MAT JOURNALS
Journal of Modern Thermodynamics in Mechanical System
Volume 1Issue 1

# Latest Trends in Novel Applications of Various Heat Exchangers for Enhancement of Heat Transfer

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***DOI:*** *http://doi.org/10.5281/zenodo.3337408*

## *Abstract*

*A heat exchanger is equipment used for transfer of heat from one medium to other medium. Heat exchangers are fundamental parts in many process industries (such as power plants or the chemical and the food industries), and as heat recovery units in the operation of many systems (such as domestic hot water production, space heating or car engines).In a compact structure of cryogenic and other industrial applications for enhancement of heat transfer, coil heat exchangers are generally used. Currently, increase in efficiency of heat exchanger and heat transfer rate of heat exchanger, lots of researchers are working on it.*

***Keywords:*** *Geothermal heat pump, heat exchanger, heat transfer, printed circuit heat exchanger.*

## INTRODUCTION

Generally, heat exchangers are utilized at different temperature, for flow of thermal energy between more than two fluids. For various engineering applications like air conditioning, refrigeration, excess heat recovery, space technology and electricity generation manufacturing industry heat exchangers are used. Heat exchangers are used in a wide variety of engineering applications like power generation, waste heat recovery, manufacturing industry, air-conditioning, refrigeration, space applications, petrochemical industries etc. for heat transfer between two process streams mostly heat exchangers are used. Heat exchanger can be used for cooling, heating, condensation, boiling or evaporation purpose. They are named according to their application e.g. heat exchanger being used for cooling are called as condensers and similarly heat exchangers used for boiling are known as boilers. The performance and efficiency can be measured through the amount of heat transfer using least area of heat transfer and pressure drop. We can predict economical parameter like cost and power requirement by knowing an amount or rate of heat transfer of the heat exchanger.

### Classification

There are various classifications according to the operating principle, arrangement of flow path and as per design and certain constructional features. As per nature of heat exchange process, it is classified into three types like direct contact or open heat exchanger, regenerators and recuperates. As per relative direction of motion of fluid, it is classified into parallel flow, counter flow and cross flow heat exchanger. As per mechanical design of heat exchange surface, it is classified to concentric tube, shell and tube and multiple shell and tube passes. As per physical state of heat exchanging fluids, it is classified into condenser and evaporator.

### Special Modifications/Special Applications

#### *Heat Exchanger for dairy Application*

A very large amount of milk is bringing in dairy every day. The collection center at any dairy processing unit records around 20,000 liters of milk per day. This large amount of milk must be proceed immediately and must be pasteurize in very less time period. That’s why it requires very large and high heat exchanger for the process and pasteurizes this huge amount of milk. Here we can easily predict nature of heat exchanger by its volume. In olden days shell and tube heat exchangers are widely used for small volume pasteurization, here tubes were made of steel. Here problem occurs when we want to pasteurize huge amount of milk in less time. Previously, for large volume of pasteurize process, multiplying the units of small volume heat exchangers was used, but it is not an efficient solution of this problem. The various authors have presented different solutions for dairy application problem which is mentioned below.

## LITERATURE REVIEW

Pramod S. Purandare et al.[2014][1]

In this paper,an experimental analysis is carried out to study the heat transfer phenomenon in conical coil heat exchanger with cone angle 90 degree.

M.Ghazikhani et al. [2013][2]

The experimental investigation of the effect of wedge-shaped tetrahedral VGs (vortex generator) on a gas liquid finned tube heat exchanger was studied using irreversibility analysis.

Dillip Kumar Mohanty et al. [2012][3]

In this paper, the statistical analysis is used as an invaluable tool for investigation of performance of a shell and tube heat exchanger under fouling condition.

A.I. Zinkevichet al. [2010].[4]

This paper has shown that non uniform distribution of liquid flow among the tubes of a shell and tube apparatus has to be taken into account in determining the efficiency of heat transfer. The authors of this paper have proposed a method for taking this non uniformity into account and for analyzing its effect on the intensity of heat transfer.

LIU Wei et al. [2009][5]

In this paper, heat transfer enhancement in the core flow, and with the analysis of the disturbance mechanism of longitudinal flow, a new type of high efficiency and low resistance heat exchanger with rod-vane compound baffler was designed and investigated numerically.

Seong Yeon Yoo et al. [2009][6]

The heat transfer rate of the external tube surface of the heat exchanger for a closed wet cooling tower can be divided into sensible and latent heat transfer rates. These in turn are expressed by heat and mass transfer coefficients.

Amol Niphade et al. [7]

Amol Niphade et al.,tried to enhancement ofthe rate of heat transfer using alternative material or incorporating a change in the geometry of the tube. The provision of fins or protrusions to increase the surface area of contact can result in enhanced performance.Amol Niphade et al., mainly focus on arrangement of tubes while varying with pitch and the diameter. The requisite mass flow rate calculated to achieve the given temperature (72°C) in the specified time. The actual variation to be done shall be discussed upon securing the existing configuration of the shell and tube heat exchanger.

### Spiral type ground heat exchanger for enhancing heat transfer performance of geothermal heat pump

There are two main types of the ground heat exchanger for geothermal heat pumps: vertical and horizontal closed loop types. In this matter, the vertical type has several types such as u-type and spiral that is utilized owing to some circumstances in which the borehole drilling cost is of significance. Now, enlighten on economic issue, in the cold regions, the vertical type heat exchangers are more favorable because of less area. Generally, spiral type heat exchangers are more preferable with compared to slinky and U-tube GHEs because of low cost. Recently, other studies have been done to reduce a ground heat exchangers cost which is mentioned in below

***Table1:****Studies to reduce a ground heat exchangers cost.*

| **Author** | **Work** |
|---|---|
| Dehghan et al.[8] | Assessed a new u-type model. The presented model was concurred to avoid the wrong drillingand eliminate at least 20% of GSHP costs. |
| Farabi-Asl et al[9] | Conducted an investigation which resulted in 22–36% saving for GSHP system costs by the utilization of water pumping and injection. |
| Bezyan et al.[10] | Indicated that the best ground coil shape is spiral due to analyzing three different tube types of 1-w-shape, 1-u-shape, and spiral type with inlet temperature 35°C in cooling mode of water. Afterwards, their results showed that decrease the outlet temperature,difference for spiral, u-shape, and w-shape is 7.74, 4.328, and 4.965°C, respectively. Which the largest difference between the inlet and outletfluid temperature comes from the spiral type pipe. |
| Carotenuto et al.[11] | Applied a simulation by comparing differentdesigns. They also evaluated the heat transfer process using the mixed 1D-3D approach. By comparing three types of double-u-shaped, tripleu- shaped and spiral coil tubes, the most significant difference in temperature was observed in the spiral tube at 5.38°C after 6 h, and the lowest was for the triple-shape with 2.55°C. It was also pointed out inthis study that the tube length is much more important than tube diameter. |
| Zarrella et al.[12] | Spiral pipe is technically more advantageous than the u-tube. Further, at the same condition, in terms of thermal performance, the spiral resulted better than the u-tube and triple tube. Also, when the pitch rises from 0.15 to 0.3, the pick load is reduced by about 14%. In a similar study for the same initial and boundary conditions, the performance of spiral tubes was better than u and w shape. The reduction in the heat exchange surface when the borehole diameter was smaller needed to be balanced by a thermally enhanced backfill material.That the change in pipediameter does not have much effect on the system performance. Heat exchange changes by inlet temperature linearly. |

In many studies, the numerical simulation is applied using 3D modeling. Table 2 mentioned below represent various works on thermal simulation on spiral heat exchangers.

## Thermal-hydraulic performance of printed circuit heat exchangers with zigzag flow channels

Printed circuit heat exchanger (PCHE) are widely used in advanced nuclear reactor and next generation concentrated solar power application because of it is small in size and compact and also have a high pressure and temperature capacity with high effectiveness. Minghui Chen et al., has tried to analyze thermal-hydraulic performance of a zigzag-channel PCHE with high-pressure, high-temperature helium on both the hot and cold sides was simulated using a computational fluid dynamics (CFD) software package STAR-CCM +. They have also done comparisons between the experimental data and CFD simulation results which showed good agreement with some discrepancies in the pressure drop and heat transfer results.

***Table 2:****Various works on thermal simulation on spiral heat exchangers.*

| **Authors** | **Methods** | **Time** | **Pitch (m)** | **The details and results** |
|---|---|---|---|---|
| Jalaluddin et al. [13] | Simulation (ANSYS FLUENT) | 72 h | 0.05, 0.1, 0.2 | Heat transfer rate (HTR) of the spiral pipe with pitch=0.05m increased about 34.9% in the turbulent flow and 69.2% in the laminar flow the spiral pipe provides a better HTR than the straight pipe. |
| Zhao et al. [14] | Simulation (COMSOL) | | 0.25, 0.5, 1.0, 2.0 | A rise of spiral pitch results in a decrease of the COPs from 0.77 to 16.49%A reduction of spiral pitch could increase the energy efficiency. |
| Dehghan [15] | Simulation (COMSOL) | 2400 h | 0.1 | Major diameter and Pitch of spiral GHEs are suggested to be 0.45m and 0.1m respectively. It is highly recommended to use spiral type due to their low costs in comparison with other types of GHE such as slinky and U-tube. |
| Yang et al. [16] | Experimental | 10 h | 0.1 | The decrease of the spiral pitch, the steady value of soil excess temperature increases and the corresponding steady time become longer reducing the spiral pitch can increase the total heat release rate of the coil pipe, but also result in the decrease of heat release rate per unit pipe length. |
| Wang et al. [17] | Ansys CFX analytical modeling | | 1m | A new analytical solution was developed taking the Laplace method to account. The difference between borehole and surrounding soil thermal properties for the geothermal heat exchanger with the spiral pipe was studied carefully. This new tool has proven to be an appropriate one for designing and assessing energy pile system. |
| Zhao et al. [18] | Experimental and Simulation (COMSOL) | 43 h | 0.25m | The spiral pipe heat transfer gives the lowest temperatures in circulating fluid and the minimum average internal thermal resistances under the same initial conditions and boundary conditions He spiral pipe heat transfer gives the better thermal efficiency than the W-shaped, U-shaped. |
| Leroy et al. [19] | Simulation | 2000 h | 0.4m | The expansion of a new contribution to previously developed spiral heat source models. |
| Luo et al. [20] | Experimental | 1200 h | 0.3m | Thermal performance of spiral pipe can reach 10–15% upper than single-W type Cost-benefits study expressions that triple-U type has the highest economic performance, followed by, spiral, double-W and double-U. |
| Carotenuto et al. [21] | Simulation (COMSOL) | 6 h | 0.1, 0.25, 0.5, 0.7 | Using a pitch of 0.25m instead of 0.70 m, an increase of HT efficiency of 68% can be obtained The use of a pitch size smaller than 0.25m should be avoided due to extreme pressure drops and to a less heat exchanger enhancement. |
| Dehghan [22] | Experimental and Simulation (COMSOL) | 3 months | 0.1 | Different configuration of spiral GHEs was compared. The nine spiral GHE configuration (N=9) suggested out of models including N=1,2,3,4,5,9. The proper distance between spiral GHEs was calculated to be at least 6m (dp 6 m). |
| Yoon et al. [23] | Experimental and Simulation (COMSOL) | 65 h | 0.05m | The finite line source model was suggested for the evaluation of the ground thermal conductivity. The comparison of this model with the spiral type has also been studied. |

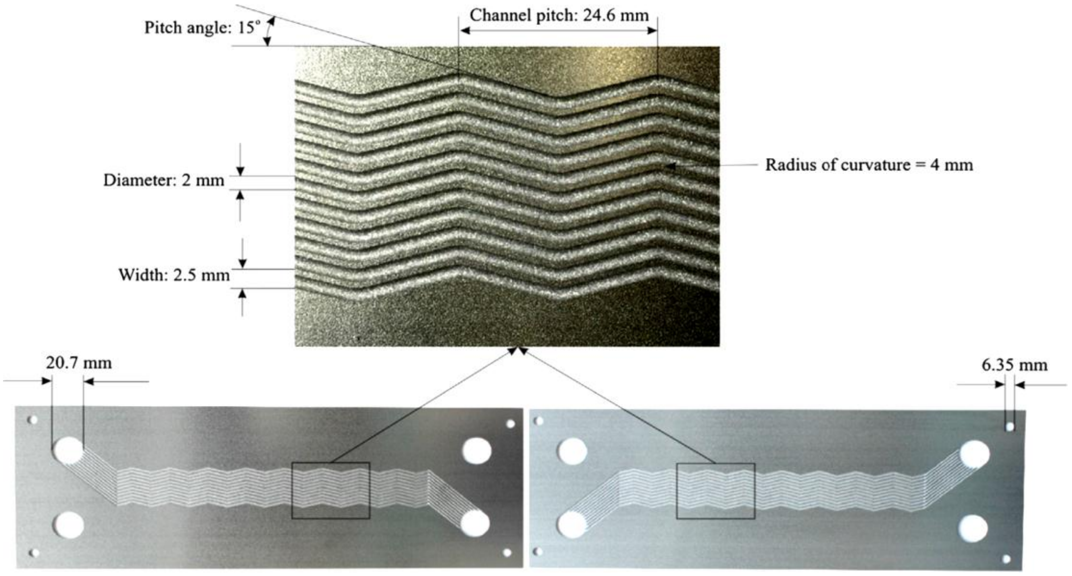

***Figure 1:** Thermal-hydraulic performance of printed circuit heat exchangers[24].*

Minghui Chen et al., have done a three-dimensional CFD study of a simplified two-channel geometry model for a fabricated zigzag-channel PCHE. They mentioned comparisons of the numerical results with the experimental data which showed good agreement in the channel Nusseltnumbers and pressure loss factors. The relatively minor discrepancies could be attributed to the lack of the detailed geometrical measurements of the flow channels in the PCHE after the diffusion bonding process and different thermal boundary conditions used in the simulations. It was observed that the wall temperatures were not uniform along the azimuthal direction of a channel cross section. The helium temperature distribution for each segment of a cross-sectional area of the channel presented a wavy shape along the flow direction. However, the global helium temperature distributions along the entire channels were approximatelylinear. For the heat flux distributions, although they were significantly different on the channel walls of different segments, the heat flux for each segment along the fluid flow direction wassimilar. Local thermal-hydraulic performance analyses also indicated that a fully-developed flow condition was never observed in the zigzag channels, due to the nature of zigzag channels, leading to periodic flow disturbance at each bend.

Various properties like fluid properties, solid thermo physical properties, radius of curvature at zigzag section, zigzag angle, pitch length, effect of these properties on the thermal hydraulic performance of the PCHE is studied. It was confirmed that Differences between the results obtained from two different gases of similar Prandtl numbers were relatively small. It was also confirmed that the mean pressure loss and mean Nusselt number in the zigzag channel with the sharp bends were larger than those in the zigzag channels with rounded bends. The effects of channel pitch and zigzag pitch angle were analyzed based on the available correlations in the literature. Both the friction factor and Nusselt number decreased as the channel pitch lengths increased when the zigzag angle was fixed[24].

## An OpenFOAM-based model for heat-exchanger design

In most cases,especially in the case of small and medium enterprises (SMEs), the design of heat exchangers relies on the expertise of their technical staff, the construction of prototypes which are improved through trial-anderror cycles, and the use of simple calculation techniques such as theLog Mean Temperature Difference (LMTD) or the Number of Heat Transfer Units (NTU). A suitable design is often found with this methodology, but it is usually far from the optimal one.

The use of Computational Fluid Dynamics (CFD) techniques for the design of heat exchangers has increased in recent years, as reported by Aslam Bhutta et al. [25] intheir review of CFD studies of heat exchangers. Fluid flow maldistribution, fouling, pressure drop and thermal performance are the main areas of analysis with CFD methods.

Rosetti et al. [26] studied the effect of the flow maldistribution in the air channel of an open refrigerated display cabinet using CFD.

Pal et al. [27] used a CFD model implemented in Open FOAM to study the heat transfer and flow distribution for shell-and-tube type heat exchangers with and without baffles.

Selma et al. [28] built a numerical model using Open FOAM to optimize the design of a heat pipe exchanger employed in buildingventilation systems. An improved design with a 30% lower pressuredrop and an increased (by 24%) thermal performance was achieved.

Cavazzuti et al. [29] applied a CFD model to optimize a finned concentric pipes heat exchanger, achieving an improvement of the heat transfer capacity of almost 11% without increasing the pressure drop.

Łopata and Ocłoń [30] developed a CFD methodology to calculate the fluid flow and heat transfer in fin-and-tube heat exchangers. This model was able to determine the effect of fouling on the performance of this type of heat exchangers.

Ramos et al. [31] compared the results of a numerical model of a cross flow air-to-water heat-pipe-based heat exchanger with experimental results; the difference between measured data and numerical results was less than 7%.Flaga-Maryanczyk et al. [32] developed a CFD model for simulating a ground source heat exchanger for a passive house ventilation system; the satisfactory agreement between experimental measurements and numerical results led them to conclude that their CFD tool was suitable for the simulation of ground source heat exchangers such as the one proposed in their paper.

Wu et al. [33] used a CFD model to research the performance of horizontal-coupled slinky ground source heat exchangers, after its validation with experimental measurements.

## Effect of materials used in heat exchanger and its performance

A number of factors need to be considered when selecting a tube material of the heat exchanger. They include corrosion and erosion, maximum temperatures, consideration of vibration and mechanical properties requirements. High temperature heat exchanger technology has become important for improving the performance of power generation. Solid material should promise for use in heat exchanger scan generally divided into four categories polymers, metals, ceramics and carbonaceous materials.

### *Ceramic Material*

Currently ceramic materials (both monolithic and composite) are used in heat exchangers.

Ceramic materials are inorganic

nonmetallic materials made from compounds of a metal and a nonmetal. The American Society for Testing and Materials (ASTM) defines ceramic materialsas “an article [whose] body is produced from essentially in organic, non-metallic substances and either is formed from a molten mass which solidifies on cooling, or is formed and simultaneously or subsequently matured by the action of the heat”.

### *Common Ceramic Material Used*

Thermal mechanical properties of various ceramic materialism shown in below Table 3 [34].

***Table3:*** *Thermal mechanical properties of various ceramic materials.*

| **compound** | **Density (gm/cc)** | **Tensile strength (Mpa)** | **Youngs modulus (Gpa)** | **Rapture modulus (Mpa)** | **Flexural yield strength (Mpa)** | **CTE linear 20ºC (μ m/mk)** | **Thermal conductivity 20ºC (W/m k)** | **Thermal Conductivity 100ºC (W/m-K)** | **Thermal Conductivity 1000ºC (W/m-K)** |
|---|---|---|---|---|---|---|---|---|---|
| **SiC** | 3.21 | | 427 | | | 4.8 | | | 42 |
| **SiC** | 3.10 | | 410 | | 379 | | | | 40 |
| **SiC** | 3.10 | 186 | | 110 | | 4.6 | 125 | | |
| **SiC** | 2.2-3.2 | | | | | 2.8-4.2 | | 12.6-200 | |
| **Si3N4** | 3.20 | | | 690 | | 3.5 | 3.0 | | |
| **Si3N4** | 1.9-3.0 | | | | | 1.5-3.6 | | 7-43 | |

Silicon carbide, silicon nitride, alumina, aluminum nitride, and ceramic matrix composites(CMC), Silicon nitride ($Si_3N_4$) exhibits excellent strength and creep resistance at elevated operating temperatures but may be limited by its ability to oxidation at temperatures exceeding 1000ºC.Alumina ($Al_2O_3$) is very stable and highly resistant to chemical attack under both oxidizing and reducing conditions[35].

### Thermoelectric materials and heat exchangers for power generation

Thermoelectric systems are widely used for converting heat energy to electric energy. A considerable attention of researchers has been drawn by the thermoelectric generator, for the aste heat recovery from engine exhaust. The thermoelectric generator is one of the promising green energy source and the most desirable option to recover useful energy from engine exhaust. A high-efficiency heat exchanger, which is an integral part of the thermoelectric generator, is necessary to increase the amount of heat energy extracted from engine exhaust at the cost of acceptable pressure drop. The present work is a summary of thermoelectric materials, and heat exchanger studies on heat transfer rate, thermal uniformity, and pressure drop.

### *Thermoelectric Material*

A thermoelectric (TE) module consist legs of n-type and p-type semiconducting materials connected thermally in parallel and electrically in series. Material structures and compositions are used to classify thermoelectric materials. Some of the main classifications are Clathrate, Chalcogenide, Half-Heusler, Skutterudite, Silicide, and Oxide. Thermoelectric material properties are highly temperature-dependent and face multiple challenges in application, such as specific materials choice.

## Summary of heat exchanger and thermoelectric material

***Table4:**Summary of heat exchanger and thermoelectric materials[36].*

| **Ref. No.** | **Author name** | **Heat exchanger** | | **Thermoelectric Module** | |
|---|---|---|---|---|---|
| | | **Type** | **Material** | **Material** | **Size (mm$^2$)** |
| **37** | Shengqiang Bai et al. | Plate shaped heat exchanger | – | Bi2Te3 | |
| **38** | Tzer-Ming Jeng et al. | Rectangular shaped heat exchanger | Copper | - | 40×40×4.0 |
| **39** | ShengChung Tzeng et al | – | Aluminum | – | 40×48×3.8 |
| **40** | Calil Amaral et al. | Aluminum plates heat exchanger | - | Bi2Te3 | 40×40×4.3 |
| **41** | X. Liu et al | Plate-shaped and hexagonal-prism-shaped heat exchanger | Brass / Aluminum | - | 50×50×5.0 |
| **42** | Cheng-Ting Hsu et al | - | Aluminum | Bi2Te3 | - |
| **43** | C. Ramesh Kumar et al | Rectangular shaped heat exchanger | Aluminum | - | - |
| **44** | Hongliang Lu et al. | Plate shaped heat exchanger | Stainless steel | - | - |
| **45** | Zhiqiang Niu et al. | - | Stainless steel | Bi2Te3 | 41×26×3.5 |
| **46** | Xing Niu et al | Multilayer plate heat exchangers | Copper | Bi2Te3 | 40×40×4.2 |
| **47** | Dan Dai et al | Plate shaped heat exchange | Aluminum | Bi2Te3 | 50×50×3.8 |
| **48** | Tongcai Wang et al. | Multi-layer compact Nickel metal foam filled plate shape heat exchanger | Steel plate | Bi2Te3 | - |

## CONCLUSION

After going through the above mentioned works done by the honorable researchers, it can be noticed that the enhancement of heat transfer rate can be done by using various kind of new and combination of different materials. We have also discussed various works by different researchers on the field of dairy application of heat exchangers. In future, there is a scope of research for high volume, high temperature heat exchanger for dairy application.

We have also discussed various researches regarded open foam based design of heat exchangers in CFD which has lots of future scope. We also mentioned various researchers work on modification of spiral type geothermal heat pump for better enhancement of heat transfer. We hope that this paper will helpful to the new and innovative researchers for brief reference about latest trends in heat exchangers. This paper will also be helpful for the researchers regarding various novel applications and problems facing while applying it, so it has a lots of future scope for work and improvement.

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**Cite this article as:**
Pandya Bhavik J., & Megha C. Karia. (2019). Latest Trends in Novel Applications of Various Heat Exchangers for Enhancement of Heat Transfer. Journal of Modern Thermodynamics in Mechanical System, 1(1), 16–26. http://doi.org/10.5281/zenodo.3337408