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Design Development of Fluropolymer Spiral Tube Heat Exchanger

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ABSTRACT:

In process industry there is always a need of chemically inert and non corrosive heat exchangers , although the conventional heat exchangers made from copper, aluminium and other metallic materials seldom prove useful in these cases. Polymeric materials heat exchangers although chemically inert , but lack the thermal capabilities suitable to heat exchangers. The only polymeric heat exchangers to offer modest heat transfer abilities are the fluropolymer heat exchangers Another dominant problem in the heat exchangers is that of fouling as the condensate substrates are deposited on the conductive surfaces or wetted perimeter area of the tubes. As a result of fouling the heat transfer rate and overall effectiveness of the heat exchanger comes down considerably . Heat exchangers applied in process industry , food industry, chemical industry and medical field applications require special inert or non reactive materials for the tubes so that there is no possibility of contamination and low level of scale and fouling. Owing to its geometry the spiral tube in tube heat exchangers are compact in design , although high on the pumping power . The fluro polymer spiral tube in tube heat exchanger design is selected for the development purpose with the view of producing a compact , chemically inert heat exchanger . The approach in the design and development is to deal with the problem of fouling at two levels as proposed in this paper , namely selection of an suitable material to prevent fouling and scaling issues and secondly to add a innovative geometry variation in the form of pitch augmentation where in the flat shape geometry of the spiral can be converted to an to a conical frustum. The Fluropolymers exhibit modest thermal capabilities but excellent resistance to corrosion . The paper discuses the application of fluropolymer in spiral tube in tube form for application as a condensor in ditallation of lemon grass oil used for medicinal purpose.

KEYWORDS:

Fluropolymer , Spiral tube in tube heat exchanger , heat transfer capabilites , corrosion resistance

Introduction:

Polymeric heat exchangers find application ideally in process owing to their durability and as they are not brittle like glass or graphite and provide better resistance to corrosion than almost all metals heat exchangers of steel , aluminium or copper rendering them a proffered choice for use in a number of process industry applications.

Versatility of the fluoropolymer heat exchanger in addition to resistance to corrosion makes them a singular choice. The same heat exchanger design may be used with variety of chemicals without danger of contamination or intermixing of fluids. From the start of the application of polymeric heat exchangers in the shell-and-tube designs, fluoropolymer heat exchangers have also being used other geometric configurations, especially in the primarily reactor and other forms like immersion coils

Normally the materials like stainless steel or copper are chosen for heat exchanger, depending upon the chemical makeup of a given process system that permits their use mostly economic reasons. But , if the process engineering requirements suggest the use of more costly metal material like tantalum , titaniumor Inconel, in such cases the polymeric heat exchangers should be definitely considered . Although economically polymeric exchanger are at par with the glass and graphite heat exchangers , but the polymeric heat e3xchangers win in the low maintenance cost as the maintenance required for graphite or glass te units usually is considerably higher and sometimes more than the original production cost of the unit.

Another important factor that makesd the polymeric heat exchangers more favorable is the service life , which is considerably higher than the competitors like glass and graphite. Predominantly lesser spare-parts or other inventory is required in comparison to the metal exchangers. . Another aspect is significant that repair of these heat exchanger is easy as the damaged tubing is easily replaceable without significant changes in heat exchanger. The polymeric heat exchangers donot requiere any special welding process for repair.

Some specific applications in process industry for polymeric exchangers are as follows:

- Storage condition monitoring through simple heating and cooling.
- Material recovery through condensing in distillation applications.
- Purification or production separation through vapourization
- Waste heat recovery , or salt production process
- Application as absorber in process recovery

A strong co-relation between temperature and operating pressure , as the polymeric heat exchanger tubes are in the extruded form . Generally, a polymeric heat exchanger is designed for operating pressures ranging from 20 o 40 psig and corresponding temperatures ranging from 250 to 300^{o}F (149^{o}C); in some cases the heat exchangers can be designed to operate above the above mentioned limits through appropriate selection of materials

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There is a general perception about polymers that they are bad conductors of heat although depending on the shape, size and design of tubing their thermal performance can be made at par to the performance of metals like aluminium and stainless steel .

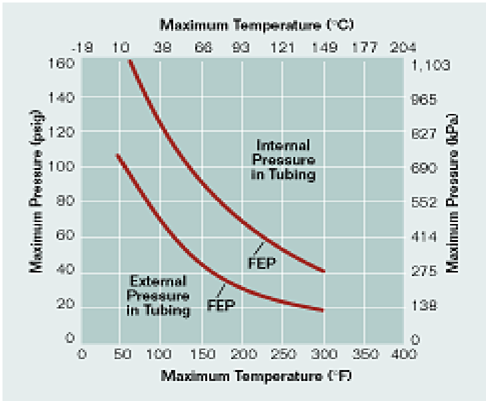

Figure 1 : Co-relation of Operating pressure and Temperature of Fluropolymer heat exchangers

Concept of Spiral Tube in tube heat exchanger

The arrangement of the tubes to attain maximum surface area would be to develop a helical tube in tube type coil heat exchanger with the cross-section of the tube structure as follows:

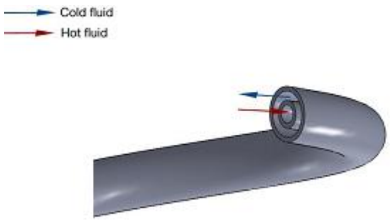

Figure 2 Tube in Tube structure of the Spiral tube heat exchagner

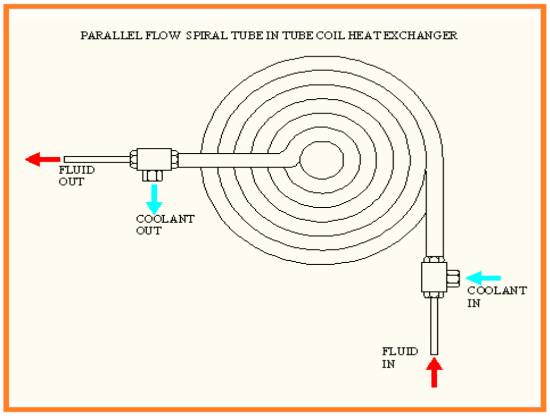

Figure 3 :Arrangement of the Spiral tube in tube heat exchanger in parallel flow configuration

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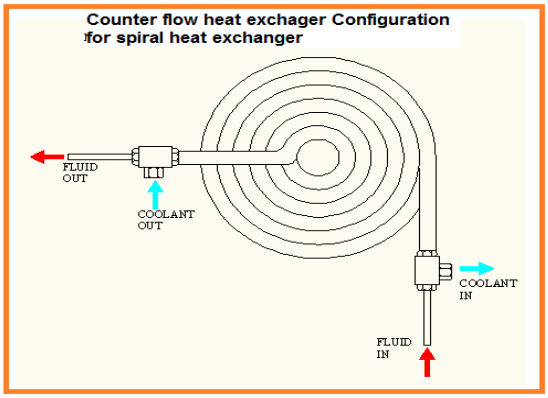

Figure 4Arrangement of the Spiral tube in tube heat exchanger in Counter flow configuration

Thermal Properties of Selected Polymers (PTFE)

Fluoropolymers are corrosion resistant to most chemicals according to Wharry (2002). Material selection is limited by the operational temperatures hence polymers like Ethylene tetrafluorethylene (ETFE) or Polyvinylidene difluoride (PVDF) which have lower temperature limits and as they sell at high temperature and ketone resins dissolve were not selected for our application. Teflon (PTFE) polymer which has high resistance to erosion by chemicals and no metallic parts are used andPTPE is highly resistant to hydraulic shock as well as thermal expansion hence we have selected PTFE as the material for tubing.

PTFE has melting point of about 621° F (327° C). where as the density is 2.13 to 2.19 gm/cc .PTFE has good resistance to chemicals and corrosion PTFE exhibits good mechanical properties for temperature range 0 to 500° F (280° C) and its low coefficient of friction than other metal materialmakes it less prone to scaling and fouling.

Property	ASTM Test Method	Units	Teflon® PTFE
Physical			
Specific Gravity	D792		2.13-2.22
Mechanical			
Tensile Strength	D1457 D1708 D638	psi	3,000-5,000
Elongation	D1457 D1708 D638	%	300-500
Flexural Modulus	D790	psi	72,000
Folding Endurance	D2176	(MIT) cycles	$>10^6$
Impact Strength	D256	ft-lb/in	3.5
Hardness, Shore D	D2240		50-65
Coefficient of Friction, Dynamic	D1894	<10 ft/min	0.1
Thermal			
Melting Point	D3418	°F	621
Upper Service Temperature (20,000h)	UL746B	°F	500
Flame Rating	UL94		V-0
Limiting Oxygen Index	D2863	%	>95
Heat of Combustion	D240	Btu/lb	2,200

Table 1 : Properties of PTFE

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Thermal Design

The thermal design of the heat exchanger has been done for an specific application . Note that , the application proposed for the helical coil tube in tube heat exchanger is lemon grass oil extraction with aqueous base of fragrant oil where in the spiral coil heat exchanger is used to reduce the temperature of the oil-water amalgamate ie(water oil mixture), this amalgamate is produced by passing the steam over the lemon grass leaves at first , steam evaporates the oil from leaves and the condensate is formed …this process is slow and the amount amalgamate produced is small amounting to hardly maximum of 6 to 8 litre per shift per unit., and thus the data pertaining to liquid A is practical where as any conventional centrifugal pump with half inch outlet with head of less than 2m can discharge upto 800 lph .. Input data :

Input data	Liquid A (inner tube) (Lemon grass .oil base)	Liquid B (annulus)(water)
Mass flow rate M kg/h	0.4	600
Inlet temperature oC	80	28
Outlet temperature	55	42
Specific Heat Cp Kj/kg k	1.68	4.187
Thermal Conductivity (k) kcal/(h)m o C	0.67	0.609
Viscosity of oil µ kg /mh	1.296	1.12

During heat exchanger design we have used the overall heat transfer coefficient to connect the temperature gradient to the heat transfer. Parameters like wall thickness, hot fluid film, and fouling resistances , cold film etc on both sides are compacted as one coefficient as shown below

Where in ,

U = Overall Heat transfer Coefficient

A = Surface area of the heat transfer surface

F= Correction factor

ΔT_{LMTD} = Log-mean temperature difference

The Overall heat transfer coefficient (U) is given by the relation Below :

$$U = \frac{1}{\left(\frac{1}{hh}\right) + \left(\frac{tw}{Kw}\right) + \left(\frac{1}{hc}\right) + ri + ro}$$

Where in ,

hh & hc are the heat transfer coefficients on the hot and cold side respectively

tw = Wall thickness

ri ad ro = are the fouling resistances on the either side

Kw = thermal conductivity = 0.25 W/m²k

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In general terms the Overall heat transfer coefficient for water to oil is given in table below :

Ref : Overall Heat Transfer Coefficient Table... | www.engineersedge.com

Cold Fluid	**Hot Fluid**	**Overall U (BTU/hr-ft 2 -F)**
Water	Light oils	60 – 160

As

1 **W/m^2** = 0.3169983306 **Btu** (IT)/**hour**/square **foot**

Thus the Overall heat transfer coefficient = 189.27 **W/m^2**

Considering parallel flow configuration

ΔT_{LMTD} = Log-mean temperature difference = 28.13 °C

F= Correction factor = 0.45

Thus the Surface area of heat transfer is given by

$Q = U * A * F * \Delta TLMTD$

0.4 * 4.187 *(80-55) = 189.27 *A * 0.4 *28.13

A = 0.028 m^2

Thus selecting the above dimensions for the tube in tube heat exchanger :

Parameter	Dimensions
Inner tube inside diameter (di)	5.9 mm
Inner tube outside diameter (do)	6.4 mm
Outer tube inside diameter (Di)	11 mm
Outer tube inside diameter (Do)	12 mm
Length of tube	1.4 m

Result and Discussion :

The following results for design of the Fluropolymer Spiral tube in tube heat exchanger

1. Fluropolymer exchangers exhibit excellent corrosion resistance and modest heat transfer abilities and hence can be applied to process industry heat exchangers

2. PTFE has good resistance to chemicals and corrosion also it exhibits good mechanical properties for temperature range 0 to 500° F (280° C) and its low coefficient of friction than other metal materialmakes it less prone to scaling and fouling , hence it is selected as the material for inner and outer tube.

3. The heat exchanger is designed for specific application of lemon grass oil extraction process where in the LMTD is 28.13 °C for given parameters.

4. The dimensions of the spiral heat exchangers are derived suitable to the application.

Conclusion:

The sizing , design of spiral tube in tube fluropolymer heat exchanger is done successfully done and the dimensions of the inner and outer tube have being determined have being determined. PTFE is selected as the material for the tubes, the heat exchanger will be first developed as a flat spiral and testing will be done in both parallel and counter flow configurations to determine the performance characteristics will be determined.

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