Use of Polymeric Composite Materials in Shell and Tube Type Heat Exchanger to Increasing the Performance

Hitesh Makwana[1] Dr. Gajendra Asthana[2]
PG Student, M.E. Thermal
Associate Professor, Department of Mechanical Engineering
L.J.I.E.T, Ahmedabad-54, Gujarat, India

Abstract--- The project compares the non-metallic/polymer heat exchangers to the current technology in metallic heat exchangers. A review of state of the art of polymer heat exchangers is presented and technological problems are identified. Simulation models were developed and used to explore the thermal-hydraulic, packaging and weight tradeoffs associated with polymer heat exchangers. Finally, the results are used to provide essential background for deciding if and where to allocate resources to more detailed analyses and prototype development.

I. INTRODUCTION

The conductivity of non-metallic/polymer tubes in heat exchangers is ~1000 times less than their metallic counterparts. But polymer/non-metallic heat exchangers could offer such benefits as design freedom, low thermal expansion, chemical resistance etc. This project analyzes the thermal-hydraulic and weight tradeoffs associated with polymer heat exchangers, to provide essential background for deciding if and where to allocate resources to more detailed analysis and prototype development.

After going through several literatures which are available we concluded that following the following could be some of the possible future applications for polymer heat exchangers

1. As refrigerators become more efficient, we can possibly replace the steel skin (wrapper) of refrigerators with structural polymers, to reject condenser heat via natural convection. Water or refrigerant could possibly flow through the polymer (polycarbonate) in these hot wall condensers, if such plates could be designed to have high conductivity perpendicular to surface. Currently available rigid polymers are designed to have high conductivity parallel to the plate to diffuse the heat (e.g. in headers of car radiators) and are thus not suitable for use in refrigerators and building walls. But, in future if structural polymers with high conductivity perpendicular to the surface could be designed then these hot wall condensers could provide lot of design flexibility in rejecting the heat. Because of their dual structural/thermal use these heat exchangers might be much lighter, than the current ones, too.
2. Polymer tubes could be used as water loops, indoors and outdoors (from evaporator and condenser), with ultra-compact chillies having tiny charge of toxic or flammable refrigerant which has zero global warming potential (e.g. hydrocarbons, ammonia). This probably means having tube banks with small diameter tubes, thin walls and creative header design.
3. Similarly for automotive air conditioning, using propane with a water loop inside car could be another application. The same loop could be used for heating as well, using pumped heat or engine waste heat, or a combination. Currently in vans and SUV's it is hard to get oil returned from evaporator in back seat, so water loop might possibly be useful for R134a systems too, if the energy penalty were not too large.

Thus, the range of applications to be targeted, has been narrowed down and so the analyses in this report are focusing on some simple geometries like cross-counter flow tube banks. It is these low pressure applications (where the tube thickness is small) that the performance of polymer tubing can approach that of conventional metallic ones, and use of polymers could be viable. The following results will be expressed in terms of their effects on system efficiency, and the tradeoff with package volume and material requirements.

A comparison of liquid-to-liquid polymer heat exchangers with their metallic counterparts, based mainly on work conducted by Davidson et al., is presented in section 1.2.1 and 1.2.2. In section 1.3, a nylon polymer-to-air heat exchanger, used in secondary loop with a vapor compression system, is simulated and compared to a micro channel condenser.

Thus, the range of applications to be targeted, has been narrowed down and so the analyses in this report are focusing on some simple geometries like cross-counterflow tube banks. It is these low pressure applications (where the tube thickness is small) that the performance of polymer tubing can approach that of conventional metallic ones, and use of polymers could be viable. The following results will be expressed in terms of their effects on system efficiency, and the tradeoff with package volume and material requirements.

A comparison of the polymer heat exchanger with copper one is given in Table 1.2.1.1. It is interesting to note that the thin-walled nylon heat exchanger has a very similar performance as the copper heat exchanger.

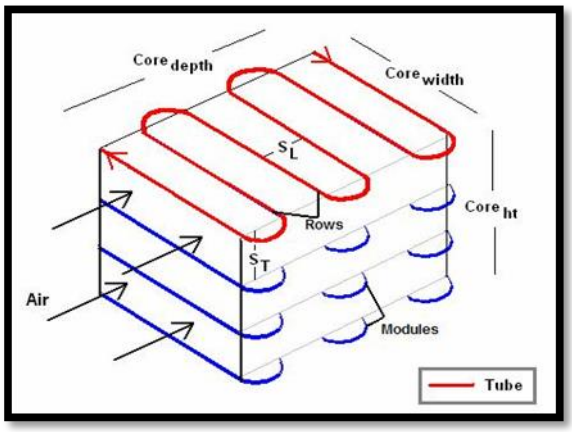
Table 1.2.1.1 Heat transfer surface areas for tube-in-shell HX at 5.7L/min [1]

Heat transfer capacity	PEX	Nylon	Copper
3000 W	1.78 m^2	0.50 m^2	0.50 m^2
6000 W	7.78 m^2	2.16 m^2	2.19 m^2

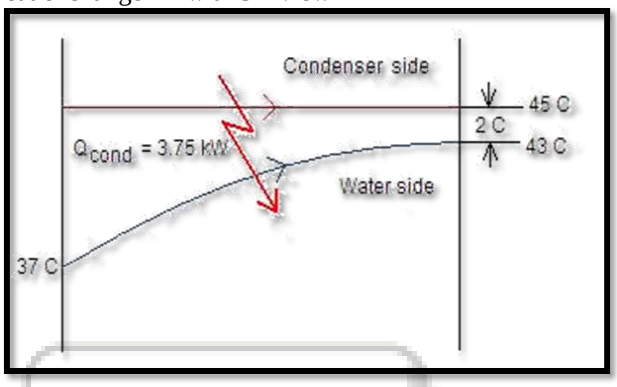
Heat transfer surface areas for immersed HX .

Heat transfer capacity	PEX	Nylon	Copper
3000 W @ 5.7L/min	4.21 m^2	1.89 m^2	1.10 m^2
6000 W @ 11.4 L/min	8.42 m^2	3.78 m^2	2.03 m^2

All rights reserved by www.ijsrd.com



Heat exchanger – with 3D view



A NXN system model, shown in Figure 1.3.1.3, was developed in EES to explore the design space for an optimal polymer heat exchanger configuration which could then be compared to a typical metallic counterpart. For ease of analysis, the polymer heat exchanger has been modeled as a simple counterflow configuration. The modeling and analysis has been done for a vapor compression a/c system having one ton cooling capacity. Also, the tubes have been assumed to be made of a commonly used material - DuPont's Nylon (Zytel HTN 51G15).

To provide a realistic system context for the optimization, the evaporator capacity, inlet air and water temperatures into the polymer hx, geometry variables like tube diameter, ratio of the outside diameter to the tube thickness (SDR – Standard diametric ratio), ratio of tube diameter to transverse/longitudinal pitch (D_{out}/S_L) etc. were specified and system performance parameters like COP, outlet air and water temperatures etc. were calculated. Initially, the face area was specified as 0.4 m^2, which is a typical value of the face area per ton for metallic heat exchangers. The aspect ratio (AR) was taken as 1, representing a square geometry.

A. Calculation :-

This vapor compression system efficiency was combined with the other component efficiencies to express the system COP as

$$COP_{sys} = \frac{Q_{evap}}{\left(W_{comp} + \frac{W_{fan}}{\eta_{fan}} + \frac{W_{pump}}{\eta_{pump}}\right)} \qquad \text{(Eq. 1.3.1.1)}$$

Variable	Value	Notes
Qevap	3.5 kW	1-ton
UAcond	0.86 kW/K	Assumed value
Dout	4 mm	Initial guess
SDR (Dout/ttube)	15	Initial guess
RatioSTDout	2	Initial guess
Aface	0.4 m^2	Typical of air cooled cond.
ΔTapproach,hx	2 C	Initial guess
Vw	0.00015m^3/s	Initial guess
Vface,air	1.0 m/s	Typical of air cooled cond.
Tair,in	35 C	Rating condition
Tevap	12 C	Ensure dehumidification
ΔTsup	5 C	TXV or EEV
ΔTsub	5 C	Typical at rating condition
ηpump/fan	0.2	Assumed pump/fan efficiency
ηisen	0.7	Assumed isentropic efficiency
ktube	0.31 W/mK	Nylon conductivity

Table 1: Outputs from hot HX simulation

Output	~Value
tube	0.26 mm
Corewidth	0.63 m
Coreheight	0.63 m
Coredepth	0.30 m
nrows	38
nmodules	79
ntotal	3010
Tw,,in,hx	45.8 C
Tw,out,hx	39.6 C
Tair,out	43.8 C
UAhx	1.3 kW/K
COPcyc	4.28
COPsys	4.06

At this point, it would be appropriate to establish a benchmark COP for a better understanding of the effect of different parameters on the polymer heat exchanger performance and overall system performance. Also, this allows us to quantify the inefficiencies incurred by adding a secondary heating loop instead of using the condenser to directly heat the air. Consider the vapor compression cycle shown in Figure 1.3.1.7 in which there is no pressure drop in the condenser and the condenser temperature is equal to the ambient temperature. The remainder of the cycle is characterized by 5°C superheat, a 12°C evaporator temperature, and an isentropic efficiency of the compressor of 0.7. The COP_{cyc} of such an idealized cycle was found out to be ~6.8. This is the thermodynamic limit to the COP_{cyc} which can be achieved by within the given evaporator and the specified ambient temperature, allowing for the possibility of near-infinite condenser air flow rate.

All rights reserved by *www.ijsrd.com*

Table2: Parameter constraints for multi-dimensional optimization

Variables	**Bounds**	**Notes**
Dout	3 – 6 mm	Lower bound – Manuf. limit
RatioSTDout	1.5 – 3.5	Typical range
Vdot,w	Lower: 0.00012m^3/s - 0.00015m^3/s Upper - 0.00027 m^3/s	Lower limit varies according to ΔTapproach,hx
ΔTapproach,hx	2°C – 5°C	Typical range

Table 3: Results for optimal configuration

Variables	**~Value**
Dout	6* mm
RatioSTDout	1.5*
Vdot,w	0.00041 m^3/s (6.5 gpm)
ΔTapproach,hx	3.5°C
Outputs	**~Value**
Corewidth	0.63 m
Coreheight	0.63 m
Coredepth	0.20 m
Corevolume	0.08 m^3
Nrows	23
Nmodules	70
Ntotal	1600
Tw,in,hx	13.0°C
Tw,out,hx	15.0°C
Tair,out	16.6°C
UAhx	0.56 kW/C
COPcyc	5.42
COPsys	5.28
Volumepolymer	0.007 m^3
masshx	8.0 kg
masswater	21.5 kg

Parameter at lower/upper bound

II. Conclusion

The state of the art of polymer heat exchangers was reviewed, and their suitability for HVAC&R applications assessed. Currently such heat exchangers are used primarily in corrosive environments. These are small-volume applications where customized tradeoffs can be made between material properties and thermal performance and cost penalties. Another class of applications is low-temperature water heating, where the thermal resistance of the polymer is a relatively large part of the total and thin walls are necessary to achieve thermal performance levels comparable to their metallic counterparts. Potential applications in HVAC&R, however, are likely to be air-side dominated, so thin walls may not be the most critical factor. Two other factors were found to limit the thermal-hydraulic performance potential: 1) conductivity is too low for polymers to be used for extended surfaces; and 2) conductivity in structural polymer materials (e.g. polycarbonate) can be enhanced relatively easily in the direction parallel to the plate surface but with great difficulty perpendicular to it. That is why the use of such structural polymers have been limited to diffusing heat from hot spots (e.g. in auto radiator headers) and they would be unsuitable for wall panels or refrigerator wrappers.

A simulation model was developed to get a quantitative estimate of the thermal and material tradeoffs incurred by using polymers in a heating coil tube bundle. Results for a hypothetical 1-ton a/c system showed that systems with optimally-configured polymer heat exchangers could achieve thermal performance similar to their metallic counterparts. But, because of lack of extended surfaces, exchangers are ~ 6 times more massive, and occupy ~ 20 times more volume than conventional microchannel heat exchangers.

The simulation model was also used to explore the potential for using polymer materials to construct tube bundles for cooling coils and cooling tower applications. Such heat exchangers could conceivably be used in secondary loops to facilitate charge minimization in chillers and in systems using toxic or flammable refrigerants, e.g. in vehicles and residential applications. Again, the results showed that an optimally-configured 1 ton a/c system with polymer heat exchangers could achieve thermal performance similar to their metallic counterparts. But, the polymer heat exchanger would be ~ 8 times more massive and occupy ~10 times more volume than conventional tube and fin coils. This estimate is based on a 'fully wet' coil and represents a lower bound on such heat exchangers. Actual coils, which might be running fully/partially dry, would be even more massive.

References

[1] Davidson, J. and S. Mantell, "Use of polymers in liquid-to-liquid heat exchangers; Applied to low-cost solar water heating systems", Task III Report, University of Minnesota, 1998.
[2] Heating, L. W., J. H. Davidson, R. Raman and S. C. Mantell, "Thermal and economic analysis of plastic heat exchangers for solar water", Proceedings SOLAR '99, ASES, Portland, ME. http://www.me.umn.edu/divisions/environmental/solar/research.htm
[3] Shannon, M. A., M. L. Philpott, N. R. Miller, C. W. Bullard, D. J. Beebe, A. M. Jacobi, P. S. Hrnjak, T. Saif, N. Aluru, H. Sehitoglu, A. Rockett and J. Economy, "Integrated mesoscopic cooler circuits (IMCCS),"
[4] Proceedings of the 1999 International Mechanical Engineering Congress and Exposition, Nashville, TN,AES-Vol. 39, pp. 75-81, November 1999.
[5] http://www.microplastics.com/Materials/NYLON%2066.htm
[6] Barnes, P.R. and C. W. Bullard, "Minimizing TEWI by charge reduction in a compact chiller", ACRC TR-176, August 2000.
[7] Davidson, J., University of Minnesota, personal communication, 2004.
[8] Rubio, M., Fafco Co., personal communication, 2004.
[9] Gneilinski, V., "New equations for heat and mass transfer in turbulent pipe and channel flow", Int .Chem.Eng., Vol. 16, pp. 359-368, 1976.
[10] Churchill, S. W., "Friction-factor equations spans all fluid flow regimes", Chemical Engineering, pp. 91-92, 1977.
[11] Zukauskas, A. and Ulinskas, R. "Efficiency parameters for heat transfer in tube banks", Heat Transfer Engineering, 6:2 pp 19-25, 1985.

All rights reserved by *www.ijsrd.com*