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An Empirical Study of Helical Coil Heat Exchanger Used in Liquid Evaporization and Droplet Disengagement for a Laminar Fluid Flow

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Abstract

Heat exchanger is an important component in industrial systems especially in process industries. Many commercial designs and types of heat exchangers are available in market for transfer of heat as well as for recovery of waste heat for the process plants.

As helical coil have compact size and higher heat transfer coefficient they are widely used in industrial applications such as food preservation, refrigeration, process plant, power generation, etc. An attempt has been made to study the parallel flow and counter flow of inner higher temperature fluid flow and lower temperature fluid flow, which are separated by copper surface in a helical coil heat exchanger. Helical geometry allows the effective handling at higher temperatures and extreme temperature differentials without any highly induced stress or expansion of joints. These heat exchanger consists of series of stacked helical coiled tubes and the tube ends are connected by manifolds, which also acts as fluid entry and exit locations. In this paper, we focus on design parameters and heat transfer conditions of a vaporizer or generator of a simple vapour absorption refrigeration system having flow condition of refrigerant taken as laminar flow.

Keywords : Helical coil heat exchanger; Heat exchanger; Heat transfer in vaporizer; Heat transfer in generator.

Introduction

Heat exchangers are the essential engineering systems with wide variety of applications including many power sectors, nuclear reactors, refrigeration and air-conditioning systems, waste heat recovery systems, chemical and food industries.

Natural convection is a process of heat transfer, in which the flow of fluid is caused by density differences in the fluid occurring due to various temperature conditions. Here the fluid which surrounds a heat source receives heat, becomes less dense and rises. The working fluid that is surrounding the high temperature fluid is cooler and then moves in to replace it. After that cooler fluid gets heated and the process continues, resulting convection current. [1] Forced convection in a heat exchanger is the flow of heat from one moving stream to another stream through the wall of the pipe. The low temperature fluid removes heat from the comparatively high temperature fluid as it flows along or across it. If it moves along the hot stream then it's called parallel flow and if they are across then its counter flow.

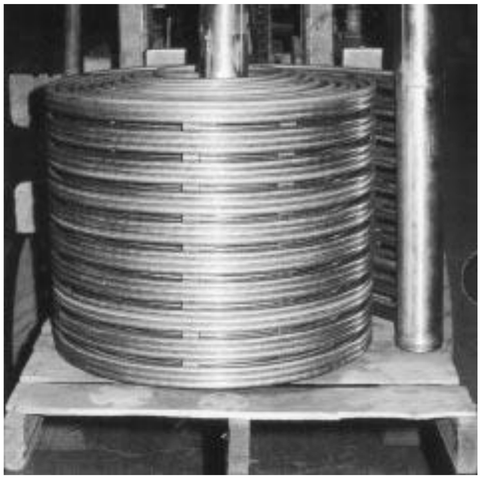


Figure : Bundle for a water vaporizer in a supercritical water-extraction process.

Helical coil configurations are very effective for heat exchangers and chemical reactors because of their large heat transfer area in a small space, with high heat transfer coefficients. Recently developments of heat exchangers, coil type heat exchangers are being used because the spiral coil configuration has the advantage of more heat transfer area and better flow pattern without air chocking in the pipes as compared to the series of parallel U-tubes in the pile.[2] Additionally, the spiral coil system can reduce the complexity of the pipe connections and decrease to a certain extent the thermal ‘‘short-circuit’’ between pipes i.e supply and return pipes. A general Schematic Diagram of the geometry of helical tube heat exchanger is shown in figure given below:

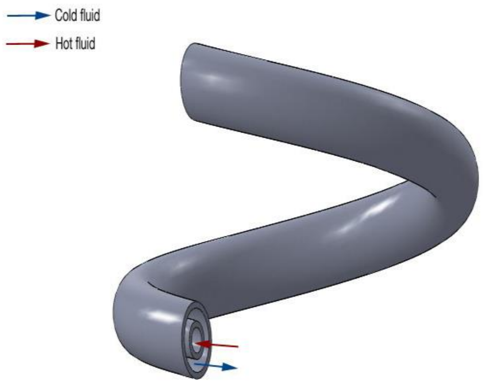


Figure: Schematic Diagram of the geometry of helical tube heat exchanger.

A survey of the open literature[3-6] indicates that many of papers have been published to include the flow and heat transfer characteristic in helical tube followed by laminar flow condition. Some configurations of helical tube heat exchangers are discussed below:

- ✓ Multiple pass design heat exchanger, which increases tube side velocity, thereby improve the heat transfer rate. With this configuration, there is an implementation in tube side pressure drop.
- ✓ Vaporizer or generator design for liquid vaporization and droplet disengagement.
- ✓ Condenser design, which comes in some typical configurations. Each condenser depends on the process and vessel’s discharge conditions.

Among of these, in this paper, we are focusing on heat transfer in generator of vaporizer of simple vapour absorption refrigeration system. Since it has been a need of the industry to spend less energy and extract maximum work possible out of it. Waste heat recovery deals with the extraction of heat from flue gases or other sources, which are otherwise termed as waste, and utilize it for further production or process. Now a days, various heat exchange systems are available for recovery of waste heat. Selection of the unit for a particular use depends on various factors such as potential of heat available for recovery, space available for installing the system, and of course, cost! The relative increase in heat transfer in spiral tube over a straight tube was noted 40 % higher at Re 2000 i.e the Laminar flow condition.

Heat exchanger for droplet disengagement and liquid evaporization.

As we know that the vapour absorption refrigeration systems are low grade heat operated systems. In the absorption system the compressor of the vapour compression system is replaced by the combination of “absorber” and “generator”. A solution known as the absorbent, which has an affinity for the refrigerant used, is circulated between the absorber and the generator by a pump (solution pump). The absorbent in the absorber draws (or sucks) the refrigerant vapour formed in the evaporator thus maintaining a low pressure in the evaporator to enable the refrigerant to evaporate at low temperature. In the generator the absorbent is heated. There by releasing the refrigerant vapour (absorbed in the absorber) as high pressure vapour, to be condensed in the condenser. Thus the suction function is performed by absorbent in the absorber and the generator performs the function of the compression and discharge. The absorbent solution carries the refrigerant vapour from the low side (evaporator–absorber) to the high side (generator-condenser). The liquefied refrigerant flows from the condenser to the evaporator due to the pressure difference between the two vessels; thus establishing circulation of the refrigerant through the system.The general diagram of ammonia water absorption system is shown in figure given below. Also the design parameters of generator are discussed with it.

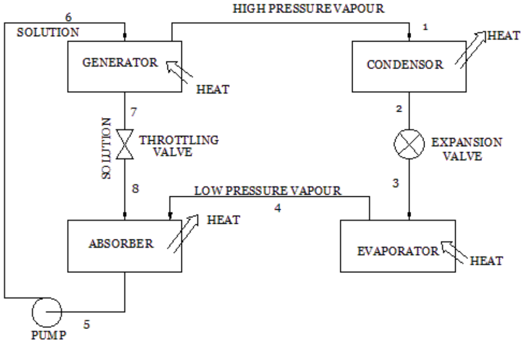


Fig: Schematic diagram of vapour absorption refrigeration system.

Design of Generator :

State Point 5: strong solution entering the pump as saturated liquid

$P_5 = 4.7$ bar Xs = 0.42

Using enthalpy-concentration diagram;

$T_5 = 52$℃ ; $h_5 = 0$ KJ/Kg

State Point 6: high pressure saturated strong solution entering the generator

$P_6 = 10.7$ bar; Xs = 0.42; $h_5 = h_6 = 0$ KJ/Kg

State point 7: weak solution leaves the generator at saturation temperature of generator

$P_7 = 10.7$ bar $X_w = 0.38$
Using h-x diagram
$H_7 = 255$ KJ/Kg; $T_7 = 120$℃
Using energy balance for generator
Q_G = Heat added to generator.
$Q_G = m_r h_1 + m_w h_7 - m_s h_6$
$= (10.341 \times 1335) + (144.774 \times 255) - (144.774 \times 0)$
$= 50.722$ kW

Assuming the heat is supplied to ammonia generator by condensing steam at 2 bar and 90% dry. Assuming the only latent heat of steam is used for this purpose.
From steam table at 2 bar
$h_{fg} = 2201.6$ KJ/Kg.
Mass flow rate of steam to generator = $(17.1435 \times 60)/2201.6 = 0.04672$ Kg/min

Steam Generator or Vaporizor

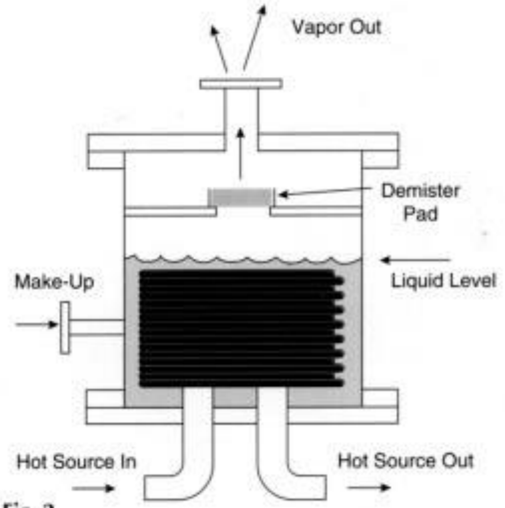


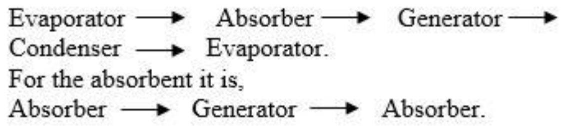
Fig. 2

Heat transfer coefficient:

As we studied form various papers, if the heat transfer is occurring in a stream due to density difference then its convective heat transfer. If a film is placed between fluid of different density then conduction heat transfer will occur through that film. The rate of heat transfer under steady state is given by the equation :
$Q = hA(t_w - t_{atm})$,
Where h= coefficient of heat transfer (W/m^2 K)
A= area of the wall
T_W = wall temperature
T_{atm} = surrounding temperature.

The value of h, depends upon the properties of fluid. It depends on the different properties of fluid, dimensions of the film surface and velocity of the fluid as well as nature of flow.[7]

Flow Path : The refrigerant path is:


Evaporator → Absorber → Generator → Condenser → Evaporator.
For the absorbent it is,
Absorber → Generator → Absorber.

The absorbent solution passing from the generator to the absorber is hot and ha to be cooled. On the other hand the absorbent solution sent to the generator is cooled and has to be heated in the generator for the regeneration of the refrigerant. A shell and tube heat exchanger is introduced between the generator and the absorber.

On the basis of above discussion we can design the heat exchanger or generator for required cooling parameters. As per calculation of this case the coils of heat exchanger can sustain the pressure of steam more than 11 bar and temperature of 120℃.

Higher film coefficients are achieved on both the coil and casing side. The fluid flow path i.e helical flow path, imparts higher shear rates and turbulence at a given pressure drop, which can result in film coefficients up to 40% higher than those achieved with many comparable shell and tube heat exchangers. Departure from laminar floss and fully developed turbulent flow occur at lower Reynolds numbers. The 100% counter-current flow allows maximum use of the available LMTD and makes temperature cross-when the higher temperature side outlet temperature is cooled below the lower temperature side outlet temperature-possible without multiple tubes in series or parallel. The flow geometry of a helical heat exchanger is such that a temperature cross is managed within a single unit.

Advantages of use.

- ✓ Cleaning the casing-side flow area is easily managed.
- ✓ The casing can be unbolted and the entire bundle assembly removed for inspection or replacement.
- ✓ The coil's compactness also provides advantages, because the exchanger requires minimum floor space.
- ✓ The heat exchanger's spring-like coil eliminates thermal shock problems that often occur during startup or during cryogenic or high-temperature service.

Lower maintenance cost and less possibilities of damage.

Limitations

There are very few limitations for the use of helical coil heat exchangers. Generally, a pressure limit of 10,000 psig covers the majority of applications. Also temperature limits are determined by construction materials, as are the corrosion rates. Surface areas of 1 to 600 sq. ft. are available, and using units in series or parallel may extend this range substantially.[8]

Other General Applications

Some most common applications for helical coil heat exchangers are discussed above, but their use in industry is far greater. Helical oil heat exchangers commonly are used as water pre heaters, steam condensers, interchangers, vacuum system inter- and after-condensers, batch heaters and/or coolers and reactor-jacket coolers. These heat exchangers offer distinct advantages, such as improved thermal efficiency, easy maintenance and lower installed cost and space. Whenever an application requires heat exchanger suitable for high operating pressure and/or extreme temperature gradients, a helical coil unit should be considered. The heat exchangers also are suitable for less demanding applications, such as waste heat recovery, condensing, boiling and basic heat exchange.

Conclusion

Heat exchangers having helical coil configuration are much effective as compare to other straight configured heat exchangers due to their compactness. Their characteristics of heat transfer are much better than that of straight heat exchangers with remarkable increase in heat transfer co-efficient. As per the calculations it is concluded that for simple vapour absorption refrigeration system the helical coil heat exchanger could be considered which sustain a pressure of 11 bar and temperature at least 130 degree centigrade for safe running conditions. Due to the requirement of less space for generator or vaporizer, these heat exchangers are preferable. If the required design parameters would be changed, then the effectiveness of heat exchanger remains same by increasing the surface area of helical coils.

For a particular mass flow rate, helical coil heat exchanger provides an increase in heat transfer coefficient by 20%. From the simulations made, it is also found that the heat transfer coefficient could be increased with the mass flow rate.

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