CFD Analysis of Fin And Tube Intercooler With Different Fin Models

Shaik. Khaleel Pasha[1], Vallapureddy. Siva Nagi Reddy[2]. Abdul Arif [3]
[1]Research Scholar.
[2,3]Asst Professor, Dept. of Mechanical Engineering.
[1,2,3] Aditya College Of Engineering & Technology Surampalem, East Godavari, Andhra Pradesh.

Abstract- *There is always a need to improve automobile thermal management system to attain maximum efficiency driven by the trend that the automobile power train system operates towards higher power output with smaller system size. The intensified heat dissipation due to the system needs more efficient cooling solutions. In automobiles for cooling internal combustion engines, the intercooler transfers the heat from the fluid inside to the air outside, thereby cooling the fluid, which in turn cools the engine. Traditionally forced convection heat transfer is performed to cool circulating fluid which consists of water or a mixture of water and air. The project deals with the CFD Analysis of Heat transfer air flow in a fin and tube intercooler. The intercooler is air/air type and is used for the four stroke compression ignition engine. The Solid works software is used for modelling of the 3D space geometrical model of the intercooler. The pre-processor Mesh generator is used for the creating of the needed computational mesh and the Flow simulation - CFD (Computational Fluid Dynamics) software is then used for the simulation itself and the post processing. The Turbocharger inlet to the intercooler and the outlet to engine interface can be modified. The concept here is to reduce the temperature of the air by obtaining maximum heat transfer. For this we are optimizing the design of waved fin structure in the intercooler to Sine wave, Rectangular, Triangular, Semi triangular wave fins along with three different materials like aluminium 6061, copper and brass respectively. To determine the heat transfer coefficient of the individual fin model, commercial CFD packages are obtained to determining the contours of pressure, velocity and temperature with heat transfer rate after obtaining the contours the analysis is then compared with all four combinations of fin models to conclude which fin gives the maximum heat transfer rate.*

Keywords- Solid works, CFD, Different wave fins, Intercooler, Flow simulation.

I. INTRODUCTION

An intercooler is any mechanical device used to cool a fluid, including liquids or gases, between stages of a multi-stage compression process, typically a heat exchanger that removes waste heat in a gas compressor. They are used in many applications, including air compressors, air conditioners, refrigerators, and gas turbines, and are widely known in automotive use as an air-to-air or air-to-liquid cooler for forced induction (turbocharged or supercharged) internal combustion engines to improve their volumetric efficiency by increasing intake air charge density through nearly isobaric(constant pressure) cooling.

1(a) INTERNAL COMBUSTION ENGINES

Intercoolers increase the efficiency of the induction system by reducing induction air heat created by the supercharger or turbocharger and promoting more through combustion. This removes the heat of compression (i.e., the temperature rise) that occurs in any gas when its pressure is raised or its unit mass per unit volume (density) is increased.

A decrease in intake air charge temperature sustains use of a denser intake charge into the engine, as a result of forced induction. The lowering of the intake charge air temperature also eliminates the danger of pre-detonation (knocking) of the fuel/air charge prior to time spark ignition. This preserves the benefits of more fuel/air burn per engine cycle, increasing the output of the engine.

Intercoolers also eliminate the need for using the wasteful method of lowering intake charge temperature by the injection of excess fuel into the cylinders' air induction chambers, to cool the intake air charge, prior to its flowing into the cylinders. This wasteful practice (before intercoolers were used) nearly eliminated the gain in engine efficiency from forced induction, but was necessitated by the greater need to prevent at all costs the engine damage that pre-detonation engine knocking causes. The inter prefix in the device name originates from historic compressor designs. In the past, aircraft engines were built with charge air coolers that were installed between multiple stages of forced induction,[citation needed] thus the designation of inter. Modern automobile designs are technically designated aftercoolers because of their placement at the end of the supercharging chain.

This term is now considered archaic in modern automobile terminology, since most forced-induction vehicles have single-stage superchargers or turbochargers, although "aftercooler" is still in common use in the piston-engine aircraft industry. In a vehicle fitted with two-stage turbocharging, it is possible to have both an intercooler (between the two turbocharger units) and an aftercooler (between the second-stage turbo and the engine). The JCB Dieselmax land speed record-holding car is an example of such a system. In general, an intercooler or aftercooler is said to be a charge-air cooler.

Intercoolers can vary dramatically in size, shape and design, depending on the performance and space requirements of the entire supercharger system. Common spatial designs are front mounted intercoolers (FMIC), top mounted intercoolers (TMIC) and hybrid mount intercoolers (HMIC). Each type can be cooled with an air-to-air system, air-to-liquid system, or a combination of both.

II. LITERATURE REVIEW

Yang et al. [1, 2] simulated numerically the flow and temperature fields of air-cooled condenser under different apex angles of tube bundles, different inlet temperatures and velocities of air flow, as well as various natural wind conditions. The results showed that apex angles of ACC affected the flow and heat transfer characteristics obviously. They also proposed several methods to overcome the adverse impact of natural wind on air-cooled condensers.

Zhang et al. [3] further studied the fin distance and height, and found that there existed the optimal fin space in which the convection heat transfer was the most powerful for each inlet air flow velocity. The surface heat transfer coefficients decreased with the increase of fin height. The above studies focused on the continuous wave finned flat tube, which was popularly applied in the air-cooled power generating units. However, due to the long length of the continuous wave fins along long axis of flat tube, the development of flow and thermal boundary layer can suppress the air-side heat transfer enhancement to a great extent.

The previous study has shown that there existed a direct relationship between the temperature field and velocity field in convective heat transfer, and their synergy has significant effect on heat transfer [4].

The purpose of heat transfer enhancement has been achieved extensively by applying the structures offset fin or serrated fin as the extended heat transfer surface in the fields such as aviation, vehicle and gas turbine, by increasing the disturbance of the near wall region [5–8].

Yuan et al. [9, 10] studied the flow and heat transfer performance of the intermittent flow channel with rectangular rib arrangement under various ranges of Reynolds number by numerical calculation. The results show that the heat transfer enhancement of air flow, namely Nu/Nu0, is larger than 5, and can reach to 10 at most in the periodically ribbed channel with the rib distance, c/a, varying in the range of 0.32–0.64 at Re =300–800 and the rib row distance, b/a=0.6.

Saad et al. [11] studied the effects arrangement and tip-to-shroud distance on flow and heat transfer characteristics of longitudinal rectangular-fin array. The empirical correlations were obtained for the variations of Nu with Re including various geometric parameters, such as fin height, thickness, spacing distance and tip-to-shroud distance.

Mutlu et al. [12] executed the experimental study on the heat transfer characteristics with a shrouded array of interrupted fins. They also studied the impact of crossflow on its performance. The results showed that the crossflow exerted a certain effect on both pressure drop and heat transfer.

Jiang [13] investigated the heat transfer and pressure drop characteristics of the tube fin with interrupted half annular grooves by using heat-mass transfer analogy. The experimental results showed that both the heat transfer and pressure drop coefficients of the heat exchanger surface increased greatly and the pressure drop increased even more as compared with the smooth tube fin heat exchanger surface.

In the fields of electronic cooling and air conditioning, researchers also explored the impact of the discontinuous short rib structures on the enhanced heat transfer [14–16].

Recently, several Chinese researchers proposed the concept of entropy dissipation, which was introduced into the design optimization of heat transfer exchanger [17]. Employing the configuration of discontinuous short fin, the development of flow and thermal boundary layer can be broken by the gaps between the fins, meanwhile, flowing vortex generated by the upstream fin increases the turbulence of the downstream fin [18, 19].

III. METHODOLOGY

POWERFUL AND INTUITIVE CFD SIMULATION FOR PRODUCT ENGINEERS:

Built to tackle CFD engineering challenges, SOLIDWORKS Flow Simulation enables engineers to take advantage of CAD integration, advanced geometry meshing capabilities, powerful solution convergence, and automatic flow regime determination without sacrificing ease of use or accuracy.

Product engineers and CFD experts alike, armed with the power of SOLIDWORKS Flow Simulation, can predict flow fields, mixing processes, and heat transfer, and directly determine pressure drop, comfort parameters, fluid forces, and fluid structure interaction during design.

SOLIDWORKS Flow Simulation enables true concurrent CFD, without the need for advanced CFD expertise.

SOLIDWORKS Flow Simulation software takes the complexity out of flow analysis and enables engineers to easily simulate fluid flow, heat transfer, and fluid forces so engineers can investigate the impact of a liquid or gas flow on product performance.

A typical product development cycle involves the following steps:

- Building your model.
- Building a prototype of the design.
- Testing the prototype in the field.
- Evaluating the results of the field tests.
- Modifying the design based on the field test results

This process continues until a satisfying result are reached. SOLIDWORKS Simulation can help you achieve the following tasks:

Instead of an expensive field test, simulate the model on the computer thereby reducing the cost and time

Reduce time to market by reducing the number of product development cycles

Improve products by quickly testing many scenarios and concepts before making a final decision, giving you more time to think of new designs

SOLIDWORKS Simulation will help you to Efficiently optimize and validate each design step using quick solving, CAD integrated SOLIDWORKS Simulation to ensure quality, performance and safety

3(b) ADVANTAGES OF USING SOLIDWORKS:

Examine complex flows through and around your components with parametric analysis

Align your model with flow conditions, such as pressure drop, to satisfy design goals Detect turbulences and recirculation issues with animated flow trajectories Understand the flow of non-Newtonian liquids, such as blood and liquid plastic

Assess the impact of different impellers and fans on your design Include sophisticated effects like porosity, cavitation, and humidity

SOLIDWORKS Simulation is a design analysis tool tightly integrated with SOLIDWORKS.

SOLIDWORKS Simulation provides simulation solutions for linear and nonlinear static, frequency, buckling, thermal, fatigue, pressure vessel, drop test, linear and nonlinear dynamic and optimization analysis.

Powered by quick and accurate solvers, SOLIDWORKS Simulation enables you to solve large complex problems parallel while you design.

3(c) REDUCES THE RISK OF OVERHEATING IN YOUR DESIGNS:

- Visualize and understand temperature distribution in and around your products
- Couple flow with thermal analysis, simulating convection, conduction, and radiation effects.
- Simulate advanced radiation with semi-transparent material and wavelength-dependent radiative properties with the HVAC module.
- Apply time- and coordinate-dependent boundary conditions and heat sources
- Find the best dimensions to satisfy your design goals, such as heat exchanger efficiency.
- Get thermal heat sources and PCB layer definition from EDA thermal properties.

IV. RESULTS

4(a) SINE WAVE FIN AND TUBE INTERCOOLER CONTOURS OF SIMULATED SINE WAVE FINS:

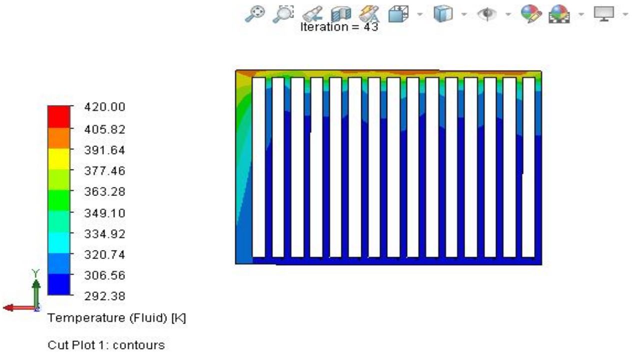


FIG 1 Contour of the Temperature of the Fluid with sine wave Fins

The above figure represents the temperature distribution of the fluid with sine wave fins in the picture we can observe that the red colour represents the maximum temperature and the blue colour represents minimum temperature.

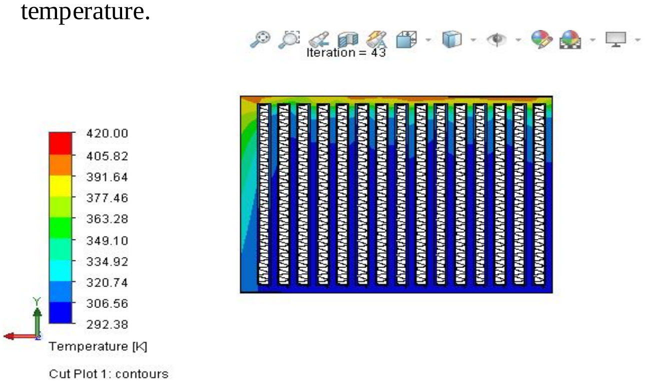


FIG 2: Contour of the overall Temperature of the Fluid & Solid with sine wave Fins

The above figure represent the temperature distribution of the fluid and solid with sine wave fins in the picture we can observe that the red colour represents the maximum overall temperature and the blue colour represents minimum overall temperature.

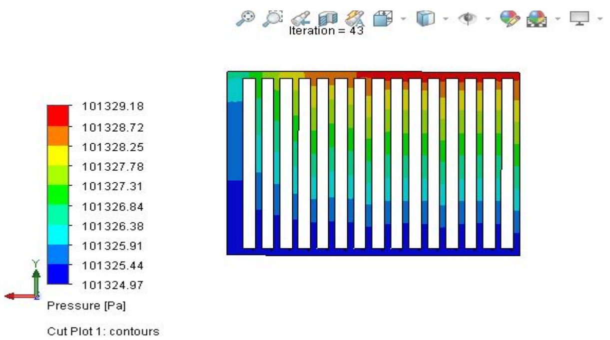


FIG 3: Contour of the Pressure of the Fluid with sine wave Fins

The above figure represents the pressure distribution of the fluid with sine wave wavy fins in the picture we can observe that the red colour represents the maximum pressure and the blue colour represents minimum pressure.

4(b) NEWTON'S LAW OF COOLING

According to Newton's law of cooling, the relation is

Heat transfer rate, $Q = h A (T_w - T_A)$

Where Q = Heat transfer rate, w

h = heat transfer coefficient, w/m^2-k

A = Area of the cross-section, m^2

T_W = Wall temperature, k

T_A = Air temperature, k

6.6. THEORETICAL CALCULATION:

Case1: Aluminium 6061 material is used for all fins and tube intercooler

1. From simulation of sine wave fin, the following parameters of a single sin wave fin are as follows:

Heat transfer rate, Q = 0.004 W

Area of the cross section of sine wave fin, A = 0.0014 m^2

Wall temperature, T_w = 442 K

Air temperature, T_A = 415 K

Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004}{0.0014(442-415)}$

h = 77.14 W/m^2-k

2. From simulation of rectangular fin, the following parameters of a single rectangular fin are as follows:

Heat transfer rate, Q = 0.004 W

Area of the cross section of sine wave fin, A = 0.0015 m^2

Wall temperature, T_w = 451 K

Air temperature, T_A = 428.39 K

Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004}{0.0015(451-428.39)}$

h = 60.29 W/m^2-k

3. From simulation of semi triangular fin, the following parameters of a single semi triangular fin are as follows:

Heat transfer rate, Q = 0.004 W

Area of the cross section of sine wave fin, A = 0.0016 m^2

Wall temperature, T_w = 445 K

Air temperature, T_A = 416.08 K

Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004}{0.0016(445-416.08)}$

h = 72.30 W/m^2-k

4. From simulation of triangular fin, the following parameters of a single triangular fin are as follows:

Heat transfer rate, Q = 0.004 W

Area of the cross section of sine wave fin, A = 0.0017 m^2

Wall temperature, T_w = 443.23 K

Air temperature, T_A = 438.73 K

Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004}{0.0017(443.23-438.73)}$

h = 10.58 W/m^2-k

Case2: Copper material is used for all fins and tube intercooler

1. From simulation of sine wave fin, the following parameters of a single sin wave fin are as follows:
Heat transfer rate, Q = 0.00428 W
Area of the cross section of sine wave fin, A = 0.0014 m^2
Wall temperature, T_w = 442.6 K
Air temperature, T_A = 414.51 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.00428}{0.0014(442.6 - 414.51)}$

h = 85.97 W/m²-k

2. From simulation of rectangular fin, the following parameters of a single rectangular fin are as follows:
Heat transfer rate, Q = 0.004182 W
Area of the cross section of sine wave fin, A = 0.0015 m^2
Wall temperature, T_w = 452 K
Air temperature, T_A = 426 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004182}{0.0015(452 - 426)}$

h = 72.48 W/m²-k

3. From simulation of semi triangular fin, the following parameters of a single semi triangular fin are as follows:
Heat transfer rate, Q = 0.00408 W
Area of the cross section of sine wave fin, A = 0.0016 m^2
Wall temperature, T_w = 447 K
Air temperature, T_A = 418 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.00408}{0.0016(447 - 418)}$

h = 74.05 W/m²-k

4. From simulation of triangular fin, the following parameters of a single triangular fin are as follows:
Heat transfer rate, Q = 0.00401 W
Area of the cross section of sine wave fin, A = 0.0017 m^2
Wall temperature, T_w = 444.72 K
Air temperature, T_A = 426.8 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.00401}{0.0017(444.72 - 426.8)}$

h = 11.25 W/m²-k

Case3: Brass material is used for all fins and tube intercooler

1. From simulation of sine wave fin, the following parameters of a single sin wave fin are as follows:
Heat transfer rate, Q = 0.00428W
Area of the cross section of sine wave fin, A = 0.0014 m^2
Wall temperature, T_w = 441.71 K
Air temperature, T_A = 414.52 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.00416}{0.0014(441.71 - 414.52)}$

h = 80.804 W/m²-k

2. From simulation of rectangular fin, the following parameters of a single rectangular fin are as follows:

Heat transfer rate, Q = 0.004089 W
Area of the cross section of sine wave fin, A = 0.0015 m^2
Wall temperature, T_w = 455 K
Air temperature, T_A = 430 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004089}{0.0015(455 - 430)}$

h = 67.67 W/m²-k

3. From simulation of semi triangular fin, the following parameters of a single semi triangular fin are as follows:
Heat transfer rate, Q = 0.004035 W
Area of the cross section of sine wave fin, A = 0.0016 m^2
Wall temperature, T_w = 444 K
Air temperature, T_A = 415 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.004035}{0.0016(444 - 415)}$

h = 71.34 W/m²-k

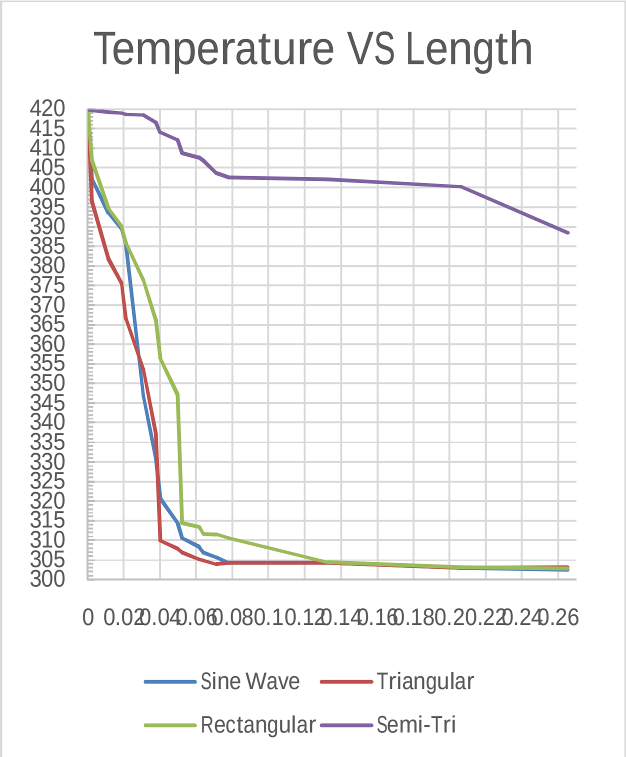
4. From simulation of triangular fin, the following parameters of a single triangular fin are as follows:
Heat transfer rate, Q = 0.00401 W
Area of the cross section of sine wave fin, A = 0.0017 m^2
Wall temperature, T_w = 446.12 K
Air temperature, T_A = 430.78 K
Heat transfer coefficient, $h = \frac{Q}{A(T_W - T_A)} = \frac{0.00401}{0.0017(446.12 - 430.78)}$

h = 10.90 W/m²-k

V. CONCLUSION

The graph shows the conducted simulation of the intercooler bed with different fin geometries are successfully done and from the results obtained from simulation is sine wave performs much heat transfer rate than the other type of fin geometries.

Because of the wavy nature of the fins and smooth edges that is intersecting the surfaces of the flow section. The maximum amount of heat conducting from the flow domain solid is directly transferred to the fin surface which gives more efficient heat transfer than the usual fins. The current simulation is done for the different fin geometries of the fins to investigate the maximum heat transfer coefficient is found in Sine wave. From all the values, sine wave fins is giving the best heat transfer coefficient as well as best heat transfer rate.



Graph 1: Temperature vs Length with all fin geometries

REFERENCES

[1] Yang L J, Du X Z, Yang Y P. Measures against the adverse impact of natural wind on air-cooled condensers in power plant. Sci China Tech Sci, 2010, 53(5): 1320–1327

[2] Yang L J, Zhou J, Du X Z, et al. Numerical analysis of flow and heat transfer outside the flat wave-finned tube (in Chinese). J Eng Thermophys, 2007, 24(1): 122–124

[3] Zhang K F, Yang L J, Du X Z, et al. Flow and heat transfer characteristics of cooling air outside the flat wave-finned tube banks of aircooled condensers (in Chinese). Proc Chinese Soc Elec Eng, 2008, 28(26): 24–28

[4] Guo Z Y, Li Z X, Zhou S Q, et al. Principle of uniformity of temperature difference field in heat exchanger. Sci China Ser E-Tech Sci, 1996, 39(1): 68–75

[5] DeJong N C, Zhang L W, Jacobi A M, et al. A complementary experimental and numerical study of the flow and heat transfer in offset strip-fin heat exchangers. J Heat Trans, 1998, 120(3): 690–698

[6] Burton R L, Jacobi A M, Michna G J. An experimental study of the friction factor and mass transfer performance of an offset-Strip fin array at very high Reynolds numbers. J Heat Trans, 2007, 129(9): 1134–1140

[7] Eckert E G, Goldstein R J, Patankar S V, et al. Heat transfer—A review of 1981 literature. Int J Heat Mass Trans, 1982, 25(12): 1783–812

[8] Liu W, Liu Z C, Wang Y S, et al. Flow mechanism and heat transfer enhancement in longitudinal-flow tube bundle of shell-and-tube heat exchanger. Sci China Ser E-Tech Sci, 2009, 52(10): 2952–2959

[9] Yuan Z X, Wang Q W, Ma C F, et al. Numerical simulation on the heat transfer and fluid flow in the parallel-flate channels with longitudinal fin arrays (in Chinese). J Eng Thermophys, 1998, 19(6): 720–723

[10] Yuan Z X. Prediction of 3-D turbulent flow and heat transfer in a channel with longitudinal periodical rectangular fins (in Chinese). J Beijing Polytech Univ, 1999, 25(2): 1–6

[11] Saad A E, Shamloul M M, Ahmed M A, et al. Investigation of turbulent heat transfer and fluid flow in longitudinal rectangular-fin arrays of different geometries and shrouded fin array. Exp Therm Fluid Sci, 2002, 26(8): 879–900

[12] Mutlu I, Al-Shemmeri T T. The effect of crossflow on heat transfer augmentation with interrupted longitudinal fins. Exp Therm Fluid Sci, 1994, 8(1): 91–100

[13] Jiang G D. Heat transfer and pressure drop of tube banks with interrupted half annular groove fin (in Chinese). J Chem Indus Eng, 2000, 51(5): 604–608

[14] Chang S W, Su L M, Yang T L, et al. Enhanced heat transfer of forced convective fin flow with transverse ribs. Int J Therm Sci, 2004, 43: 185–200

[15] Dogana M, Sivrioglub M. Experimental investigation of mixed convection heat transfer from longitudinal fins in a horizontal rectangular channel. Int J Heat Mass Trans, 2010, 53(9–10): 2149–2158

[16] Tang J C, Ma C C, Su X C, et al. Comparison convective heat transfer effect study on intermittent and flate fins of air cooling coil in air conditioning engineering. Energy Technol, 2010, 31(5): 259–262

[17] Guo J F, Xu M T, Cheng L. Principle of equipartition of entranspy dissipation for heat exchanger design. Sci China Tech Sci, 2010, 53: 1309–1314

[18] GU W Z, et al. Enhancement Heat Transfer (in Chinese). Beijing: Science Press, 1990. 445–451

[19] Wang S P, Chen Q L, Zhang B J, et al. A general theoretical principle for single-phase convection heat transfer enhancement. Sci China Ser E-Tech Sci, 2009, 52(12): 3521–3526