International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Design and Effects of the Fluoropolymer Tube used in the Development of the Multi Tube Heat Exchanger

Dilpreet Kaur Hora*, Nitnaware Pravin T and Tapobrata Dey

Mechanical Engineering,D.Y.Patil College of Engineering, Akurdi, Pune, Savitribai Phule Pune University, India

Accepted 10 June 2017, Available online 22 June 2017, **Vol.7, No.3 (June 2017)**

Abstract

Heat exchange is the most important process which is used in the engineering. The device by which one may be able to achieve the heat exchange process is known as heat exchanger. With the help of heat exchanger we can transfer the energy in the form of the heat to the flowing fluid. When the fluid is running continuously in the exchanger it not only changes the effectiveness and quality of the tubes from which the working fluid flows but it also change the properties of the fluid like; the changes in its thermal conductivity, mass flow rate, density and viscosity. On the other hand with the continuous flow of the chemicals mixed fluid from the heat exchanger its metallic counterparts get corroded and it changes the thermal, mechanical and chemical properties of the running fluid from it. So for the betterment of the heat exchanger and the tubes placed in it we may replace the inner tube of the heat exchanger which is made up from the metal with the tube which is not only chemical inert but it is also non –corrosive in nature. This tube is made up of the material known as the fluoropolymer. This material is made by the PFA polymers (perfluopolyethers) whose most important property is its overall same construction. With the help of this tube the steel surface may be become hydrophobic. So when the one tube is became chemical inert the rate of the corrosion is decreased and the life and durability of the exchanger is increased.

Keywords: *Perfuoropolyethers , Fluoropolymers , Thermal efficiency , Hydrofobic, (HEX) Heat Exchanger.*

1. Introduction

For the exchange of the heat unit which is used is known as the heat exchanger. The heat exchanger is used for the transformation of the energy in the form of heat from one fluid to another fluid. Heat exchanger works on the well- known principle of the chemical science and it is Calorimetry Principle. Whose function is to transform the heat from one fluid or solid to another one till that time when the temperature of both the parts become equal. In the heat exchanger the working fluid is separated by the wall which controls the flow of both the fluids and help them to be separated by each other. In present time the heat exchangers are used in the every industry of science and technology like in the chemical plants , boilers, refrigeration system, air conditioning system, domestic Among all the three kinds of heat exchanger the most important heat exchanger is recuperative type HEX. The according to one of the following types:

- Parallel-flow
- Counter-flow
- Cross-flow

*Corresponding author: **Dilpreet Kaur Hora**

Parallel–flow Heat exchanger: The exchanger in which both the fluids flow in the same direction.
Counter-flow : The exchanger in which the fluids flow in the opposite direction.

Cross-flow: The exchanger in which the fluids are perpendicular to each other is known as the cross flow heat exchanger.

These HEX are classified as the following recuperative type of heat exchanger which is the most common in practice and it may be designed:

- Shell and tube heat exchanger
- Plate heat exchanger
- Plate and shell heat exchanger
- Adiabatic wheel heat exchanger
- Plate fin heat exchanger
- Pillow plate heat exchanger
- Fluid heat exchangers
- Waste heat recovery units
- Dynamic scraped surface heat exchanger
- Phase-change heat exchangers

Heat exchanger can be also divided by the tubing arrangement and these are as follows

- Shell and tube type heat exchanger
- Spiral coil tube heat exchanger

- Helical coil tube heat exchanger

A.C system, medical Science, power-station, natural-gas processing, and sewage treatment
There are many kinds of heat exchanger used today and these are as follows:

Recuperative type: The heat exchanger in which the fluids exchange heat on either side of a dividing wall is known as a recuperative type of heat exchanger.
Regenerative type: The heat exchanger in which hot and cold fluids occupy the same space containing a matrix of material that works alternatively as a sink or source for heat flow is known as regenerative type of heat exchanger.

Evaporative type: The exchanger such as cooling tower in which a liquid is cooled evaporative in the Same space as coolant is known as evaporative type of heat exchanger fluoropolymer which is easy to handle and the cost of the design is also less.

2. Introduction to the polymers

Polymers are that organic molecules which consist a series of repeating units named monomers. Primarily they are made up of hydrogen and carbon atoms which arranged in the form of long chains. There are two kinds of polymers:

- Natural polymer: The natural polymers are found naturally example: cotton, wood, rubber etc.
- Synthetic polymer: With the help of some chemical reactions the natural polymers can be processed and they are converted into synthetic polymers. Again these polymers are subdivided into the two parts:
- Thermoplastics: They are the polymers which when heated become soft and when cooled they again became hard
- Thermosets: These are the polymers which cannot be reversed after one time process.

3. Literature Review of Fluoropolymer Hex

Mamunya *et al*. (2002) in his theory he gave the detailed description of percolation for conduction (electrical and thermal) in particle-filled PMCs. By this we may be able to sudden rise or fall in the nature of properties.

Boudenne *et al*. (2004) gave the information about the density, thermal conductivity, specific heat capacity, crystallinity, and thermal diffusivity of polypropylene–aluminum particulate composites.

Serkan Tekce *et al*. (2007) studied the impact of various types of copper fillers (i.e. spheres, flakes, and short fibers) in a polyamide matrix

Krupa *et al*. (2004) studied PE composites filled with graphite particles. The electrical conductivity showed percolation behavior at a volume fraction of 0.11.
Norley *et al*. (2001) and Norley (2005) discovered the new composite named as graphite-epoxy polymer which is light in weight with only up to 1.9 g/cm^3 density that . This The HEX devices are traditionally made-up from the metallic material for achieving the high rate of heat transfer co-efficient and for the maximum efficiency and thermal conductivity. But when there is a continuous flow of chemical mixed fluid from these tubes take place not only these tubes degrade but also the thermal, chemical and mechanical properties of the flowing fluid changed. To overcome this situation and for avoiding the corrosion the sensitive parts of the HEX are exchanged with the steel or Some other costly alloys. By using these our exchanger become costly so in order to maintain both the quality as well as cost the method which we applied is to replace the inner tube with the PFA polymer material known as fluoropolymer which is easy to handle and the cost of the design is also less.

4. Need of Fluoropolymer Hex

Fibre reinforced composites is the inability to fully utilize the inherent properties of these materials. Heat exchangers are very useful in all the industries related with the heating and cooling processes in present time. These are not only useful in the industries but it is applied in our day to day life also. Use of fluoropolymer heat exchanger in the place of metallic heat exchanger. In some areas like in the field of hospitals, and domestic uses enhances the technology and provide the idea to us that when there is no need of high heat transfer rate we can applied these method because it works in the same way as any other traditional heat exchanger with no corrosion and fouling. Widely used polymer materials in heat exchanger applications are PVDF(Polyvinylidene fluoride), In the fluoropolymer heat exchanger the metallic tube is exchanged with the PFPE (perfuropolyether) tubes to prevent the instrument from corrosion to increase the life of the HEX and the quality of the fluid remain unchanged

5. Operational features of fluropolymer heat exchanger

The features of the above said heat exchanger are as follows:

- Fully drainable inner and outer coil: Best advantage of using this kind of heat exchanger in the industry is that there is the facility of fully draining in the exchanger. No cavity should be formed due to the blockage of water or any other fluid when it passes from it.
- Spiral wound for maximum counter flow efficiency: There is a presence of the spiral wound in the fluoropolymer heat exchanger. By the spiral wounding we can obtain the max counter flow efficiency
- Excellent for multi-phase/multi-component: Since it is made up of light material its handling is also easy.

Highly resistant to thermal and hydraulic shock material is being used today as a fin material in combination with an aluminium or copper base to make hybrid heat sinks.

Weber *et al*. (2003) performed thermal conductivity testing of carbon-filled Nylon6.6 and polycarbonate based resins

Jordan *et al*. (2005) presented a review on this topic as well as the trends and initial tests found in previous studies. It was found that the behavior of NCs differs from composites with larger scale inclusions.

Gao (2004) compared clay–polymer NCs to conventional GFRPs. In theory, the reinforcement of polymers at the nanometer scale has significant advantages over traditional fiber reinforcement. The main weakness of modern.

6. Properties of the Fluoropolymer Heat Exchanger

- **Non corrosive**: As it is made up of the materials like PFPE, PE TEFLON etc , it is non –corrosive. There should be a polymer tube instead of the metal so when the fluid passes from it continuously it could not be able to form cavities and the layer of corroded metal.
- **Chemical resistance:** The biggest property of the fluoropolymer HEX are that they are resistant towards chemicals .As when the fluids passes through it will not get changed chemically.
- **High and low temperature capability:** There should be the high and low temperature capability in the following kind of heat exchanger.
- **Resistance to weathering:** There should be no change in the working of the exchanger during the change in the atmospheric condition as it is resistant towards the weathering conditions
- **Electrical and thermal insulation:** As we know that the plastic are very poor conductor of the electricity so it is also electrically insulated.
- **Lowest coefficient of friction:** its coefficient of friction is also very low in the comparison of any other metallic HEX
- The tubing is translucent white in colour.

7. Thermal Properties of Some Polymers

Fluoropolymers are that materials which are resistant to corrosion towards many chemicals due to their chemical structure, as discussed by Wharry (2002). Where thermal margins of safety is to be considered it is critical condition so we used:

- Polyvinylidene difluoride (PVDF) and ethylene tetrafluorethylene (ETFE) for their upper operating temperature limitsPVDF is also swells in ketones and easily dissolves in polar solvents it is not recommended for the bases based applications.
- Teflon (PTFE) is the polymer which is chemically due to the absence of metallic parts PFPE is highly resistant to thermal and hydraulic shock.
- Spiral wound for maximum parallel flow efficiency: As it is use of the fluoropolymer HEX is offered to calculate the parallel flow efficiency.
- Constant fluid velocity: As we know that the fluoropolymer heat exchanger is made of polymer so in the absence of metal the corrosion is negligible which can change its velocity. So using this we may be able to maintain the constant velocity of the fluid flowing from it.
- No dead spots or crevices: Another important feature of this exchanger is that there is no dead spots or crevices.

Whenever anyone wants to design the new heat exchanger not only the thermal but mechanical properties are also important to be considered. We have to consider the standards and codes (ASTM, ASHRAE, ARI, etc.) for the selection of metals and the working fluid.

The thermal conductivity, specific heat capacity, maximum operating temperature (thermoplastics soften on heating), coefficient of thermal expansion, ultimate tensile strength, tensile modulus, and a very low coefficient to thermal expansion characteristics are attractive for the manufacturing of heat excahanger. By using fillers (e.g. glass fibers and silica powder), the mechanical properties can be further enhanced.

8. Mechanical Properties of Some Polymers

- Polypropylene (PP) is non-toxic, non-staining, and it is very excellent corrosion resistant. It has a significant application in mechanical vapor compression desalination units.
- Polyethylene (PE) polyethylene is a polymer with the small density. It is robust towards breaking,at the room temperature it is chemically inert but with the time duration it can be slowly attacked by the oxidizing agents which can make them soft and swell
- Polycarbonate (PC) polycarbonates are good resistant to the acid like mineral acids organic acids greases and oils but they are not reactant towards the alkalis. It can be dissolve in nitrile, polyamide and hot melt. It has a service temperature range of 4 to 135 C.
- Polyphenylene oxide (PPO) its chemical composition is similar chemical composition to polyphenylene either (PPE) so in the chemical science they are known as equivalent. From the heating oer of view it is good but chemically it is not resistant. But considering its strength, stability, and flame retard ness it is used in machines and hosing resistant to everything except molten alkali metals and fluorine. It can withstand temperatures up to 204 C. Teflon is used for the recovery of bromine system, for the metal plating, and for the deionizing process of the water. It is well known for its non-stick properties so it is used in the non-sticking cooking pans.
- Liquid crystal polymers (LCPs) this is the only material which combines the properties of polymers and liquid crystals. Reay (1989) believed

that these materials might be useful at temperatures in excess of 300 C due to the self-reinforcing characteristics and the good creep resistance. Deronzierand Bertolini(1997) presented pure LCP alkalis stability. It is resistant to most solvents, oils, acids, and alkalis, appliance. The lack of chemical resistance and color stability means that it often has to be painted in these applications. Low water absorption leads to the use of PPO in various water-handling products. Moreover, PPO can also be electro plated.

- Polyetheretherketone (PEEK) has an estimated continuous working temperature of 250 C, with excellent retention of mechanical properties at over 300 C. In addition to its high resistance to chemical attack, it can be used at high temperatures (>250 C) in steam or high pressure water environments without significant property degradation. The only common materials that attack PEEK are supposedly concentrated nitric acid.
- Polysulfone (PSU) is an amorphous thermoplastic with a maximum continuous use temperature of 190C.It has a high creep resistance and thermal stability. It is resistant to most solvents, oils, acids.
- Although the thermal conductivity of fluoropolymer material is lower than the metallic counterpart but much of the initial interest in the development of polymer heat exchangers was stimulated by their ability to handle both the matter liquids and gases (i.e. single and two phase duties), their resistance to fouling and corrosion, and their possible use in both humidification and dehumidification systems. Perhaps most importantly, the use of polymers weight, volume, space, and cost savings which can provide a competitive edge over heat exchangers manufactured from more exotic metallic alloys.

Table 1 Thermal properties of the polymers

S.No	Polymer	Density(g/cc)	Thermal conductivity(W/mK)	Yeild tensile strength(MPa)	Tensile moduls(GPa)	Flexural modulas (GPa)	Melting point(c)
1	PVDF	1.78	0.19	44	1.8	1.7	160
2	PC	1.2	0.2	62	23	23	
3	PPS	1.43	0.3	68	3.6	4.9	280
4	PTPF	2.7	0.27	12	0.61	0.52	332
6	PS	1.05	0.14	44	3	2.8	139
7	PEEK	1.33	0.25	99	4.5	4.8	340
8	PFA	2.12	0.87	13.8	2.9	0.59	310

Table 2 thermal properties of the metal

S.No	Metal	Density (g/cc)	Thermal conductiviy(W/mK)	Specific heat(J/Kg k)	Yield strength (Mpa)	Tensile strength(Mpa)	Melting point(C)
1	Al	2.71	169	921	69	179	629-652
2	Cu99.9	8.89	391	385	69	221	1083
3	S.S 304	7.92	52	502	207	586	1393
4	S.S 316	8.08	52	502	276	621	1393
5	S.S 446	7.47	57	502	345	552	1373

9. Objective

According to the previous evaluation we used the fluoropolymer tube in the multi tube HEX for the following purposes.

- Testing of tube heat exchanger in counter flow configuration to determine
- LMTD
- Capacity ratio
- Effectiveness

To study the effect, design and fabrication of the fluoropolymer. The only main objective of this HEX is to minimize the fouling, cost of the exchanger and its maintenance of the. because it is clear that the with the metal tubes used in any heat exchange decayed by the time and on the other hand there is a mixing of the removal of these tubes in the flowing fluid which changes the flow of fluid and affected its quality.

10. Procedur

From the above schematic test ring we may be able to perform the analysis of U- tube shaped heat exchanger with the fluoropolymer as inner tube in it. There is a storage tank which is mounted above and the hot fluid is stored in it. The one thing which should be kept in the mind is that only hot water is placed above. The flow of hot water always takes place in one direction which is top to bottom due to the gravity and the flow of the fluid is controlled by using a flow control valve. The temperature measurement is done by using a j-type thermocouple with single channel digital indicator whereas the flow measurement is done using a measurement beaker with stop watch.

Table 3 Specification of the parts used in the HEX

S. No	Parts used	Specification
1	Tank used	3.75 lit.
2	Coil water heater	350 watt power , temp range 80^0 C
3	Circulation pump	30 watt power,250 LPH discharge
4	Boom structure	50 mm height, 20mm breath
5	Holder pin	With 600 N/MM^2 U.T.S &380 N/MM^2
6	Fluoropolymer Tube	AMETEK U- tube with polymers srtands.
7	Outsider shell of the tube	Structure of mild steel welding
8	Digital Temp thermometer	For calculating the temp difference

11. Experimental set-up of the exchanger used fluoropolymer tube

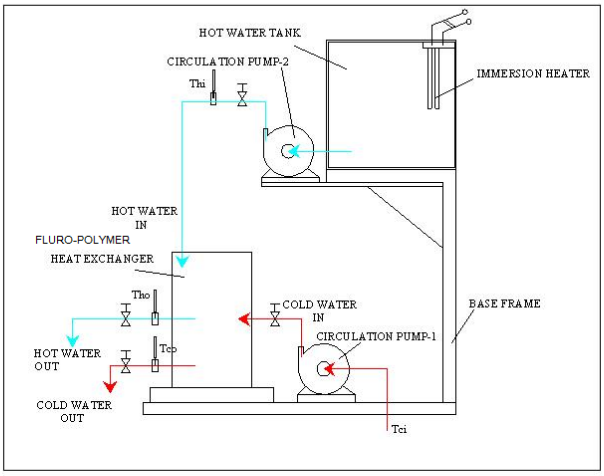

Figure 1 : Set –up for the fluoropolymer HEX

12. Specifications of the equipment used in the Pf-Hex

1) Heating tank: In the above stated HEX we may use the tank of stainless steel of capacity 3.75 Lit. This tank is used to store the water or any other fluid which we may apply for the heating exchange purposes.

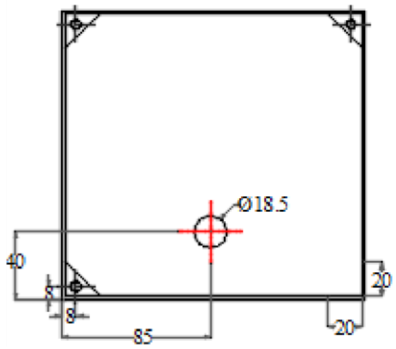

Figure 2: 2-D Drawing of the tank used in the PF-HEX

2) Immersion Coil water heater: The coil water heater used in the fluoropolymer is immersion coil heater. Its power is 350 watt and the temp range is 80^0 C. This coil is dipped in the tank and it raise the temperature of the water and fluid which is present in it.

Figure 3: Immersion Coil water heater

3) Circulation pump: This circulation pump is used to circulate the water of the tank to the polymer HEX. This circulation pimp is of 30 watt power and 250 LPH discharge.

Figure 4 : Circulation pump

4) Holder pin: This pin is used to hold the tank and boom devices in the fluoropolymer HEX.

Figure 6: Holder pin

The UHP heat exchangers are available in shell diameters ranging from three to fourteen inches.

Figure 7: Photograph of U- shaped polymer tube used as inner tube of HEX

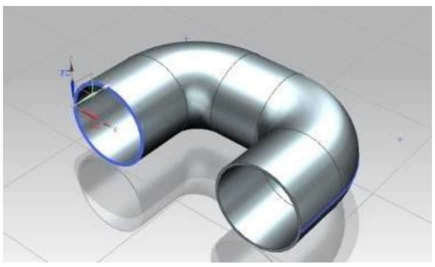

Figure 8: 3-D drawing of the metallic outside tube

5) Boom: This is the vertical stand in which the whole experimental–setup is stand. This is made up off stainless steel material.

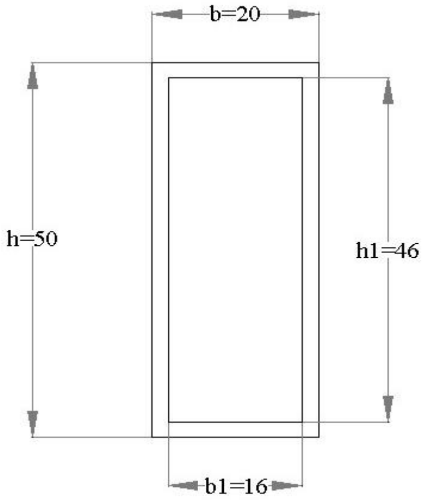

Figure 5: Design of the boom

6) Fluropolymer inner tube: This tube is imported from AMETEK fluoropolymer products 455 Corporate Boulevard Newark, Delaware 19702 United States. This is a leader company in fluoropolymer heat exchanger. The manufactures tubing and pipe from various grades of fluoropolymer resins to meet customer applications. Heat exchangers made with ultrahigh-purity (UHP) PFA tubing that allow chemical processors and others to conform to the highest standard of purity. They are ideal for heating and cooling ultrapure water, acids and other corrosive chemicals typically used in electronics, pharmaceutical, and semiconductor manufacture. Both these outer or inner tube are used in such a way that they can offer the heat exchange. The tubes are arranged in the U-tube geometry with one of the metallic outing and the polymerised fluoropolymer tube which is inside it

Table 4 dimensions of the tubing arrangement

S. No	Diameter of outer tube	Di	13.5mm
1	Diameter of inner tube	Do	6.8nn
2	Length of tube of polymer	L	3.0 m
3	No. of turns of coil	N	78 turns
4	Pitch of coil	P	32
5	Outside diameter of Coil	Dc	158mm

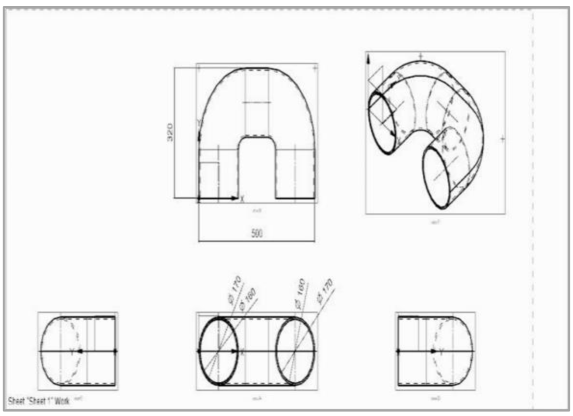

Figure 9: 2 –D drawing of the tube

12. Experimental data and basic calculation

Table 5 Temperature readings of the HEX during test

S.No	Cold water Inlet temp (T_{ci})	Cold water Oulet temp (T_{ci})	ΔT cold water	Hot water inlet temp (T_{hi})	Hot water outlet temp (T_{ho})	ΔT hot water
1	28	40	12	91	56	35
2	28	42	14	90	49	41
3	28	37	9	89	47	42
4	28	43	13	90	52	38
5	28	45	17	93	54	39

T_{hi} = Temperature of hot water at inlet = 90^0 C
T_{he} = Temperature of hot water at outlet = 41^0 C
T_{ci} = Temperature of cold water at inlet = 28^0 C
T_{ce} = Temperature of cold water at outlet = 38^0 C

1) LMTD (θm) = (θ1- θ2) / ln (θ1/ θ2)

Where θ1 = Thi –Tce = 62^0 C , θ2 = The –Tci = 13^0 C

LMTD (θm) = 42.838629 ^{0} C

Table 6 Mass flow rate of the hot water for calculating the capacity ratio

S. No	Volume in beaker	Time(sec)	Mass flow(kg/sec)
1	100	25	0.004
2	300	66	0.004545
3	500	104	0.004807
4	700	146	0.004794
5	900	180	0.005

Table 7 Mass flow rate of the cold water for calculating the capacity ratio

S. No	Volume in beaker	Time(sec)	Mass flow(kg/sec)
1	100	10	0.01
2	300	24	0.0125
3	500	44	0.01136
4	700	66	0.0106
5	900	83	.01084

2) The overall heat transfer coefficient can also be experimentally obtained from the heat duty as follows:

U = 0.34486 / (0.0528) x 42.8386
U = 0.152 W/ m^2k

3) Capacity ratio: C
C = (m Cp)small / (m Cp)large
= 0.077 / 0.33486
C = 0.2299

3) Effectiveness: (ε)

ε = (Thi – The) / (Thi - Tci)

ε = (90-50)/ (90-28)
=.645

Table 8 Result table

S.No	mCp T (hot water)	mCp T (Cold water)	LMTD	U W / m2 k	Capacity ratio	Effectiveness
1	0.31 2	0.01	36.54	0.159	0.256	0.593
2	0.31 1	0.01 2	34.05	0.168	0.299	0.621
3	0.33 3	0.01 1	43.03	0.145	0.25 0	0.641
4	0.30 2	0.01 0	33.03	0.168	0.30 5	0.631
5	0.32 65	0.01 0	35.05	0.170	0.32 0	0.620

13. Fouling Factor

Phenomena in which there is a decomposition of the metallic tube due to the deposit of impurities on its surface after the continuous flow of the working fluid.These depositions not only degrade the metallic counterparts but also the effectiveness. Fouling is occurred by these reasons:

- Low fluid velocity
- Low wall shear stress
- Reaction of the products to the metal

Fouling factor is a function of resistance to flow of fluid due to scaling in the heat exchanger, especially at the hot water side , in case of the u-shape fluoro polymer heat exchanger we shall compare the flow rates at various percentage of valve opening for the flow control valve opening in the condition where the conventional flow will be compared to the flow through the

Table 9 Fouling factor of u-tube HEX

S. No	Percentage opening of Valve	Flow rate for conventional method w/o u-polymer	Flow rate for u -polymer heat exchanger	Fouling factor
1	50	0.011577	0.012001	1.036624341
2	60	0.014061	0.012002	1.034538951
3	70	0.015144	0.013286	1.063769231
4	80	0.016407	0.015667	1.065445459
5	90	0.0187	0.012182	1.735

14. Result and Discussion

From the above collected data using polymer tube in HEX it is clear that the whole process of the heat transformation is similar to any other heat exchanger. As these are shock resistance, chemical inert and fully drainable the problem of cavitation and chocking is not occurred. In this way the life and durability of the instrument is increased. On the other hand the quality of the fluid is also remain unchanged. When the LMTD is decreased the overall heat transfer rate is increased, also the effectiveness is increasing. Capacity ratio is increased. The maximum fowling takes place at 70% valve opening.

Conclusion

The interest in polymer materials used for the design of heat exchanger heat exchangers applications has been driven by their high chemical stability and their resistivity towards corrosion. It was shown that through the use of a polymer coating and polymer tubing, heat recovery from solvent-laden streams is possible. However, because of the low thermal conductivity of polymers, using polymers in a standard design configuration will likely result in a dominating heat transfer resistance by the polymer walls . But by using very thin polymer structures, both plate and tubular heat exchangers can be successfully designed, constructed, and tested with their performance being comparable to conventional units at lower cost and reduced weight. By using polymer matrix composites, light weight heat sinks have been built that achieve similar performance as the copper equivalent. If one considers the advances made in composite materials, as well as the new emerging technologies such as nano scale composites, it is clear that, through careful material selection and design modification, the incorporation of polymer materials into HVAC&R applications has a bright future.

1) By the experimental model and the available data it can be concluded that the heat exchangers constructed by the polymers can be used in the corrosive environment. These are the applications having small volume.
2) Another important application of the polymer heat exchanger is there low temperature water heating, where the thermal resistance of the polymer is relatively large part of total and thin wall.
3) Using the polymer HEX the cost of the exchanger is reduced up to 5 and 6 lakh per annum. In this heat exchanger all the operations are as same as in any other traditional HEX. But by using the fluoropolymer heat exchanger one may be able to reduce the fouling as well as the corrosion which optimize the cost of the arrangement as well as its maintenance.

Nomenclature

Symbol	Discription
U	Overall heat transfer co efficient
A	Total surface area of the exchanger
T_i	Inlet temperature of the tube
T_o	Outlet temperature of the tube
C	Capacity ratio
T_o	Outlet temperature of the shell
T_{si}	Inlet temperature of the shell
F	Fouling factor
H	Mass flow rate of the cold fluid
$TC_{p(cold)}$	Specific heat of the cold fluid
$C_{p(hot)}$	Specific heat of the hot fluid
$T_{(cold)}$	Temperature of the cold fluid
$T_{(hot)}$	Temperature of the hot fluid
Re	Reynold no
Nu	Nusselt No
ε	Effectiveness

References

Fouling of heat exchanger ISBN 0444821864, Elsevier science and technology book .BOTT T.R.(1995)

Tonelli C., Gavozetti P., Strepparola E (1999), Linear per fluoropolyethers difunctional oligomers: chemistry, properties and application Jouranal of fluoirne chemistry, Vol. 95 pp 51-70Forster M. Bohnet . M (1999) Influence of the interfacial free energy crystal/heat transfer surface on the induction period during fouling, *International journal of thermal sciences ,* Vol .38 ,pp. 944-954

Fabbri p.,(2007) coatings on perfluropolyethers to make it Hydrophobic and oleophobic of the sol-gel method, *Advances in polymer technology,* Vol. 25 ,No. 3 , pp. 182-190.

Zhao Q., Liu Y., Wang C., Wang S. And Muller Steinhagen H (2005) , Effect of surface free energy on the adhesion of biofouling and crystalline fouling , *Chemical Engineering Science ,* Vol. 60 pp 4858-4865.

Costa A.L.H.,(2008) Design optimization of shell and tubes heat exchanger *Applied thermal engineering,* Vol .28, pp 1798-1805.

.Malayeri M.R., A1 Janabi A., Muller Steinhagen H (2009) Application of nano –modified surfaces for fouling mitigation , *International Journal of Energy Research,*Vol. 33 pp 1103-1113.

Martinelli E., Agostini S., Galli G., Chiellini E ., Glisenti A., Pettit M.E., Callow J.A., Graf K., and Bartels F.W (2008) Nanostructured films of amphiphilic fluorinated block copolymers for fouling release appilication ,*Langmuir* Vol. 24, pp 13138-13147.

Rosemaninho R., Santos O., Nylander T.,Poulsson M., Beuf M.,Benezech T., Yantsios S., Andristos N., Karabelas

A., Rizzo G., Muller Steinhagen H., And Melo L.F (2007) Modified stainless steel surfaces targeted to reduce fouling- Evaluation of fouling by milk components , *Journal of food engineering*, VOL . 80, PP1176-1187

Zhang H., Lamb R., Lewis J(2005) Engineering nanoscale roughness on hydrophobic surface preliminary assessment of fouling behavior, *Science and technology of advanced materials* ,Vol. 6 pp236-239.

Mamunya, Y., Davydenko, V., Pissis, P., Lebedev, E., 2002. Electrical and thermal conductivity of polymers filled with metal powders. European Polymer Journal 38, 1887–1897

Krupa, I., Choda´k, I., 2001. Physical properties of thermoplastic/ graphite composites. European Polymer Journal 37, 2159–2168.Norley, J., Chen, G.G., 2002. High performance, lightweight graphite heat sinks/spreaders, Proceedings of PCIM 2002, Nu¨rnberg, Germany.

Weber, E.H., Clingerman, M.L., King, J.A., 2003. Thermally conductive nylon 6.6 and polycarbonate based resinsdI. synergistic effects of carbon fillers. Journal of Applied Polymer Science 88, 112–122.

Boudenne, A., Ibos, L., Fois, M., Gehin, E., Majeste, J.C., 2004. Thermophysical properties of polypropylene-aluminum composites. Journal of Polymer Science part B 42, 722–732.

Serkan Tekce, H., Kumlutas, D., Tavman, I., 2007. Effect of particle shape on thermal conductivity of copper reinforced polymer composites. Journal of Reinforced Plastics and Composites 26, 113–121.