhancement can be obtained by placing different protrusions on the fin surface since these protrusions disturb the gas flow between fins and create vortices. However, the flow disturbance has also an adverse effect on pressure drop values of gas flows. So, the investigation of protrusions' effects also attracted many researches and the exploitation of the protrusions in heat exchangers has received a lot of attention. Most common types of protrusions investigated in the literature are winglet, wing, dimple (imprint), louver and wave type protrusions. Gentry and Jacobi [12] determined heat and mass transfer enhancement for a plate fin with the use of delta wing located at the leading edge, experimentally. Chen et al. [13] made a numerical analysis in order to explore the influence of delta winglet pairs which are punched in in-line arrangement on a fin and oval tube heat exchanger. Ligrani et al. [14] investigated a channel with a dimpled wall in a wind tunnel. They observed that the protrusion provides flow mixing. Wang et al. [15] conducted flow visualization observations for fin-and-tube heat exchangers with plain fin and fins having two different wave type vortex generators using dye-injection technique in a water tunnel. Mahmood and Ligrani [16] examined the flow and local Nusselt number distribution of a dimpled channel. Leu et al. [17] analyzed a three-row fin and tube heat exchanger with rectangular winglets in their numerical and experimental investigation. The best winglet span angle is found as 45° in the study. Sommers and Jacobi [18] examined the effect of delta wing vortex generator on the performance of a heat exchanger operating under frosting and dry conditions. The results for dry operating conditions showed a 17–67% pressure drop increase with an increase in heat transfer. Pesteei et al. [19] accomplished an experimental study in order to determine the effects of delta winglet location. The delta winglet with constant geometrical dimensions and a 45° angle of attack is placed at 5 different locations on the fin. It was found that the placement of delta winglet at downstream locations provides more heat transfer increase than the placement at upstream location. Allison and Dally [20] conducted flow visualization experiments using dye injection technique in a water tunnel in order to investigate the flow and vortex generation for flow up and flow down configurations of the winglet. They reported that the flow up configuration shows more promising flow characteristics as it directs the flow toward the tube. Lienhart et al. [21] investigated both numerically and experimentally the use of dimples in a turbulent channel flow. An increase in friction coefficient for the channel with one dimpled wall and the channel with two dimpled walls is observed compared to the channel with plane fins. Wu and Tao [22] investigated numerically the laminar flow in a rectangular channel which has a punched rectangular winglet pair on one of its walls. Their results indicated that the highest performance can be achieved when the winglets have a 45° angle of attack. Wu and Tao [23] continued their numerical study and investigated the winglet pair effect for a laminar flow in a channel using the field synergy principle. Tian et al. [24] made numerical simulations investigating the effects of rectangular and delta winglet pairs placed on a flat plate channel laminar flow. Their findings revealed that both winglet types provide a significant Nusselt number increase accompanying high pressure drop values. Chu et al. [25] performed a numerical inquiry about the influence of delta winglet pairs on a fin and multi row oval tube heat exchanger. Downstream region is also found more efficient for the winglet and as the tube row number is decreased better heat transfer characteristics are encountered in their study. Bilir et al. [26] investigated the effects of three different protrusion types, winglet, imprint and balcony, on heat transfer and pressure drop performances of a fin and tube heat exchanger. First, the influence of each protrusion is examined separately. According to the results obtained, they examined two different fins with all three protrusion types, placed together on the fin surface. They found that all three protrusion types provide heat transfer enhancement along with a pressure drop increase compared to plate fin. Furthermore, the two fins with all three protrusions make an additional heat transfer increase compared to the fins with only one type protrusion.

As can be seen from the literature, there is a great effort made by many researchers in order to obtain more efficient heat exchangers by changing the geometrical parameters of plate fin, fin tube and by placing some types of vortex generators, which will disturb the fluid flow between the channel created by two fins, on the plate fin surface. However, it is also noticed that there is not any study in