ADVANCEMENTS IN COOLING SYSTEM OF MARINE GEAR BOX: A COMPREHENSIVE REVIEW

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ABSTRACT
In last few years cooling and heating equipment's like Chemical reactors, air conditioning, refrigeration system heat Exchangers facing many problems to meet the society demand. Hence to fulfil this demands many techniques are used to enhance the performance of these heat exchangers. This review provides a Collective survey of different researchers on techniques to enhance performance of heat exchangers. Author found that many techniques are commonly used while some are used for specific work conditions. Mainly categorised in Passive techniques and active techniques. In passive techniques mainly work on modification of surface while in active techniques external power source are used. This paper review the work carried out for both active and passive enhancement techniques for enhancement of heat exchangers

Keywords
heat exchangers, enhancement techniques of STHE's, Twisted tape, Helical fins, Coil inserts, Corrugated tube, Ultrasonic wave, electro hydrodynamic

Abbreviations –
HE's- Heat Exchangers, STHE- Shell and tube heat exchangers, LMTD- Logarithmic mean temperature difference

INTRODUCTION
Heat exchanger is a device used to transfer heat between two or more fluids between two systems. Use of heat exchangers are different with different working condition. In refrigerator it exchange the heat with atmosphere for cooling purpose, In Solar heating system it exchange the heat with ambient air for heating purpose likewise in several sectors heat exchangers are widely used for exchange the heat **[01].** But due to advancement in technology, increased populations and modernizations performance demand of such equipment increases very sharply to achieve it many techniques are used. All techniques are categorised in active methods, passive methods and compound methods of enhancement of heat exchangers, these techniques are depend upon type of heat exchanger used Various types of heat exchangers are available as per working environment and requirement of industry. The type of HE used will depend on various factors like required heat transfer rate, the types of fluids involved, and the available space and resources. **[02]**

EXISTING HEAT EXCHANGERS FOR INDUSTRIAL USE
Heat exchangers are the most widely used device in cooling system because of their simple manufacturing and their adaptability to different operating conditions.
Shell and tube heat exchangers (STHE)- Most common type of HE. It is having a cylindrical shell contaning a bundle of tubes inside. One fluid flows inside the tubes, while the other fluid flows around the outside of the tubes in the shell. it is also useful because of its performance can be easily enhanced by Active and passive technique. According to their application STHE can easily designed also it can be made more efficient, less expansive and compact in design as per use of it **[03]**

Fig 01: Shell and Tube HE

Plate heat exchangers (PHE) – It is modern heat exchanger mostly used for heat recuperation. It consist of a series of plates arranged in a stack. The plates have channels through which the fluids flow. The plates are typically corrugated to increase the surface area available for heat transfer **[04][05]**

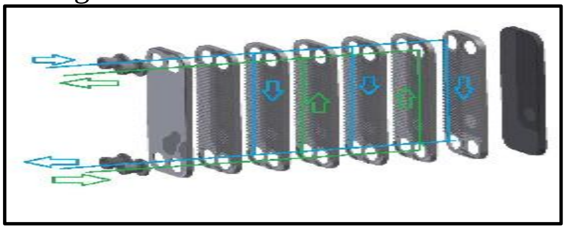

Fig 02: Plate HE

Spiral heat exchangers

Spiral heat exchangers consist of two long, coiled metal strips, one of which is wound around the other to create two separate channels for the fluids to flow through. One fluid flows through centre and another fluid flows over periphery. it can handle easily highly viscous fluid without fouling. It made of from stainless steel or carbon steel it is used in oil industry, alcohol industry, Pharmaceuticals and Biotech etc. **[06][07]**

Fig 03: Spiral HE

Finned tube heat exchangers

In finned tube heat exchangers fins attached to the outer surface of the tubes to increase the surface area available for heat transfer. Different types of fin like trapezoidal, rectangular, pin type, circular are used to increase the thermal performance **[08][09]**

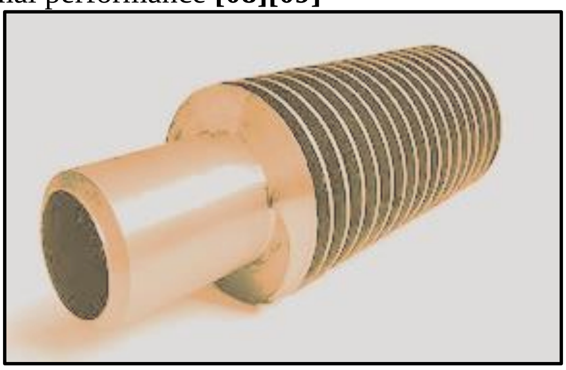

Fig 04: Finned tube HE,[10]

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Regenerative heat exchangers
Regenerative heat exchangers use a matrix of solid material to absorb and release heat as the fluid's flow through it. The matrix can be made of ceramic, metal, or other materials. There are many systematic effects of HE. By using heat of waste stream with incoming stream energy efficiency can be increased and energy consumption is reduced and overall running cost also reduced. Heat exchanger maintain product quality by maintaining temperature of process fluid. Heat exchanger also reduce wear and tear of machine parts by maintaining operational temperature low which reduce many risk like breakdown and increase the life of equipment. HEs can reduce the environmental impact of systems by reducing the energy required to operate them, which can reduce greenhouse gas emissions and other pollutants. **[11]**

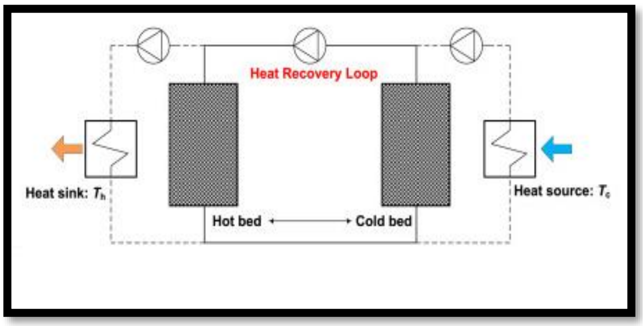

Fig no 05: Cooling system by regenerative heat exchanger

From all above heat exchangers most commonly used heat exchanger is STHE due to its easy design and various application in many sectors, also we can enhance its performance by active, passive and compound techniques easily

Geometry of Shell and tube heat exchangers
Number of tube structures combined called tube bundle used to make the STHEs, which carry either heated or cooled fluid. That used to supply or absorb the heat as required, the term "tube bundle" refers to a group of tubes. Because of such a tough design Shell and tube type Heat exchanger generally used for high pressure work. For high performance of STHE, It modified to maximize surface area for maximum heat transfer but due to such complex structure its maintenance and cleaning methods are very critical, also fouling is one of major problem in heat exchangers which affect the efficiency of heat exchangers. **[12]**

Component of Heat Exchangers
Tube bundle
tube sheet
baffles
Gasket
shell
head
connections
support

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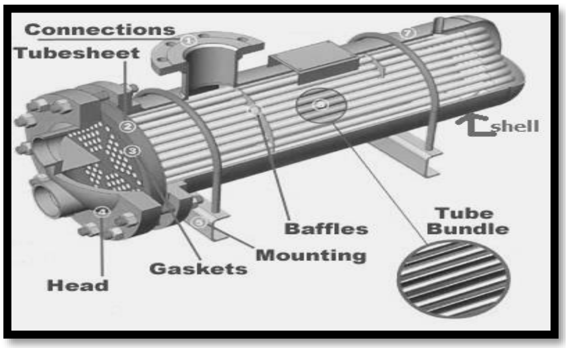

Fig 06: Geometry of Shell and tube heat exchanger [13]

Geometrical parameters of STHE [12][13]

Length of tube (L)
Shell side inlet temperature
Shell side outlet temperature
Mass flow rate
Tube side inlet temp
Tube side outlet temp

Consideration for designing the STHE

For safe and efficient operation of STHE minimum parameter such as pressure, working temperature, fouling areas, flowing rate of fluids and materials used for designing are needed to consider. Because it affects the effectiveness in following ways
Material used to build the HE should capable to withstand with high working temperature

Design of HE should be withstand for high working pressure
Design of heat exchanger should have minimum fouling
flow rate of working fluid should be adequate so heat transfer rate will constant
Performance parameter of STHES-

Performance parameter of STHES are Effectiveness **(ε),** overall heat transfer coefficient **(U),** number of transfer units **(NTU)** these are the heat exchangers performance calculating parameters **[14]**

Overall heat transfer coefficient (U) given by the relation **[15]**

$Q = U\ A\ \Delta T_{LMTD}$

Where A = Area of heat transfer

ΔT_{LMTD} = Logarithmic mean temperature difference

Effectiveness (ε) –

The effectiveness (ϵ) of a heat exchanger is defined as the ratio of the actual heat transfer to the maximum possible heat transfer. It can be calculate by **[16]**

$$\varepsilon = \frac{Q}{Q_{max}}$$

$$\varepsilon = \frac{M_h\, C_{ph}\, (T_{h1} - T_{h2})}{M\, C_{ph}\, (T_{h1} - T_{c1})} = \frac{M_c\, C_{pc}\, (T_{c2} - T_{c1})}{M\, C_{ph}\, (T_{h1} - T_{c1})}$$

T_{h1} and T_{h2} are hot fluid inlet and outlet temp
T_{c1} and T_{c2} are cold fluid inlet and outlet temp

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Number of transfer units (NTU) – it is a percentage of total thermal sizing and minimum storage capacity which can be given by [17]

NTU = $\frac{A_o\, U}{M\, C_p}$

TECHNIQUES TO ENHANCE THE EFFECTIVENESS OF HEAT EXCHANGERS

The main parts of heat exchangers heat transfer surface area, inlet and outlet of heat exchangers and type of stream

Various techniques are developed for enhancing the application of heat exchanger which generally includes increasing the area for heat transfer and lowering the size of heat exchanger and also expense. Methods to achieve it are

Improve the system efficiency.

Minimize the overall cost

Reduce the size of equipment.

Another method is to increase the heat transfer q which can be done by two methods that is Active and passive methods

Passive methods include surface adjustment like insertion of twisted tape, extended surface, insertion of wire coil, these methods do not require any external power source and Active method require power source for surface or flow vibration use of electromagnetic field. [41]

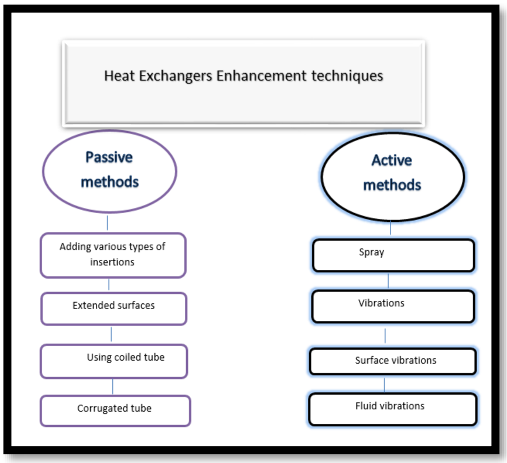

Chart 01: Passive and Active methods to enhance the effectiveness of heat exchangers

Work justifications

Many studies reviewed on Heat exchangers available for industrial used and their enhancement techniques. So authors carried out collective review of techniques available for enhancement of STHE's

As mostly used HE for industrial application is STHE so there is need to increase its performance

Even there is many study carried out for performance enhancement but no collective methods were discussed. This paper gives collective discussion on passive methods to enhance the thermal performance of STHE

Passive techniques can be easily adapted and also cost efficient because it does not require any external source. Advantage of passive techniques are

Require simple geometrical changes and modifications.
Easily used in compact heat exchangers.
Any passive techniques can be used as per working condition.
Existing heat exchangers can be modified accordingly.
No power source is required.

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Passive methods for enhance the effectiveness of heat exchangers

Effect of twisted tape-

Twisted tapes are metallic strips of different shapes and size which are inserted in the flow. This method is commonly used to increase the heat transfer performance of heat exchanger the twisted tape inserts used as a heat transfer enhancement device particularly most widely used for reduction of size and cost. As per application, twisted tapes are used with different twist ratio, with varying twist direction, fit and loose tape insert, full and short tape insert [18-25]

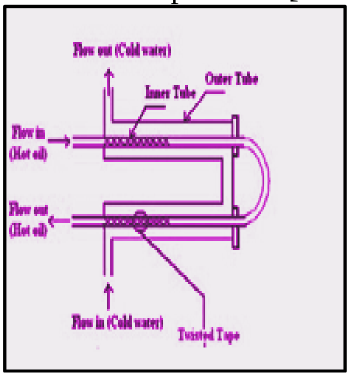
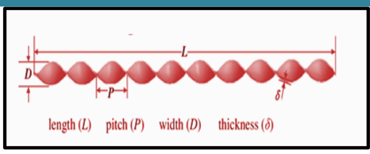
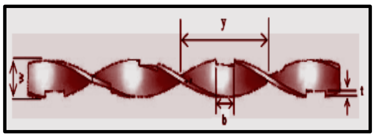
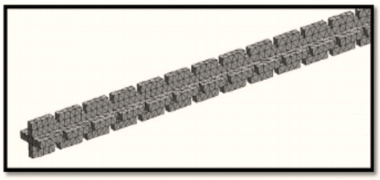
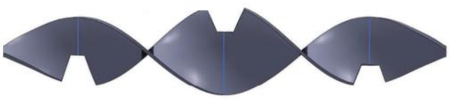
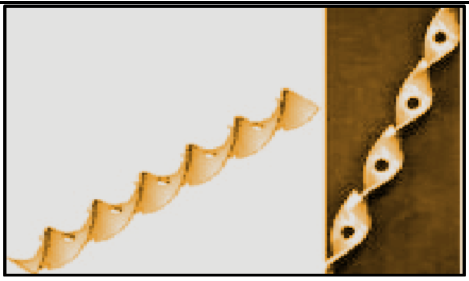
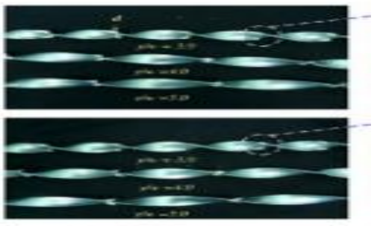


Fig 07: HE with twisted tape inserts

Some Recent study on use of different twisted tape insertion for enhancement of heat transfer rate are given below

Table no 01. Twisted tape types

Author	Year	Type of twisted tapes	Geometry	discussion
Li et al. [19]	2018	Helical Twisted tape		Heat transfer enhanced by 14.7%
Gnanavel et al. [20]	2019	Square cut tape		Thermal performance enhanced by 1.55 factor
Paneliya et al. [21]	2020	X- shaped tape		X-shaped tape showed an enhancement of 1.27 times in heat transfer rate compared to twisted tape
Murali et al. [22]	2020	Trapezoidalcut twisted tape		This can be enhance thermal performance by 36%

Kumar et al. [23]	2021	Perforated twisted tape		Thermal performance factor is 1.49 times greater than that of a plain twist tape insert.
Yadav AS [24]	2020	Half length twisted tape		It best efficiency
Eiamsa-ard S [25]	2020	delta-winglet twisted tape inserts		It achieve highest value for Nu and f

By using different twisted tapes inserts, the rotation of fluid between the tube and the twisted tape increases, causing more contact between the fluid flow with the pipe wall and the twisted tapes, result in increased heat exchange rate.

Use of Extended surfaces –

Heat transfer enhancement can be achieved by using phenomenon of extended surfaces or fins. It can be achieved by increasing convection. Thus, extended surface increase the surface area this can be good solution to heat transfer enhancement. The fins can be divided into a constant area straight fin, a variable area straight fin, a pin fin, and an annular fin.[26-31]

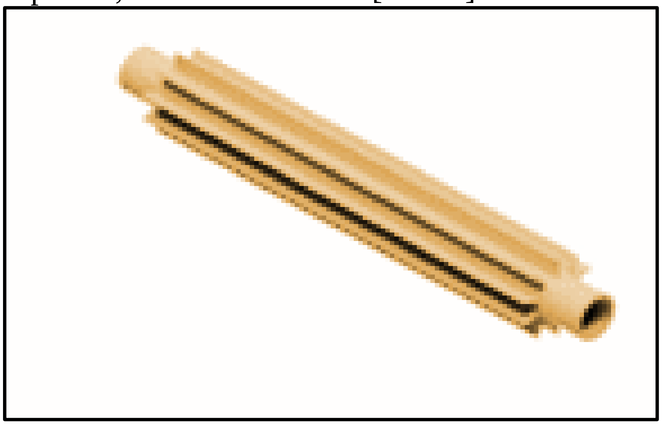
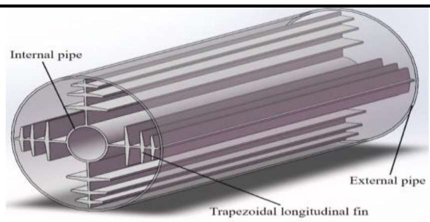
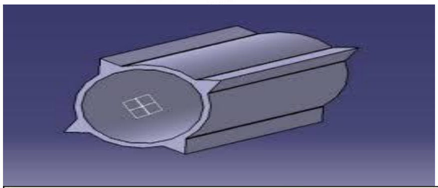
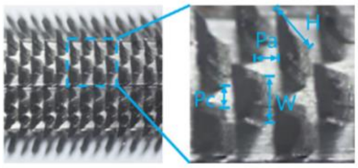
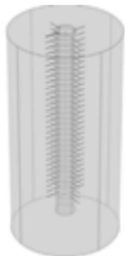


Fig 11: Extended surface (fins)

Table no 02. Types of extended surfaces

Author	Year	Type of fin	Geometry	discussion

Balaram Kundu [29]	2015	Trapezoidal fin		Pressure drop is more
Ammar M. Abdulateef [28]	2018	Triangular fin		Enhance heat transfer rate by 14% to 16%
Borhani et al. [27]	2019	Spiral fin		Enhance heat transfer rate by 56%
Zhang et al [30]	2019	Three dimensional		Heat transfer rate incesed by 3%
Saeidi et al [31]	2018	Novel spiral		Heat transfer rate improved by 30%

Conical wire coil inserts

The use of coiled circular wire causes a high pressure drop increase which depends mainly on spring pitches and wire thickness and also provides considerable heat transfer augmentation.

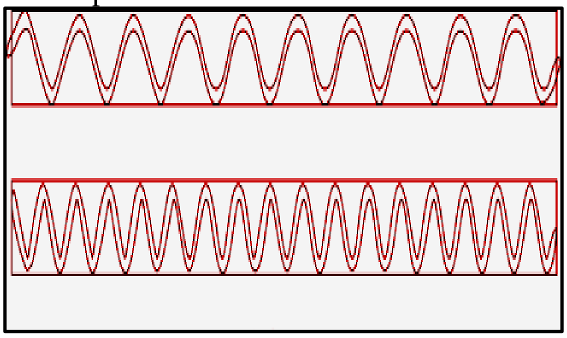
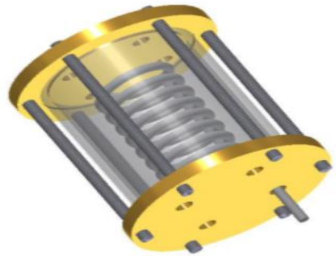
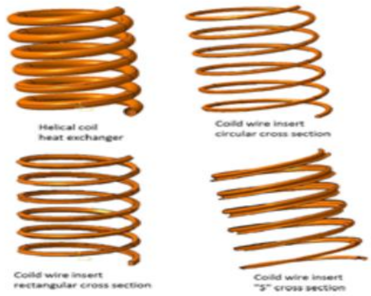
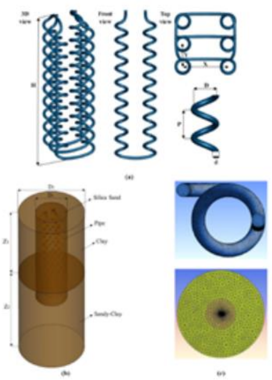


Fig 12: Conical wire inserts

If wire coils are compared with smooth tubes at constant pumping power an increase in heat transfer is obtained especially at low Reynolds number although fairly large differences have been observed among the analysed coil wires. Their evaluated performance is quite similar. The coil circular wire should be applied instead of the smooth one to obtain higher heat transfer and performance leading to a more compact heat exchanger. [32]

Table no 03. Various conical wire inserts use.

Author	Year	Geometry	Discussion
Andrzejczyk and Muszynski [33]	2017		The influence of water mass flow and heat flux on the HTC is presented.
Gholamali zadeh et al. [34]	2019		- A correlation is proposed to predict the Nusselt number.- The maximum value of COP for the inlet mass flow rate of 0.1 is 2519
Palanisamy and Kumar [35]	2019		The maximum overall heat transfer coefficient of nanofluids is 52% higher than the water at 0.5% nanofluid with the Dean number 4200.
Javadi et al [36]	2019		Helical coil length is the most influential parameter in heat exchanger performance.- Proposed equations are capable of predicting the thermal properties of the heat exchanger.

Effect of corrugated Tube

In this technique Heat transfer is mainly improved by the fluid impact to the wall with little effect by the spiral flow. The heat transfer performance is linearly decreased with the increase in shell diameter. Matching mass flow rates of tube and shell sides are investigated by simultaneously considering the overall heat transfer coefficient, total pressure drop and energy benefit, with the multi objective optimization method.[37]

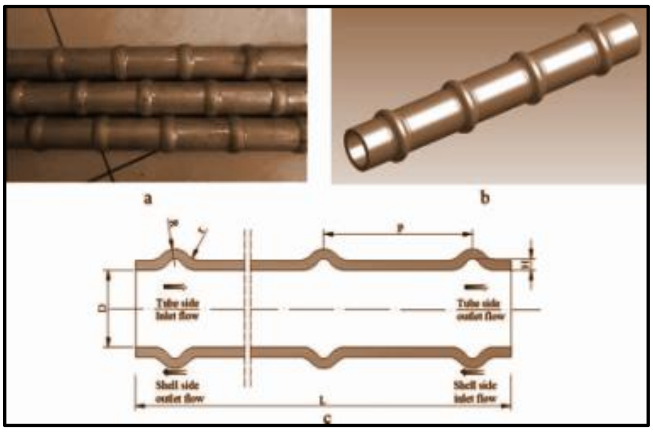
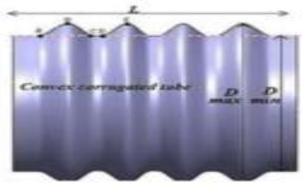
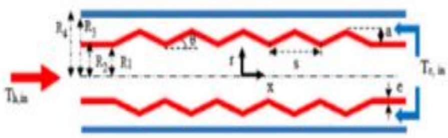
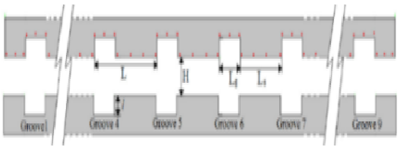
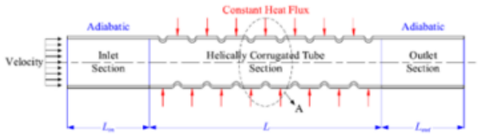


Fig 13: corrugated tube

Table no 04. Various use of corrugated tube in heat exchangers.

Author	Year	Geometry	Discussion
Sadighi Dizaji H [40]	2017		When a corrugated tube was used, the dimensionless exergy loss rises by about 4–31%, whereas the loss rises by about 17–81% when the tube and shell were both corrugated
Akbarzadeh and Valipour [38]	2020		The maximum thermal performance enhancement is 107.2% using the corrugated tube compared to the smooth tube
Begag et al [39]	2021		- Thermal performance improves up to 60% by applying the corrugated surface compared to the smooth surface

Ashouri et al [42]	2021		The thermal performance is enhanced by 1302% and 19.8%
Zontul et al. [43]	2021		Thermal performance increases by 2.5 times compared to a plain channel.
Hu et al. [44]	2021		A helically corrugated tube increases the thermal performance up to 1.69 times compared to the smooth tube.

Use of Nano Fluid

Latest technology used to increase the working System of heat exchangers is the use of Nanofluid, Due to its better thermal properties than other fluids like water ethylene glycol or oil. Mostly metallic nanoparticles used because of its greater heat transfer capacity, but particle size has an inverse relation with thermal conductivity. Because of the increase in their collision rate, small size particles could move faster, achieving higher thermal conductivity. Although it has major issues, that is its stability and price. and it shows some drawbacks like increasing pressure drop, erosion, clogging, and particle sedimentation. Heat transfer efficiency of heat exchanger depends on temperature, flow rate, nanofluids Concentration, nanoparticle size, and shape.[45]

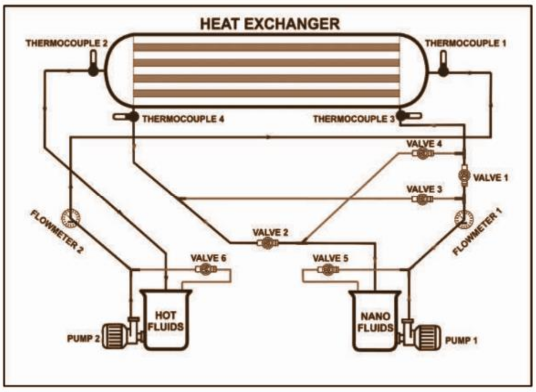


Fig 14: HE with nano Flui

Table no 05. Various types of nano particals use in heat exchangers.

Author	Year	Base fluid	Nano Partical material	Remark
Huang et al[46]	2015	Water	Al2 O3 MWCNT	Heat Transfer upsurges with increase in volume fraction though heat at constant Reynolds number HTC ought to obtain enhanced
Huang et al[51]	2016	Water	Al2 O3 - MWCNT hybrid	The hybrid nanofluids with provided pumping potency reveals maximum heat transfer coefficient. Also mixing of alumina and MWCNT nanoparticles seems difficult.
Cieśliński et al[52]	2017	Water	Al2 O3	The vivid reduction of overall HTC and rise of pressure drop was logged. The reason behind such behaviour with PHEs was augmentation.
Bhattad et al[47]	2018	Water	Al2 O3 - MWCNT	At lower temperatures the improvement in effectiveness of PHE is found less. If viscosity is increased acts as a penalty
Wang et al[48]	2018	EG/W (50:50)	Graphene nano-platelets (GnPEGW)	Comparison between nanofluids and base fluids for heat transfer enhancement on identical Re number misleads and also overestimates the real heat transfer scenario.
Teng et al. [49]	2019	Water	CNT	Here 0.2 vol% was found to be optimum. Also CBNFs provides higher heat transfer rates compared to conventional fluids
Bhattad et al[50]	2019	EG/water PG/water (20:80)	Magnesia- silver and Alumina- silver	The brine-based hybrid nanofluids justifies the desired output and can be used for low temperature applications and milk chilling.

Active methods for enhance the effectiveness of heat exchangers

Spray

A spray has liquid droplets by using a pressure-assisted atomizer Because the drops spread over the surface and evaporate or form a thin film of liquid Impinging on the heated surface with droplets increases the heat transfer [53]. It another active method of increase enhancement by use spray. Spray uses droplet in air which contains moisture, which will then spread over heated surface thus heat transfer occur. By evaporation, convection and secondary nucleation heat transfer is more even at low temperature. The heat transfer behavior (heat flux versus wall temperature) using spray cooling presents the following specification: For low wall temperature ,the heating plate temp is reduced or cooled by a single-phase regime. Because the flow is rapidly expelled from the heating surface ,in that temperature range, the liquid does not have time to warm up enough to attain the boiling condition at the heating wall. Convection heat transfer is increased because droplets acts on the liquid film thus mixing the fluid better. Below the saturation temperature, the curve slope may increase due to the evaporation of a thin liquid film formed on the heating surface When liquid near the heating wall becomes superheated, heat transfer may be increased by secondary nucleation or boiling which increase the heat transfer coefficient, the evaporation rate and the turbulence When the motion of flow increases further, the surface start to dry. The vapor generated by phase change is quickly removed Because the critical heat flux is higher for spray cooling than for pool boiling Spray cooling is very difficult because it depends on many parameters .for example, ,nozzle-to-heating surface distance, incident angle, droplet size ,air pressure, droplet velocity, droplet density, surface roughness and orientation, non condensable gas, air pressure, etc [54].

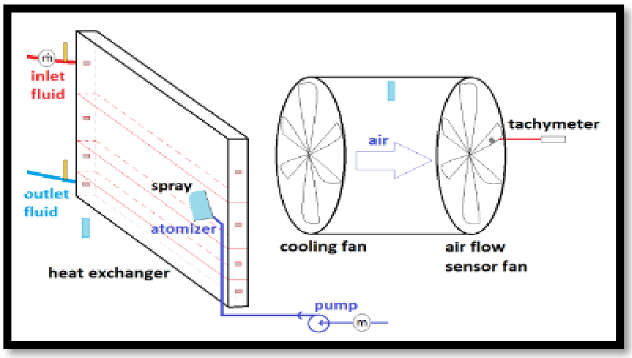


Fig 15 Heat exchanger with water spray

Surface vibrations

Surface vibration may be at low or high frequency has been used firstly to rise or increase single-phase heat transfer. To vibrate a surface and spray few droplets onto a heated surface to promote spray cooling, a piezoelectric devices are used. There are three main heat transfer enhancement techniques involving cyclic movement of a solid wall are considered here: acoustic waves formed by high frequency oscillations of a membrane; synthetic jet where the flow is imposed by the motion of a diaphragm bounding a void; dynamic deformity of a solid at high amplitude [55]. High amplitude vibratory motion through the solutions using the deformation of a wall to increase shift, one is particularly studied. It consists in evaluating the impact of an oscillation of a movable blade constituting a" piezoelectric fan". Such a piezoelectric fan could be reduce which is consistent with the objective of compactness. Piezoelectric fans are used to impose motion on a fluid locally in a globally stagnant fluid area, increasing heat transfer in a hot spot, and so reducing local temperature. Other studies have been conducted. For example, using a plate oscillating in a channel enhances natural and forced convection. In the same way, a vibration can be imposed directly on the wall of a channel. Repeatedly moving a wall strongly enhances heat transfer, either with or without boiling of the moving fluid. An acoustic wave reduces cavitation's phenomena which in turn enhance heat transfer through a mixing effect. In the boiling structure, acoustic waves increase both heat transfer and critical heat flux. Increasing the amplitude at lower frequencies sets the fluid in motion and thus enhances the convective effect.[56]

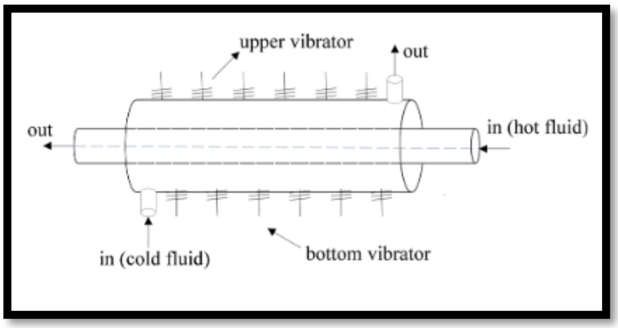


Fig 16 Heat exchanger with Surface Vibration

Fluid vibrations

It is more experimental type of vibration enhancement because of the mass of most heat exchangers .The vibrations spread from pulsations of about 1 Hz to ultrasound. Single phase fluids are of primary task. They are applied in many variant ways to dielectric fluids. Generally speaking, electrostatic fields can be directed to cause greater mixing of fluid in the vicinity of the heat transfer of surface[57] The control of fluid motion in the vicinage of the wall is essential to increase heat transfer rate. Active techniques act on the fluid in touch with the wall. The most efficient methods of heat transfer enhancement are those generating a rebirth of the fluid in the immediate vicinage of the wall. A possible technique is the use of movable walls at the location where the taking out of heat takes place. But, wall deformation is not without its disadvantages

Conclusions:-

The Heat exchangers available for application have an impact on the overall efficiency and size of a system. There is a lack of a Collective Study that covers all the passive methods of Heat exchangers enhancement techniques. The work shows that the paper lies in its ability to provide a Collective, up-to-date, and systematic review of the various methods and techniques available for enhancement of cooling system which gives the most effective result.

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