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Numerical Study for Connecter and Section Shape of the Internal Heat Exchanger on Automotive Air Conditioning

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Abstract

Regulations affecting the refrigerant used in automotive air conditioning systems are gradually being made compulsory. The Global Warming Potential (GWP) of R-134a refrigerant, which is typically used for conventional automotive air conditioning, is very high. It was therefore necessary to create a new one with a low GWP value, and R-1234yf refrigerant was the result.The new refrigerant solves the GWP problem (its GWP is much lower); however, when it is used, there is a drop in system cooling performance and efficiency. To solve the performance problem, a new automotive cooling system was developed, based on the inclusion of an Internal Heat Exchanger (IHX). The purpose of this study was to verify the effectiveness of the type of IHX pipe-sections and the shapes of connecters, which are welded on the both ends of the IHX pipes in the newly developed system. In the study of the types of IHX pipe-sections, there was a small difference in the efficiency of the jointed and extruded IHX pipe designs.In the study of the connecter shape, the highest heat-transfer rate was achieved by the connecter with the least width. The heat-transfer volume was 385.68 watts. These results confirm that the connecter shape and width influences the effectiveness of heat transfer, and that this effect is greater than that caused by differences between these two pipe-section types.

Keywords: Automotive Air Conditioning, Internal Heat Exchanger, Refrigerant, R-134a, R-1234yf

1. Introduction

Automotive air conditioning system provides a comfortable cabin environment for the driver and occupants. Such systems are also important safety features in that they allow for defogging and defrosting the glass inside the automotive. However, the global warming problem, part of which in attributed to the refrigerant (R-134a) currently used for most automotive air conditioning, has become an international issue. Furthermore, limitations on this refrigerant have consistently been imposed by the Montreal and Kyoto Protocols[1].

The Global Warming Potential (GWP) of R-134a refrigerant is 1,430; so this refrigerant seriously influences global warming. There was an obvious need for a new refrigerant with a lower GWP value, and R-1234yf (with GWP = 4) was the result[2]. The replacement of R-134a refrigerant by R-1234yf in automotive air conditioning systems has benefited reduction of global warming, but has also resulted in drops in cooling performance and efficiency. In response to this new challenge, a new cooling system was developed specifically for use with R-1234fy coolant. For the new air conditioning system, an internal heat exchanger (IHX) was added to provide heat transfer between the hot liquid and cool suction lines in this system.

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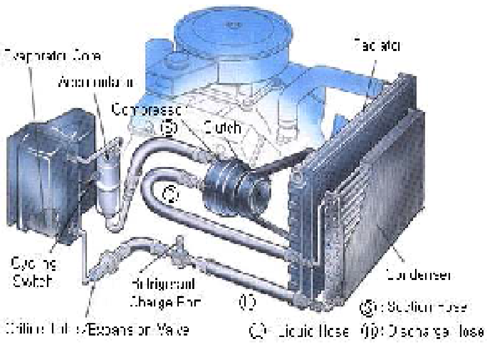

Figure 1. Typical automotive air conditioning system.

Figure 1 shows the configuration of a typical automotive air conditioning system, which consists of compressor, condenser, expansion valve and evaporator, and in this case, is operated using sequentially circulated R-134a refrigerant.

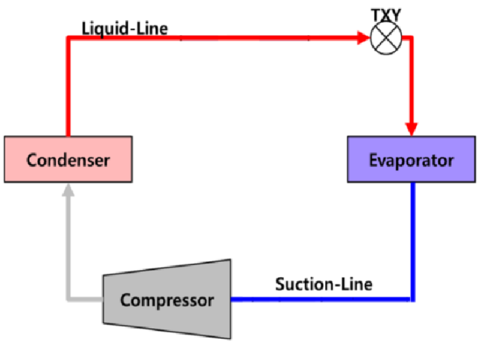

Figure 2. Flow diagram of the typical air conditioning system.

Figure 2 shows the flow diagram of a typical automotive air conditioning system. Note that there is no internal heat transfer between parts of the system, only that resulting from circulation of the refrigerant vapor.

In the new cooling system (Figure 3.), there is internal heat transfer in the IHX zone, between the overheated refrigerant liquid passing through the condenser, and the cooled refrigerant vapor passing through the evaporator. Cooling effectiveness is improved by the heat transfer between the heated and cooled fluids, and overall cooling efficiency is further increased by the use of less energy for operating the compressor[3].

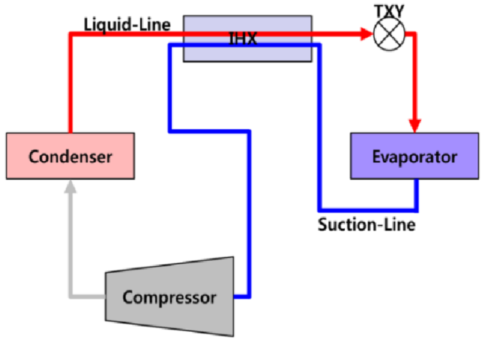

Figure 3. Flow diagram of the IHX air conditioning system.

The purpose of this study was to confirm the influence of the type of IHX pipe-section, and the shape of connecters (welded to both ends of the IHX pipes), on the performance of this new air conditioning system. Numerical analysis was conducted to determine the most effective condition for each part. In previous studies of IHX systems, the focus was comparison of the performance of the refrigerants. Navarro-Esbri et al.[4] and Cho et al.[5] conducted experiments comparing the performance of R-134a and R-1234yf refrigerants. Sahin et al.6 compared the performance of three coolants (for R-134a, R-404A and R-407C) in an IHX-based cooling system. In other words, there is little information about the impact of the condition of the components of the IHX system on its heat-transfer efficiency, and this is known to influence the effectiveness of other automotive air conditioning systems.

2. Shape of the IHX Section and Connecter

The new IHX system involved two aluminum pipes: a low-pressure suction line and a high-pressure liquid line. Figure 4 shows the newly designed IHX pipe-sections. The big section on the inside acted as a suction line and the small sections on the outside acted as a liquid line. The inner diameter of the inside suction pipe was Ø18; the outer diameter of the liquid pipe was Ø25. The first design-model (DM1) was made of jointed aluminum pipes. The second design-model (DM2) was made of extruded aluminum. These pipe-section shapes were designed according to factors such as their heat-transfer rate, ease of manufacture, economic value and potential for cost reduction. The numerical analysis was conducted to investigate the influence of the shapes of the IHX pipe-sections. Figure 5 shows IHX system sample with connecters welded at both ends of the IHX pipe.

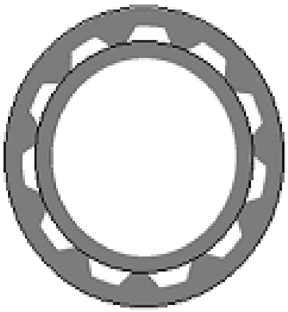

Figure 4. Design section shapes for the IHX pipe.

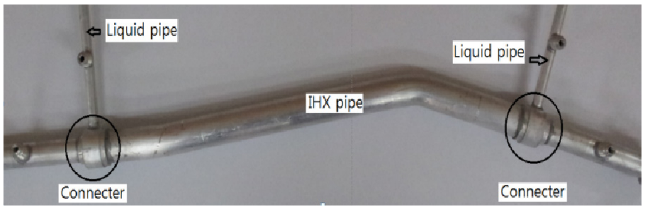

Figure 5. IHX pipe sample welded connecters.

The shape of the IHX connecters is another important factor in the heat-transfer rate. Because one connecter is welded to the liquid pipe, its shape should be optimized for maximum cooling efficiency. The shapes of the connecters were therefore analyzed to determine their effect on the heat transfer rate.

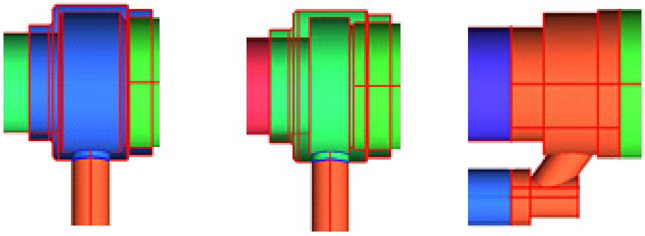

Figure 6. Designed connecters.

Figure 6 shows three connecter designs. The concepts affecting the design of these connecters included the possibility of connection with the IHX pipe, and the economic value of the material used (aluminum). In Figure 6, Model A shows the standard connecter type (width 14.3 mm) that has typically been used for this connection. Model B shows the minimized width of the connecter (just 9.3 mm), and Model C shows the horizontal liquid line welded to the connecter. The differential pressure and efficiency of heat transfer of these three types of connecters were analyzed using numerical analysis.

3. Numerical Analysis

Figure 7 shows the numerical analysis domain for the IHX pipes. The lay-out of the IHX pipes was adapted for the performance test. The length of the IHX pipe was 550 mm. This figure shows the inlets and outlets of the suction and liquid pipes, respectively. Table 1 shows the properties of the numerical analysis of the R-1234yf refrigerant. Table 2 shows the boundary conditions for the numerical analysis.

Analysis was conducted of the flow of R-1234yf refrigerant through the IHX pipes (see the pipe-sections in Figure 4). The pipe section that achieved the best cooling efficiency was chosen using the analysis results. The CFX program was used for the numerical analysis[7].

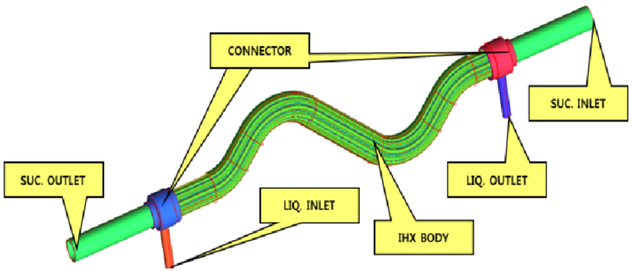

Figure 7. Analysis domain.

Table 1. R-1234yf thermodynamic properties

Properties	Unit	Value
Boiling point, T_b	°C	-29
Critical point, T_c	°C	95
P_{vap}, (25°C)	MPa	0.677
P_{vap}, (80°C)	MPa	2.44
Liquid density, (25°C)	kg/m^3	1094
Vapor density, (25°C)	kg/m^3	37.6

Table 2. Boundary conditions for the numerical analysis

Applied data	Unit	Value
Refrigerant pressure of liquid inlet	kPa(abs.)	1600
Refrigerant temperature of liquid inlet	°C	50
Refrigerant pressure of suction inlet	kPa(abs.)	300
Refrigerant temperature of suction inlet	°C	11
Refrigerant mass flow	kg/h	234

4. Analysis Results

The results from analysis of the differential pressure, flowing velocity, temperature and enthalpy of the pipe-section, are listed in Table 3. DM2 gave better enthalpy results than DM1. However, the differential enthalpy of DM1 and DM2 was just 2,284 J/kg. This difference was not considered significant. Since the manufacturing cost of DM1 was lower than that of DM2, DM1 was chosen as the experimental IHX pipe-section.

The results of the flow analysis for IHX DM1 and designed connecters are listed in Table 4. The liquid pressure drop and the amount of pressure drop, for Model B was about 0.82 kPa lower than for Model A. Even so the amount of heat transferred was about 10% higher than for Model A. For Model C, the amount of liquid pressure was about 0.5 kPa higher than for Model A and the amount of heat transfer was about 4% higher than for Model A.

Figure 8 shows the amount of the pressure drop in the liquid and suction lines in the connecter shape analysis. Figure 8 shows the amount of heat transfer in the IHX pipes for each type of connecter design. The smallest amount of pressure drop, and the greatest amount of heat transfer, occurred in the Model B connecter.

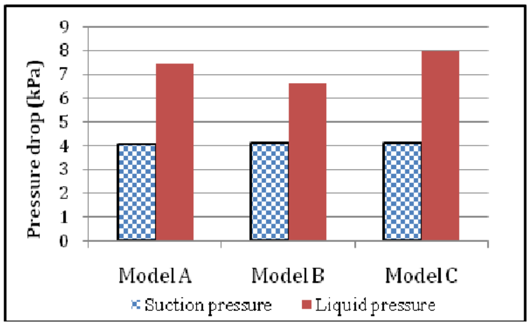

Figure 8. Amount of the pressure drop.

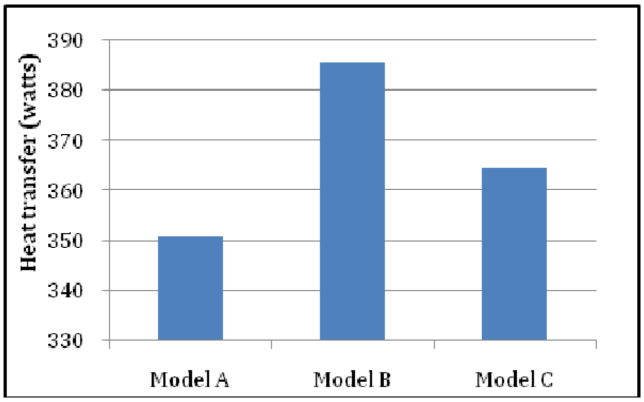

Figure 9. Amount of the heat transfer.

Table 3. Numerical results for the IHX pipe sections

	DM1			DM2		
	Inlet	Outlet	Δ	Inlet	Outlet	Δ
Suction pressure [kPa]	300	293.86	6.14↓	300	295.02	4.98↓
Liquid pressure [kPa]	1600	464.50	1135.50↓	1600	732.134	867.87↓
Suction velocity [m/s]	61.73	71.79	10.06↑	61.76	70.9	9.14↑
Liquid velocity [m/s]	32.73	32.25	0.49↓	42.47	43.37	0.9↑
Suction temperature [°C]	11	21.14	10.14↑	11	23.67	12.67↑
Liquid temperature [°C]	50	49.06	0.94↓	50	48.57	1.43↓
Suction enthalpy [J/kg]	424236	439381	15145↑	424236	441665	17429↑
Liquid enthalpy [J/kg]	37325	35927	1398↓	37325	35885	1440↓

Table 4. Numerical results for the connecter shapes

	Model A			Model B			Model C		
	Inlet	Outlet	Δ	Inlet	Outlet	Δ	Inlet	Outlet	Δ
Suction pressure [kPa]	300	295. 9	4.04	300	295.9	4.09	300	295.9	4.0
Liquid pressure [kPa]	1600	1592.5	7.41	1600	1593.4	6.59	1600	1592.0	7.9
Suction temperature [°C]	11	16.3	5.93	11	17.4	6.42	11	17.1	6.1
Liquid temperature [°C]	50	46.4	3.52	50	46.2	3.79	50	46.3	3.6
Suction Enthalpy [J/kg]	5.19	7.2	1.31	5.1	7.32	1.41	5.9	7.2	1.3
Liquid enthalpy [J/kg]	25.0	26.3	1.31	25.0	26.4	1.41	25.0	26.4	1.3
Heat transfer [watts]			351.1			385.6			364.6

These results were verified by the analysis results of the flow-stream of liquid refrigerant through the Model A and Model B connecters. There were vortices in the corners of the connecters. The vortex in Model A was bigger than that in Model A was greater than for Model B. This phenomenon influenced the total heat-transfer volume.

5. Conclusion

The operation of an IHX-based automotive air conditioning system was numerically analyzed to verify the influence of the type of IHX pipe-sections, and the shape of connecters, on heat-transfer efficiency. First, two kinds of pipe-sections were compared. The Model 1 was made of jointed pipes, and The Model 2 was made of extruded aluminum. The amount of the heat transfer for the extruded pipe was about 2,284 J/kg greater than for the jointed pipe-sections. Nevertheless, the jointed pipe was chosen as best IHX pipe because the difference in the amount of the heat transfer was not considered significant, and the manufacturing cast the Model 2 was cheaper. In the analysis of the connecter shapes, the connecter with the smallest width was selected because the smallest vortex in the corners of the Model B connecter reduced the pressure drop. These results verified that the type of IHX pipe-section and the shapes of connecters influence the heat-transfer efficiency.

6. Acknowledgement

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7. References

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