NUMERICAL INVESTIGATION AND DESIGNING OF A MOLTEN SALT TO AIR HEAT EXCHANGER BY VARYING INTERNAL AND EXTERNAL PARAMETERS

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Abstract - *A serpentine coil cross flow Heat Energy with molten salt on hot fluid side and atmospheric air on the cold fluid side has been fabricated to study and improve the thermal efficiency. The boundary conditions like temperature, pressure is optimized in order to improve the effectiveness of the shell and tube heat exchanger. Multi-objective whale optimization technique is used to increase the pressure and temperature parameters, resulting in optimization. In multi-objective whale optimization, the factors like thickness of the plate, distance between each plate, lateral distances, longitudinal distances are changed for optimizing the sensitivity. The amount of heat transferred and deuteration of pressure are the main objective which are done by multi-objective whale optimization. The design parameter which gives out maximum efficiency is considered for proposal. This design parameters are used for designing of salt-to-air heat exchanger.*

Key Words: **Heat exchanger, MOWO - Multi-objective whale optimization.**

1. INTRODUCTION

Heat exchangers are widely used in transportation of power, Refrigeration and Air conditioning, heat transmission process, alternate fuels and most commonly in the manufacturing and production sector. They are utilized as parts of cooling and cooling frameworks or of warming frameworks. Numerous modern procedures require a specific level of warmth to work; notwithstanding, ordinarily incredible consideration must be taken to shield these procedures from getting excessively hot. Inside modern plants and manufacturing plants heat exchangers are required to keep hardware, synthetic compounds, water, gas, and different substances inside a safe working temperature. Warmth exchangers may likewise be utilized to catch and move steam or warmth exhaust that is discharged as a side-effect of a procedure or activity with the goal that the steam or warmth can be put to all the more likely use somewhere else, consequently expanding proficiency and setting aside the plant cash. Various kinds of warmth exchangers work in various manners, utilize distinctive stream courses of action, gear, and configuration highlights. One thing that all warmth exchangers share for all intents and purpose is that they all capacity to straightforwardly or by implication uncover a hotter medium to a cooler medium, subsequently, trading heat. This is typically practiced by utilizing a lot of cylinders housed inside some sort of packaging. Warmth exchanger fans, condensers, belts, coolants, extra cylinders and lines, alongside different parts and hardware work to build warming and cooling effectiveness or improve stream.

Molten salt-to-air heat exchanger was initially developed by Oak Range National Laboratory (ORNL) as effective heat sinks to cool high temperature molten salt through radiator coils in MSRE, while it was discovered that the heat removal capability of the air-cooled heat exchanger did not meet the expec tation, and the most likely reason for this was that the basic heat transfer correlations and the heat transfer film coefficients of mol- ten salt were not applicable to design the specific structure of mol- ten salt-to-air heat exchanger. The molten salt systems discussed herein use alloys, such as Hastelloy N and 242, that show good corrosion resistance in molten salt at nominal operating temperatures of up to 700°C. These alloys were diffusion welded, and the corresponding information is presented. Test specimens were prepared for exposing diffusion welds to molten salt environments. So as to tentatively approving of the warm estimating structure and deliberately exploring the general execution of liquid salt-to-air heat exchanger, another serpentine loop type heat exchanger is planned utilizing an intricate independent program with uncommonly chosen heat move connections in this paper. From that point forward, tests are directed to affirm the plan parameters and to assess the warmth move execution of the warmth exchanger. The warmth moves salt KNO3-NaNO2-NaNO3 (53-40-7 mol%, HTS) is utilized as the warmth move medium streaming pass the cylinder side. The key parameters of the warmth exchanger are acquired from tests and contrasted and values from calculations of the structure code. Plus, the warmth move exhibitions of the warmth exchanger are tentatively contemplated and results are talked about. It is inferred that the independent program examination and observational relationships for warm measuring structure of liquid salt-to-air heat exchanger can be approved by the test information. Results from this investigation will give helpful direction to the structure of liquid salt-to-air heat exchanger in liquid salt related propelled power frameworks.

2. Molten air and salt heat exchanger design

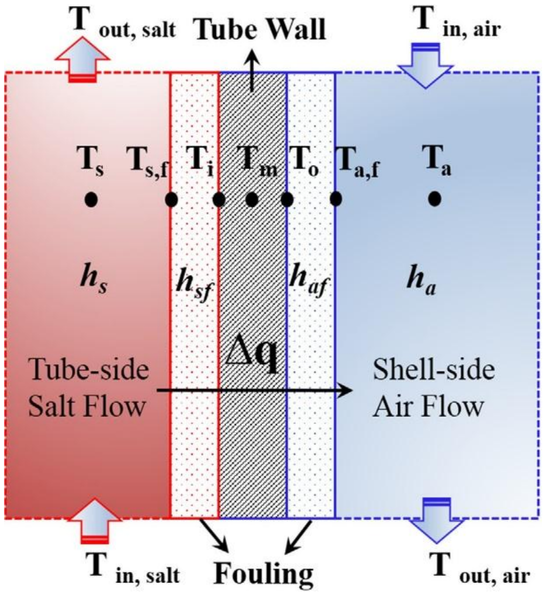
2.1 Theoretical calculation of molten salt-to-air heat exchanger

For the liquid salt-to-air heat exchanger, the warmth move professional cylinder divider can be streamlined to a schematic graph of the vitality balance at a control volume as appeared in Fig. 1. Vitality conditions for liquid salt, air and generally speaking warmth move can be composed as,

$$K = \left[\frac{d_o}{d_i}\frac{1}{h_s} + \frac{d_o}{d_i}\frac{1}{h_{sf}} + \frac{d_o}{2k}\ln\left(\frac{d_o}{d_i}\right) + \frac{1}{h_{af}} + \frac{1}{h_a}\right]^{-1}$$

$$T_i = T_s - q_s\left(\frac{1}{h} + \frac{1}{h_{sf}}\right)$$

$$T_o = T_s - q_a\left(\frac{1}{h} + \frac{1}{h_{af}}\right)$$



$$Nu = 0.012\left(Re^{0.87} - 280\right)Pr^{0.4}\left[1 + (d/L)^{2/3}\right](Pr_f/Pr_w)^{0.11}$$

$$2300 < Re < 10^6;\ 0.6 < Pr < 10^5$$

$$Nu = 1.04 Re^{0.4} Pr^{0.36} (Pr_f/Pr_w)^{0.25}$$

$$(1 < Re < 500)$$

$$Nu = 0.71 Re^{0.5} Pr^{0.36} (Pr_f/Pr_w)^{0.25}$$

$$(500 < Re < 1000)$$

2.2. Design of liquid salt-to-air heat exchanger

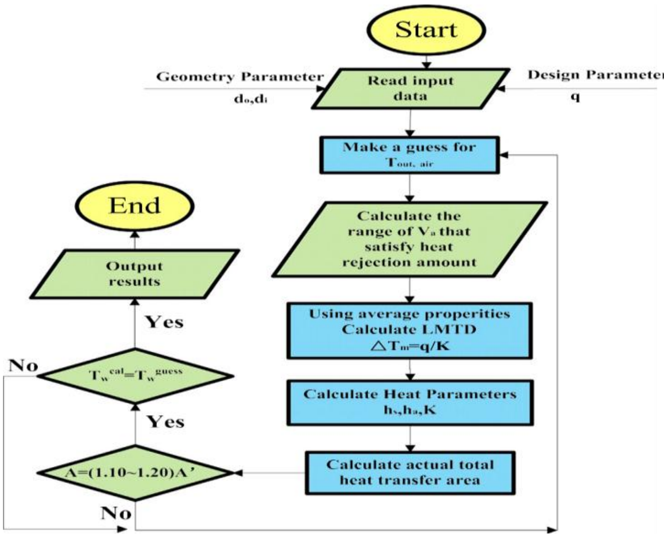
As a particular segment in liquid salt circle, liquid salt-to-air heat exchanger has some various qualities contrasted and the general low temperature heat exchangers because of high temperatures and liquefying purposes of liquid salts, and the normally utilized warmth exchanger configuration programs can't portray these exchangers precisely. Along these lines, for the liquid salt-to-air heat exchanger, independent plan programs are wanted to meet the structure criteria and fashioner's necessities. To decide warm parameters of liquid salt-to-air heat exchanger, an independent MATLAB content is created and calculations are performed. Fig. 2 shows the schematic of scientific model of warmth exchanger. From the start, the plan parameters (temperature of surrounding air and warmth move limit) and geometry parameters (heat exchanger tallness and channel measurement) as indicated by requirements are imported as info factors. At that point, air outlet gum-based paint true and speeds are determined by applying mass protection. From that point forward, utilizing related bottle physical properties, logarithmic mean temperature contrast DTm, generally speaking warmth move coefficient and complete warmth move region can be determined. In the event that the real territory equivalents to determined worth, the outlet temperature is doable, if not, the outlet temperature of air ought to be changed and past advances ought to be rehashed. At last, the structure of the serpentine loop liquid salt-to-air heat exchanger is resolved.

2.3. The planned liquid salt-to-air heat exchanger

In the trial, the liquid salt-to-air heat changer is chiefly used to keep up the warm parity of the liquid salt test circle with ostensible in general warmth move limit of 30 kW. Because of numerous points of interest, for example, no wellbeing issues brought about by absurd stream conveyance of liquid salt in tube pack, straightforward structure and simple development, just as accessible activity encounters in different offices (Toda et al., 2002), another one warmth move tube serpentine curl air-cooler is planned. The Nominal volume stream pace of liquid salt is 1.2 $m^3 h^{-1}$ and the ostensible bay and outlet temperature of liquid salt are 400 °C and 370 °C separately.

The ostensible volume stream pace of air over the cylinders is 5000 $m^3 h^{-1}$ with normal delta temperature of 32.4°C at climatic pressure. Subtleties of the plan parameters are appeared in Table 1. cylinder side is made out of just one looped tube with 52 curves and 53 straight areas, every one of these segments are then equally isolated into 3 lines with a state of ''Z". The absolute length, external width, thickness and material of the cylinder are 80 m, 0.02 m, 0.002 m and Inconel-600 individually.

The warmth exchanger gets together is housed in a protected shell associated with air ducting through the structure of the celestial circle and the evenness of the earth. Air is provided by a divergent blower which enters from the base and leaves from the highest point of exchanger. The conduit framework consolidates protected dampers at the gulf and outlet of the warmth exchanger to permit heat-up before filling Since the liquefying purpose of the liquid salt is 142 °C which is well above room temperature, electrical radiators, comprised of 15 numbers ''U" formed warming components of 0.67 kW singular warming limit are set up situating inside air ducting to preheat the heat exchanger before filling liquid salt to stay away from liquid salt freezing



3. Experimental system and facility

3.1 The Experimental system

The exploratory framework for the most part contains liquid salt stockpiling tank, radiator, siphon, liquid salt-to-air heat exchanger and estimations framework. The capacity tank is intended to allow long haul stockpiling and freezing of liquid salt. When beginning a run, the dissolved salt in the capacity tank is moved by a liquid salt siphon, which can convey a liquid salt progression of 6 $m^3 h^{-1}$ against a head of 0.05 MPa pressure, through electric-radiator with 120 kW limit and into the siphon sump tank at that point brought into the circle during activity. The planned cooler evacuates heat stacked by the warmer to guarantee warm balance of the circle framework. The Volumetric limit of air blower is 5000 $m^3 h^{-1}$ at encompassing conditions. Circle instrumentation incorporates salt stream rate, siphon release pressure, siphon tank level, and temperature estimations of circle funnels and segments. In addition, the warming intensity of electrical radiators used to preheat serpentine loop just as air temperature and stream rate over the warmth exchanger are estimated.

3.2 Experiments and data analysis

The exploratory structure generally contains fluid salt storing tank, radiator, siphon, fluid salt-to-air heat exchanger and estimations system. The limit tank is proposed to permit long stretch accumulating and freezing of fluid salt. When starting a run, the broke down salt in the limit tank is moved by a fluid salt siphon, which can pass on a fluid salt movement of 6 $m^3 h^{-1}$ against a head of 0.05 MPa pressure, through electric-radiator with 120 kW limit and into the siphon sump tank by then brought into the hover during action. The arranged cooler empties heat stacked by the hotter to ensure warm bal-ance of the circle system. The Volumetric furthest reaches of air blower is 5000 $m^3 h^{-}$

^{1} at incorporating conditions. Circle instrumentation fuses salt stream rate, siphon discharge pressure, siphon tank level, and tem-perature estimations of circle pipes and fragments. What's more, the warming power of electrical radiators used to preheat serpentine circle similarly as air temperature and stream rate over the glow exchanger are evaluated.

Table 1
Design limits of molten salt-to-air heat exchanger.

Design limits	Values	Units
Power rating	25	kW
Tube OD/ID	18/15	mm
Tube material	Inconel-600	-
Number of tubes	1	-
Tube inclined angle	7	degree
Length of tube	85	m
Molten salt inlet/outlet temperature	450/375	°C
Molten salt flow rate	1.5	$m^3 h^{-1}$
Air inlet/outlet temperature	32.4/160	°C
Air flow rate	4800	$m^3 h^{-1}$

Liquid salt course through the warmth exchanger is estimated by ultrasonic wave stream meter with estimating scope of 0–6 m^3 h^{-1} and assessed alignment precision of ±1.7%. The bay and outlet temperatures of the liquid salt are estimated utilizing PT100 thermocouples with exactness of 0.5 K and vulnerability of 1.0%. The inlet and outlet temperature of air are estimated by K type thermocouples with exactness of 1.2 K. Wind current through the warmth exchanger is estimated by a Coriolis stream meter introduced noticeable all-around pull channel of the blower with vulnerability of 0.15%. It is assessed that the greatest vulnerability of warmth move rate determined by the deliberate parameters from liquid salt side is 2.4%, while the most extreme vulnerability of warmth move rate determined by the deliberate parameters from air side is 3.7%.

For the warmth move of liquid salt-to-air heat exchanger, because of the exceptionally low warm conductivity of air contrasted with liquid salt, the warmth move obstruction offered by the convective warmth move of air streaming over the outside smooth cylinder is incredibly higher contrasted with liquid salt inside the cylinder [6]. In this manner, the general warmth move from liquid salt to the air is completely administered by the shell side warmth move coefficient. Eq. (5) improves to the fol-lowing structure:

$$\frac{1}{K} \sim \frac{1}{h_a} \qquad (12)$$

Based the measured temperatures and power, the overall con-vective heat transfer coefficient can be written as,

$$K = \frac{q}{DT_m} \qquad (13)$$

An equivalent Nusselt number that represents air-side Nusselt number can be derived as:

$$\ldots_{air} = \frac{a d_o}{k D T_m} \qquad (14)$$

The average Reynolds number of the air flow through the mol-ten salt-to-air heat exchanger can be expressed as:

$$Re_{air} = \frac{u_{max} d_o}{c} \qquad (15)$$

Fig. 3. Diagrams of designed serpentine coil molten salt-to-air heat exchanger.

Warmth move coefficients for the external cylinder, ho, can be calculated utilizing above isolated strategy as depicted. All the warm properties of liquid salt are determined from fitted bends (Chen et al., 2017) at working temperature.

4. Results and conversations

4.1. Experimental conditions and results

During the examinations, 12 arrangements of conditions including repetitions are led with liquid salt stream rate from 0.65 m^3 h^{-1} to 0.75 m^3 h^{-1}, liquid salt bay temperature from 250.0 °C to 400.0 °C, wind current rate from 0.09 kg s—1 to 0.25 kg s^{-1} and normal air gulf temperature of 32.4 °C. Since the liquid salt temperature underneath 200.0 °C isn't prudent because of the likelihood of neighborhood freezing in the individual cylinder, the activity of the framework is constrained up to a liquid salt channel temperature of 250.00 °C.

For the state of liquid salt bay temperature of 395.7 °C furthermore, stream pace of 0.75 m3 h—1, the ostensible limit of the warmth exchanger is 30.00 kW, while the deliberate liquid salt and air outlet temperature are 349.1 °C and 161.97 °C separately, and the deliberate force shipped is 29.42 kW from the liquid salt to air, where it evacuates 1.93% less force than its ostensible capacity. Further investigations are led at various liquid salt bay temperature till the chilly leg temperature lessens to nearly 200 °C. For the states of liquid salt progression of 0.76 m3 h—1, when the liquid salt channel temperature diminishes from 400 °C to 250 °C, the warmth misfortune through protection to the environmental factors will drop from 1.5 kW to 0.1 kW. Table 2 shows 4 common trial states of warmth move execution tests.

4.2. Validation of planning parameters

The outlet temperatures of liquid salt and air from the experiment information and determined qualities utilizing the independent code just as their deviations are appeared in Fig. 5. The outlet temperature of liquid salt from trial estimations are in close concurrent with the outcomes from figuring inside a most extreme deviation of 0.42%. Be that as it may, for the quality of shell-side, the deliberate qualities are generally steady with the determined qualities with deviations from 7.44% to 2.86% as the temperature increments. The fundamental explanation behind these deviations is that the outlet temperature estimation of air from thermocouple should be from the air convection heat move just, nonetheless, the situation of shell-side outlet thermocouple isn't adequately away from the air outlet, which would achieve heat pickup from the hot mol-ten salt cylinders by warm radiation, causing the deliberate qualities being similarly higher than the genuine air outlet temperature. At the point when the temperature expands, the warmth misfortune from within the warmth exchanger to the environmental factors will build, in the interim the stream pace of air increments likewise, making the commitments of warmth move to outlet thermocouples from air constrained convection moderately increment contrasted and warm radiation, along these lines the

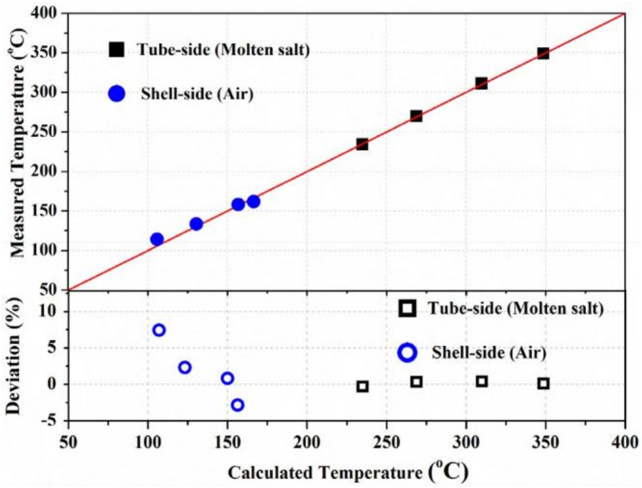


Fig. 5. Outlet temperatures of tube side (molten salt) and shell side (air) from experiments and calculations.

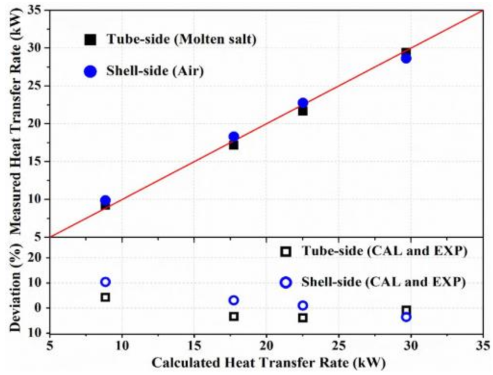


Fig. 6. Heat transfer rate for tube side and shell side from experiments and calculations.

Outlet temperature deviation of air among test and calculation will diminish.

The warmth move rate for tube-side and shell-side from the test information and determined qualities just as the deviations are appeared in Fig. 6. For the cylinder side, which is mostly brought about by the estimation vulnerability and warm properties deviations. Nonetheless, for the shell side, the deviation of warmth move rate from test information and figuring is about 10.38% at lower heat move rate and abatement to 3.57% at higher exchange rate. The principle explanation behind the difference in deviation is the expanding heat misfortune

Table 2
Details of typical experimental conditions and results from testing of molten salt-to-air heat exchanger.

Case	1	2	3	4
Tube side molten salt flow rate ($m^3 h^{-1}$)	0.80	0.75	0.74	0.644
Shell side air flow rate (kg/s)	0.25	0.19	0.18	0.22
Molten salt inlet temperature (°C)	400.7	344.8	296.9	265.3
Molten salt outlet temperature (°C)	349.1	311.2	300.2	234.2
Air outlet temperature (°C)	161.97	158.2	133.6	114.3
Tube side salt power (kW)	29.42	21.67	17.16	8.23
Shell side air power (kW)	28.65	22.76	18.31	9.88

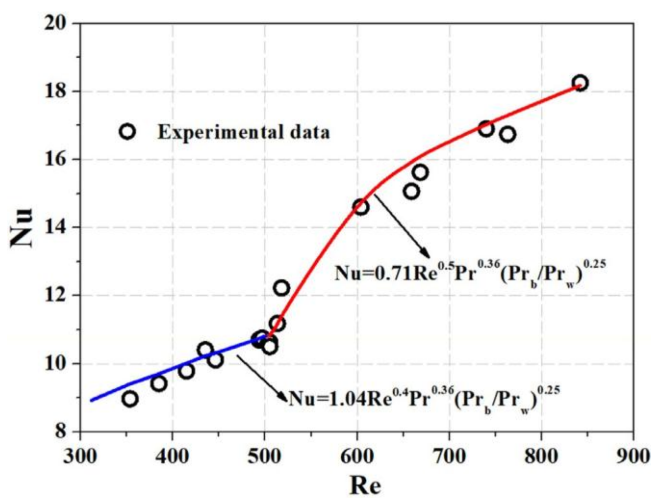


Fig. 7. Nusselt number with respect to Reynolds number of air outside the tube in molten salt-to-air heat exchanger.

Rate to the environmental factors as test temperature expands, the other is the outlet temperature estimation mistake of air as mentioned above and the resulting warm properties deviations. These reasons will likewise bring about the deviations of warmth move rate between tube side and shell side.

In light of the above investigations, in spite of the fact that there are some measurement blunders in the tests, the principle plan parameters of liquid salt-to-air heat exchanger from tests are essentially in accordance with the figurings from the independent structure code, there-fore, it tends to be presumed that the independent plan code is checked inside a sensible vulnerability run and appropriate for the plan of the liquid salt-to-air heat exchanger.

4.3. Heat exchange execution

For the warmth move of liquid salt inside smooth cylinder, arrangement of studies have been completed on the equivalent HTS circle utilizing liquid salt to oil exchanger (Chen et al., 2016, 2017). Results show that Gnielinski relationship which has been chosen in the present independent structure code had the option to portray the warmth move performance in the passable range, and subsequently appropriate for the plan of liquid salt-to-air heat exchanger.

The Nusselt number of air outside the cylinder as a component of the air Reynolds number from trial information for the liquid salt gulf temperature from 250.0 °C to 400.0 °C is plotted in Fig. 7. The Nusselt number of air outside cylinder amazingly increments as the air Reynolds number increments. For references, the experimental

Zhukauskas connections utilized in the plan code is plotted in the figure, obviously the exploratory information is near the experimental Zhukauskas relationships, which demonstrates that the Zhu-kauskas relationships can depict the warmth move performance of air outside the cylinder inside the suitable range. In this way, it is sensible to choose Zhukauskas connections in the independent structure code to foresee the air side warmth move of air-cooled heat exchanger of comparable sort.

5. Conclusions

In this investigation, another serpentine loop liquid salt-to-air heat exchanger with liquid salt on tube-side and air on shell-side is planned and arrangement of tests are performed for the code check and execution show. An independent plan program is created and used to structure the liquid salt-to-air heat exchanger. Warmth exchanger tests are performed with constrained circulation of liquid salt and air under structure and activity conditions. Results show that the outlet temperatures and warmth move rates for the cylinder side and shell-side got from test information and determined qualities are reliable inside the passable uncertainty go. Also, heat move execution of liquid salt on tube side and air on shell side are introduced and talked about, and the outcomes affirmed the ampleness of exact connections for plan of liquid salt-to-air heat exchanger. Subsequently, the independent program for the warm plan of air-cooled heat exchanger is approved by the test information. Results from current investigation will offer solid exploratory approved structure code, accessible relationships and supportive direction for the plan of enormous scope and handy liquid salt-to-air heat exchanger, and afterward give significant references in the planning of test gadget for the TMSR and other propelled power frameworks.

References

[1] Experimental and CFD analysis of turbulent flow heat transfer in tubular heat exchanger-Hesham G. Ibrahim

[2] R.K. Sinno Coulson & Richardson"s Chemical Engineering: Chemical Engineering Design (volume 6), Butterworth-Heinemann, 3rd. ed. 1999.

[3] D. Q. Kern, Process Heat Transfer, McGraw-Hill Book Company, Int. ed.1965.

[4] Optimization of micro heat exchanger: CFD, analytical approach and multi-objective evolutionary algorithms-Kwasi Folia, 1, ,Tatsuya Okabe, et.al.,

[5] Natural Convection Heat Transfer from Horizontal Rectangular Fin Arrays
F. Harahap; H. N. McManus

[6] Optimization of nusselt number in a helical coil heat exchanger with constant flux boundry conditions using FLUENT -Lalit Ranjan Nai

[7] Current progress and new developments in enhanced heat and mass transfer -Arthur E. Bergles

[8] Performance Improvement in Single phase Tubular Heat Exchanger using continuous Helical Baffles -Sunil S. Shinde, Samir S. Joshi, Dr. S. Pavithran

[9] A general simulation model for performance prediction of plate fin-and-tube heat exchanger with complex circuit configuration - W.K. Dinga, J.F. Fan, et.al.,

[10] Baffle space impact on the performance of helical baffle shell and tube heat exchangers-Farhad Nemati Taher, Sirous Zeyninejad Movassag

[11] Heat transfer enhancement in medium temperature thermal energy storage system using a multitube heat transfer array-Francis Agyenim, Philip Eames, et.al.,

[12] Experimental and numerical investigations of shell-side thermo-hydraulic performances for shell-and-tube heat exchanger with trefoil-hole baffles-Yonghua Youa, Aiwu Fan

[13] Heat transfer enhancement for thermal energy storage using metal foams embedded within phase change materials (PCMs) -C.Y. Zhao ,W. Lu,et.al.,

[14] Laminar periodic flow and heat transfer in square channel with 45 inline baffles on two opposite walls -Pongjet Promvonge*, Somchai Sripattanapipat, Sutapat Kwankaomeng

[15] An experimental study of enhanced heat transfer in rectangular PCM thermal storage- Uroš Stritih

[16] Heat transfer and pressure drop in a channel with multiple 60° V-baffle -Pongjet Promvonge

[17] Numerical study of forced convective heat transfer of Nanofluids: Comparison of different approaches R. Lotfia, b, Y. Saboohic, , , A.M. Rashidia

[18] Experimental investigation on heat transfer enhancement of a heat exchanger with helical baffles through blockage of triangle leakage Zones -Simin Wang a, Jian Wen b, *, et.al.,

[19] Numerical investigation into the convective heat transfer of TiO2nanofluids flowing through a straight tube under the laminar flow conditions- Yurong Hea, , , Yubin Mena, et.al.,

[20] Effects of baffle inclination angle on flow and heat transfer of a heat exchanger with helical baffles -Yong-Gang Lei, Ya-Ling He*, et.al.,

[21] Numerical determination and treatment of convective heat transfer coefficient in the coupled building energy and CFD simulation- Flavio C.C. Galeazzoa, Raquel Y. Miurab,Jorge A.W. Gutc, Carmen C. Tadinic

[22] Numerical determination and treatment of convective heat transfer coefficient in the coupled building energy and CFD simulation - Z Zhai, QY Chen