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Polymer Material Heat Exchangers Application in Refrigerant Cycles

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ABSTRACT

Special heat exchanger made out of polymer materials have been developed and applied in refrigeration systems. The initial purpose was to provide corrosion resistant heat exchangers for the rejection of heat into sea water for an improved efficiency compared to regular air cooling of A/C and refrigeration system condensers. Another application was the corrosion resistant heat exchanger for heat rejection or heat extraction to resp. from ground source water in A/C and heat pump installations. In a further step the polymer material have been used as solution heat exchanger (HEX) for ammonia/water absorption-resorption cycles with the advantage that this fluid pair allows cooling below 0°C and that the resorption reduces the pressure level for a further extended application of polymer material heat exchangers. As a next option modified polymer HEX will be used as desorbers and absorbers in ammonia/water cycles. A further step leads to the application of polymer HEX equipment for evaporation and condensing in compression cycles with maximum pressure below 5 bar.

1. INTRODUCTION

Polymer materials have become common in daily life and gaining increasing importance as technical design component. Advantages are low weight, corrosion resistance and easy production processes. However the application of polymer materials in heat exchangers of refrigeration equipment is not common. Reasons are the properties of polymers such as the low heat conductivity, the limited tensile strength and the limited thermal stability.

Figure 1: Raw material prices of copper /LME/

Different reasons can be found for a reconsideration of polymer materials for the application in heat exchangers. One reason is the decreasing resources of typical heat exchanger materials and the increasing raw material prices. Figure 1 shows as example the increase of copper prices with time.

Other reasons for a stronger interest in polymers as construction material for heat exchangers is the corrosion resistance. This is an interesting property if heat transfer with highly corrosive fluids is considered. Examples are sea water or ground water as source for heat pumps or as think for ground or seawater cooled systems. Current applications of polymer materials in heat exchangers of refrigeration systems include:

- Corrosion resistant coated heat exchangers;
- Integrated evaporators in the body of household refrigerators;
- Ice cold storage equipment.

Figure 2 shows the structure of a house hold refrigerator, where the evaporator tubes are under the inner surface. The inner liner of the refrigerator, which is typically formed out of polystyrene or a similar polymer, and the tubes of the evaporator, which are wrapped around the refrigerators inner liner are kept in position by the structures foam. Thus the inner liner of the refrigerator is finally a part of the evaporator, as the transferred heat has to pass it.

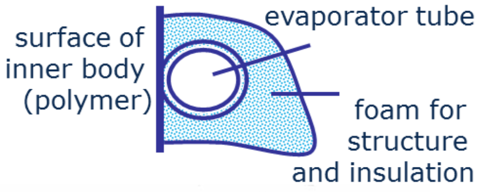

Figure 2: Evaporator tube and inner liner of a refrigerator with integrated evaporator

Another example of application of polymer materials is the application in ice storage devices, where a secondary refrigerant is used /FAF/.

2. CHALLENGES FOR POLYMERS IN HEAT EXCHANGE APPLICATION

For the application in heat exchangers the most important material property is the thermal conductivity. Table 1 shows a comparison of the thermal conductivity. It is obvious that there is a significant difference in the magnitude 10E2 to 10E3 between polymers and metals.

Table1: Thermal conductivity of some metals and polymers

Material	**Thermal Conductivity W/(K m)**
PE	0.33 - 0.57
PEEK	0.25
Cu (pure)	401
Cu (commercial)	240 - 380
Al 99,5%	236
Steel	48 - 58
Steel (SS)	15

Therefore polymers today are only used in heat exchange applications, where the heat transfer resistance on one of the fluid sides is huge, like for example in a refrigerator with free convection and a typical overall heat transfer coefficient in the range of 3 to 4 W/(m² K).

Applications with high performance heat transfer would require minimal thickness of the polymer material to reduce the heat conduction resistance. This leads to the conclusion that polymer material based heat transfer walls become thin films. This raises the question about the tensile strength of polymer materials.

Table 2: Tensile strength of some metals and polymers

Material	Tensile strength MPa
PE	30
PEEK	97
Cu	200
Al 99,5%	75 - 110
Steel	310 - 630
Steel (SS)	700 - 1300

Table 2 gives a comparison of some metallic and polymer materials. Tensile strength of polymer materials is lower compared to metallic materials. However the difference is lower than for the thermal conductivity.

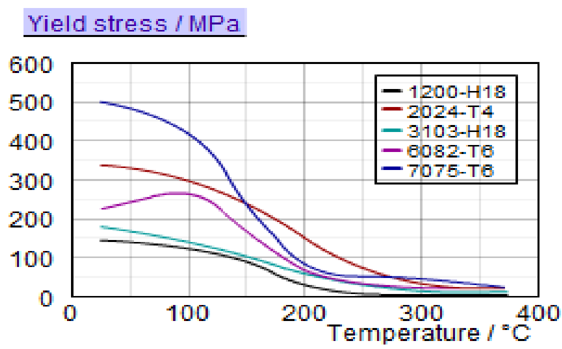

Figure 3: Reduction of yield stress of aluminum with temperature /ALU/

To make the task even more challenging the mechanical strength of the polymers is significantly reduced with increasing temperature; this effect is even more than for metallic materials as illustrated in Figure 3 for aluminum. As a further boundary condition the thermal resistance limits the application of polymers to lower temperatures. However while the limitation for PE (poly ethylene) is quite small, high performance polymers like PEEK (poly ether ether ketone) allows a range sufficient for many applications in refrigeration.

Table 3: Temperature of application for PE and PEEK

Material	Min. Application Temperature °C	Max. Application Temperature °C	Max. Temperature for Short Term °C
PE	-80	90	100
PEEK	-65	240	300

Regarding a typical high performance metal plate HEX in Figure 4, the heat transfer performance is increased by means of a structured surface leading to turbulent flow regime and an increase of the available surface area. This approach is not applicable for very thin polymer films if significant mechanical stress is applied.

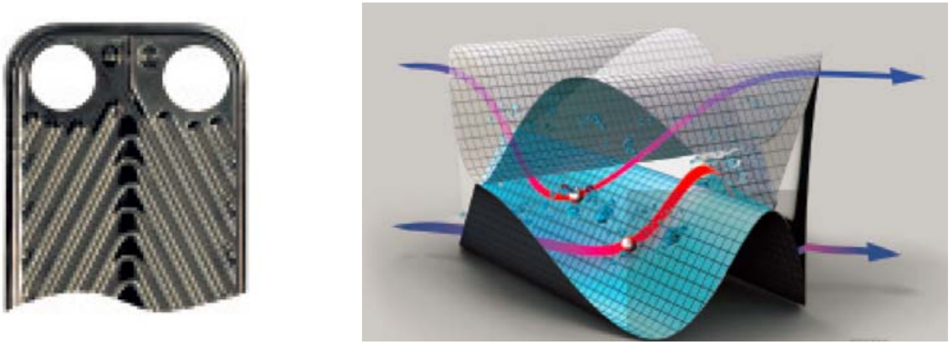

Figure 4: Metallic plate heat exchanger /DAN/

The combination of a low thermal conductivity and a reduced mechanical stability of polymers leads to the conclusion, that the utilization of polymer materials in high performance HEX applications requires totally new design approaches with very thin materials, reduced mechanical forces on the material and alternative solutions to achieve turbulent flow regimes.-

3. REALIZATION OF NEW POLYMER HEAT EXCHANGERS

The authors company[2] recently developed a new type of polymer HEX which can meet the requirements for evaporators, condensers and solution heat exchanger in cooling and refrigeration cycles. One main advantage of a polymer based HEX is the fact that no corrosion will occur in an aqueous environment. Further advantages are the reduced weight compared to metal based solutions especially for mobile applications and the possible use of low cost polymer commodities like polyolefin for applications below 80 °C.

Main component of the HEX are polymer films with a thickness in the range of 0.05 to 0.1 mm. Because a plate design would be only applicable for such thin films when no pressure forces occur, the basic design of the HEX is a spiral geometry.

To guarantee a sufficient mechanical strength of the flow channel geometry a structured spacer is applied between the polymer films, which is illustrated in Figure 5. Because a biaxial mesh structure is used, heat transfer can be enhanced due to a turbulent flow regime already at low liquid loads.

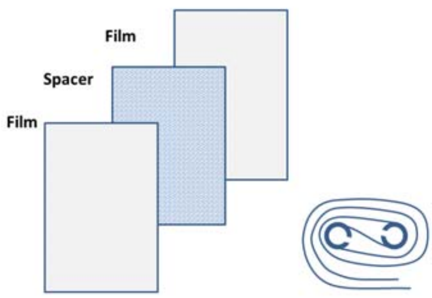

Figure 5: Polymer foils heat exchanger

The first HEX generation was developed for liquid / liquid applications. In Figure 6 the basic design is illustrated in a flat projection, which can be regarded as the initial state before the winding process of the spiral.

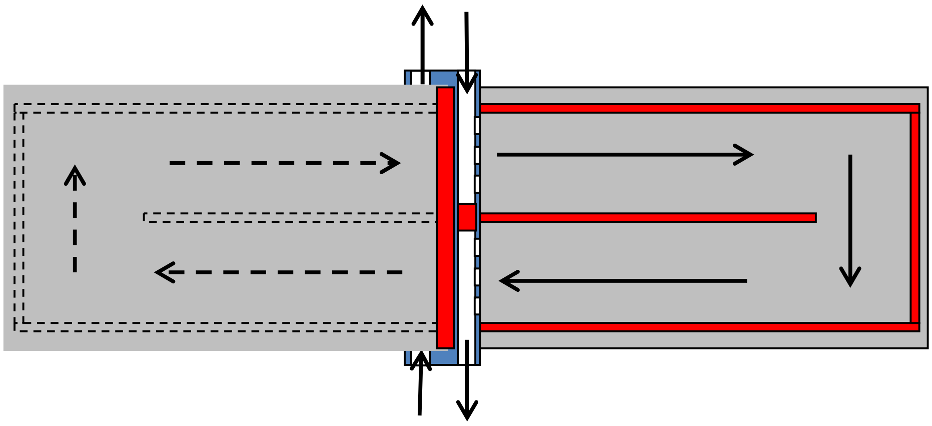

Figure 6: Basic design of a spiral HEX using polymer films

The HEX consists of a central body with two tubes for liquid in- and output. Two polymer films (grey in Figure 6) are glued on this central body in a way that winding leads to two flow channels, each connected to one of the tubes. In each of the channels meshes (as illustrated in Figure 5) are integrated to guarantee the channel geometry and to mechanically stabilize the film. The red lines in Figure 6 represent glues to define the flow direction of the liquids which are illustrated by black arrows. After winding of the films an additional potting at the front ends and a tube type housing lead to increased pressure resistance.

One main advantage of a polymer based HEX is the fact that no corrosion will occur in an aqueous environment. Therefore very promising applications for this type of liquid / liquid HEX in the refrigeration sector are solution heat exchangers in absorption or resorption systems or the use of sea water for heat rejection for all kind of cooling equipment.

For non-aqueous applications the film, mesh and glue materials can be chosen depending on the required chemical resistance. For elevated system temperatures above 90 °C and high system pressure high performance polymers can be applied. Characteristic data and limitations of today's polymer spiral HEX are summarized in Table 4.

Table 4: Spiral HEX data for liquid / liquid applications

HEX diameter	0, 1 – 0,4 m
HEX height	0,3 - 0, 8 m
HEX –weight	1 - 10 kg
Heat transfer	0,5 – 3 kW/K
Typical pressure drop	150 – 400 mbar
Typical liq. volume flow	0,2 – 1,5 m³/h
Maximum system pressure (20 °C)	9 bar
Maximum system pressure (90 °C)	5 bar
Maximum system temperature	120 °C
Maximum pressure difference between channels	3 bar

4. POLYMER HEX FOR GAS / LIQUID APPLICATION

For most gas / liquid applications the high pressure drop of the flow regime in the spiral channel is a serious disadvantage. Therefore the HEX design has been modified for all applications which require a low pressure drop for one of the streams. In Figure 7 this basic design is illustrated in a state before the winding of the spiral.

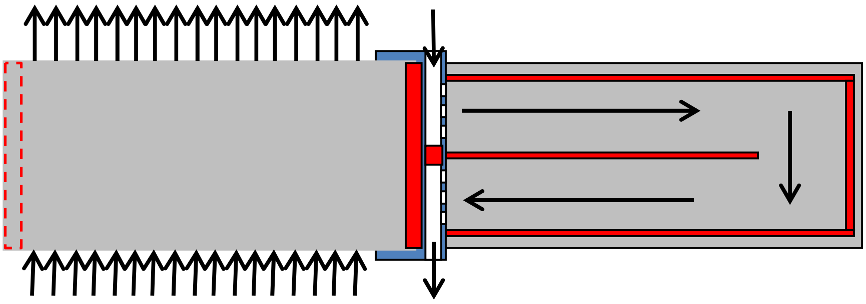

Figure 7: Basic design of a spiral HEX for gas / liquid applications using polymer films

The design is changed to a cross counter current flow regime. Now one stream, preferable the gas is flowing in axial direction through the HEX with reduced pressure drop while the second flow remains in the same regime as for the liquid / liquid HEX design. For this kind of HEX additional hoods are required at the front ends for the separate in- and outlet of the liquid and gas streams.

This design is very interesting for applications like condenser, evaporator and desorber in refrigeration cycles. A first prototype is currently tested as condenser at temperatures about 100 °C and pressures near atmospheric pressure. If the system temperature remains below 60 °C, polyolefins are suitable materials for film and meshes leading to low material cost.

Current investigations concentrate on the tasks of the reduction of pressure drop, improvement of heat transfer performance for the gas flow and the reduction of weight in combination with a further increased pressure resistance.

5. APPLICATION OF POLYMER HEX IN REFRIGERATION

The first test of the new polymer HEX was performed with a compression heat pump using ground water. Here the HEX was used to protect the heat pump by installing an intermediate circuit between heat pump and ground water, /KI2010/. To have only a moderate decrease in heat pump efficiency, the mean driving temperature difference should be below 5 K. This can be easily achieved with the authors[2] design tools for different applications. Because a standard heat pump can be used, the total invests for utilization of ground or sea water is reduced when using a polymer HEX to separate machine and water source. This can be done as well if heat rejection of AC units to sea water or swimming pools shall be realized. All applications of this kind will lead to a significant increase of the COP and thus relevant savings of electricity compared to an air based solution.

Currently the HEX is tested at the authors[2] facility as solution heat exchanger in a resorption refrigeration plant using ammonia water solutions at different concentrations, Figure 8. The plant design is explained in /DKV_ H/.

In the next step the set-up of a compression refrigeration cycle with polymer based evaporator and condenser is planned. The material selection for the HEX components: film, spacer and glue, depend on the choice of the refrigerant. The main requirement for polymer application at today's development stage is a condenser pressure below 5 bar.

Figure 8: Resorption plant with two polymer HEX as solution heat exchanger

As a very promising future application for polymer HEX equipment, NH_3-H_2O solution cycles with gas compression have been theoretically investigated at the TU Dresden in comparison with conventional water chillers and compression heat pumps. Here the corrosion resistance is the main advantage for polymer HEX. /DKV_A/

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