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Experimental study on thermal–hydraulic performance of a wavy fin-and-flat tube aluminum heat exchanger

Junqi Dong*, Lin Su, Qian Chen, Weiwu Xu

Zhejiang Yinlun Machinery Co., Ltd, Tiantai, Zhejiang 317200, China

HIGHLIGHTS

► The continuous research about the wavy fin of plat fin heat exchanger.
► Provide the experiment correlations equation about the heat transfer and pressure drop of the wavy fin.
► Using the parameter analysis optimization method do the optimization design.
► Especially applied all kinds of heat exchanger of the off-way vehicle.

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ABSTRACT

The air side thermal hydraulic performance of the wavy fin-and-flat tube aluminum heat exchanger was studied. A set of experimental tests were conducted under different operating conditions for 16 sets of wavy fin geometry parameters. The experimental correlation equations were developed for the heat transfer and pressure drop performances of a wavy fin heat exchanger by the multiple regression method. The parametric study for thermal hydraulic performance of the wavy fins was carried out using the Taguchi method. It is showed that the amplitude and length of a wavy fin were the most important factors for the heat exchanger's overall thermal hydraulic performance.

1. Introduction

As a type of compact heat exchanger, the fin-and-flat tube heat exchangers have been widely used in many automotive applications for radiators, evaporators, condensers, and charge air coolers. In these applications, the heat transfer performance is normally limited by the thermal resistance on the air side of the heat exchangers. Therefore, various enhanced heat transfer surfaces have been developed to improve air side heat transfer performance. Many enhanced heat transfer fins, such as wavy fins, offset strip fins, perforated fins, and multi-louvered fins, have been developed to minimize the thermal resistance [1–3].

The wavy fin has been one of the enhanced fins widely used in recent years due to its good heat transfer and pressure drop performances as well as its resistance to dust adherence and blockage, especially under a severe operating environment. The multi-louvered fins might have showed a better performance when new in application; however, the dust adherence and air blockage would result in a decrease in heat transfer performance over time. For this reason the wavy fin is especially welcome in off-road vehicles such as agricultural vehicles, loading machines, excavators, and engineering machinery.

For various reasons, however, the published literature about these heat transfer and pressure drop performance characteristics has been very limited. Most researchers used CFD technology to investigate the flow pattern and heat transfer mechanism, or to study the geometry parameters effect on the thermal hydraulic performance. Asako and Faghri [4] numerically investigated two-dimensional steady laminar flow with $Re = 100$–1000, and heat transfer in plate channels with triangular profile wall corrugations that were maintained at a uniform temperature. Zhang et al. [5] numerically investigated the effects of wall-corrugation aspect ratios and fin space ratios on the vortex structure and enhanced heat transfer for low rate with $Re = 100$–1000. Likewise, Metwally and Manglik [6] have investigated two-dimensional periodically developed laminar flow and heat transfer in sinusoidal wavy channel with different corrugation aspect ratios. More complex three-dimensional, cross-corrugated fin has also been

* Corresponding author.
E-mail address: dongjunqi2008@163.com (J. Dong).

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computationally modeled in a few recent studies [7,8]. Dong and Chen [9] have investigated the air flow and enhanced mechanism using the field synergy principle.

In 2007, Dong and Chen [10] had studied the heat transfer and pressure drop correlations for the wavy fin type heat exchangers and developed the experiment correlation equation. The study was limited to one fin geometry due to fin tooling restriction. It was showed that the wavy fin amplitude and wavy length have a very big effect on the overall thermal hydraulic performance [9].

In this paper, 16 heat exchanger samples were tested and studied. We made 4 types of different fin tooling according to DOE (Design of Experiment) methods to include different fin geometry parameters: the fin length, fin height, fin pitch, fin wavy amplitude, and fin wavy length. The performance tests for these samples were carried out in our wind tunnel test rigs. The experimental correlation equations of the heat transfer and pressure drop performance were developed using the multiple regression analysis methods. The results of Taguchi parametric study was also presented for the different fin geometry parameters.

Using the effective-NTU methods, the heat transfer coefficients are developed with a range of air velocities according to the thermal resistance division principle, which keeps the heat transfer coefficient of the water side constant.

All the test data were reduced using dimensionless parameters, namely, the *Nu* and *f* factors. Using the nonlinear multiple regression methods, the experiment correlation equations of the heat transfer and pressure drop were developed. The correlation equations were further checked by each parameter's significances. The comparison of the test data and the predicted data showed that the correlation errors were limited within 15% for the 95% test data.

The signal-to-noise (SN) ratio used in the analysis of the Taguchi method was measured for the overall enhanced heat transfer performance with different geometry parameters as target. The results of SN ratio showed that among the 5 fin parameters studied, the wavy fin amplitude and wavelength had the most important influence on heat transfer and pressure drop performance for a wavy-fin type heat exchanger.

These correlation equations have been used in our heat exchanger performance simulation models and have become a useful engineering tool to estimate the thermal hydraulic performance of the wavy fin heat exchanger during the initial design phase.

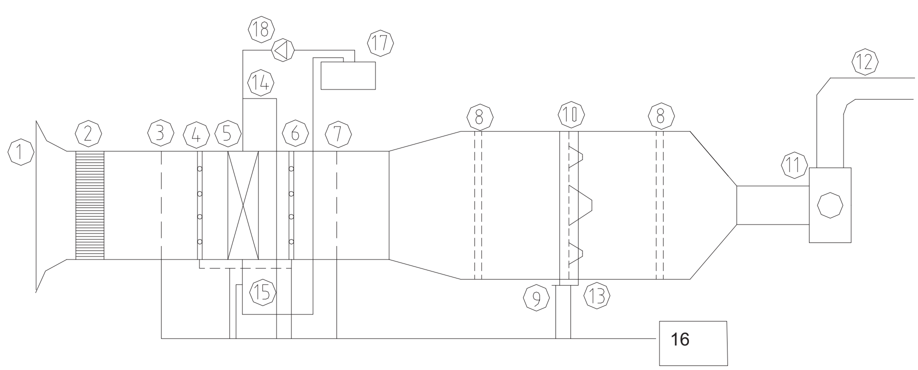
2. Experimental

2.1. Test apparatus

Fig. 1 shows a schematic diagram of the wind tunnel apparatus in the study. Air and hot water are used as working fluids. The main components of the systems are the heat exchanger test sample, water flow loop, air supply, instrumentations and data acquisition systems. The wind tunnel system is designed to suck the conditioned room air over the fin side of the heat exchanger test sample by a 15 kW centrifugal fan. The speed of the fan is adjusted by a variable frequency drive.

The inlet and exit temperatures across the air side of the heat exchanger test sample were measured by two T-type thermocouple meshes. The inlet measuring mesh consisted of eight thermocouples while the exit mesh contained sixteen thermocouples due to higher non-uniformity of the exit air temperature. The arithmetic mean value of the 16 exit thermocouples was computed for the exit air temperature. All pre-calibrated thermocouples had an accuracy of 0.1 °C and their measuring positions were per ASHRAE standard. These data signals were individually recorded and then computed. The air pressure drop across the heat exchanger test sample and the nozzles were, respectively, measured by precision differential pressure transducers, whose accuracy were 0.4% and 0.25%. The air flow measuring station was a multiple nozzle code tester per ISO 5167 standard.

The hot water flow loop consisted of a storage tank, a 100 kW electric heater, a centrifugal pump, a control unit and a flow meter. The purpose of this loop was to provide the heat source for the heat exchanger test sample. The temperature of the hot water in the water storage tank was measured by pre-calibrated RTDs (Pt-100Ω) and was controlled by the temperature controller. Its accuracy was within 0.1 °C. After heating the water to the required temperature,



1、air inlet
2、honeycomb straightener
3、T/C inlet temperature measuring station
4、pressure tap(inlet)
5、test unit
6、pressure tap (outlet)
7、T/C outlet temperature measuring station
8、setting means
9、static pressure tap
10、multiple nozzle plate
11、variable exhaust fan system
12、air outlet
13、difference pressure tap nozzle
14、inlet temperature tap water
15、outlet temperature tap water
16、data acquisition system
17、hot water tank
18、water pump

Fig. 1. Schematic diagram of the wind tunnel test apparatus.