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TEMPERATURE DISTRIBUTION OF R-134a THROUGH ALUMINUM AND PTFE EXPANSION VALVE ON AUTOMOTIVE AIR CONDITIONING APPLICATIONS

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ABSTRACT

Generally, parameters for measuring the performance of air conditioning system is COP. In a thermodynamic analysis of air conditioning system, the losses that occur in the expansion valve is not considerable. In reality, the ice formation layer phenomenon is formed around the expansion valve during air conditioning system operation. Therefore, this paper presents a study of PTFE as expansion valve materials to reduce heat loss. The temperature distribution of R-134a refrigerant before and after the expansion valve was observed to determine its effect in comparison with expansion valve made of aluminum alloy. The AC system used in this study is a car air conditioning system that is removed from the car and driven by an electric motor. From the test results with the same refrigerant mass flow, the expansion valve made of PTFE generates potential heat absorption greater than the expansion valve made of aluminum. In conclusion, PTFE is promising to be developed as an expansion valve on car air conditioning system applications.

Keywords: PTFE, expansion valve, Ice formation layer, air conditioning, cooling effect.

1. INTRODUCTION

After the 1970s, automobile air conditioning systems (A/C) become essential equipment to meet the comfort in the vehicle [1-3]. However, the air conditioning system taking considerable energy from the engine to drive the compressor [4]. Imposition of AC increased fuel consumption and CO_2 emissions during vehicle operation [5-6]. Therefore, this paper presents a study of PTFE as expansion valve materials to reduce heat loss. The temperature distribution of R-134a refrigerant before and after the expansion valve was observed to determine its effect in comparison with expansion valve made of aluminum alloy.

On the other hand, the ozone depleting potential (ODP) and global warming potential (GWP) has become an important issue in the development of new refrigerants. Hydro-fluorocarbon (HFC) refrigerants with zero ODP have been preferable for use in many industrial, automotive, and domestic applications intensively. HFC refrigerants also have the appropriate specifications such as non-flammability, stability, and the vapor pressure is equal to CFC and HCFC refrigerant [7–9].

In addition, the potential of hydrocarbons (HC) such as propane (R-290) and butane (R-600) as an alternative for CFC and HFC refrigerant widely studied to improve the environmental effect. Alsaad [10] conducted a study of LPG to replace the CFC refrigerant. A mixture of 24.4% propane, 56.4% butane, and 17.2% isobutene obtained from household LPG is preferred. Evaporator temperature capable of reaching -15 °C at the condenser temperature of 27 °C, the ambient temperature of 20 °C, and COP of 3.4. A mixture R-290 and R-600 was studied by Wongwises [11] to replace HFC-134a. Experiments carried out under the same load of 25 °C. The results of this study indicate that the R-290/R600 at a ratio of 60/40 is the most appropriate mix of the performance of HFC-134a. Performance analysis of R290/R600a as a replacement for R134a is also given by Agrawal [12] that proved higher COP than R134a at a pressure of 80 Lb/In^2 and capillary diameter of 0.5 inches.

Although in recent year the air-conditioning system has been developed in absorption system [13–16], vapor-compression system still relied on the commercial car. The basic circuit and P-h diagram of vapor compression A/C system is presented in Figure-1 and Figure-2, respectively. Likewise, HFC R-134a is still an option for the new cars production or for replacement. In many country, the presence of a new refrigerant like R-290 or R-600 as an environmentally refrigerant has not been accepted widely because not fully forced by government policies.

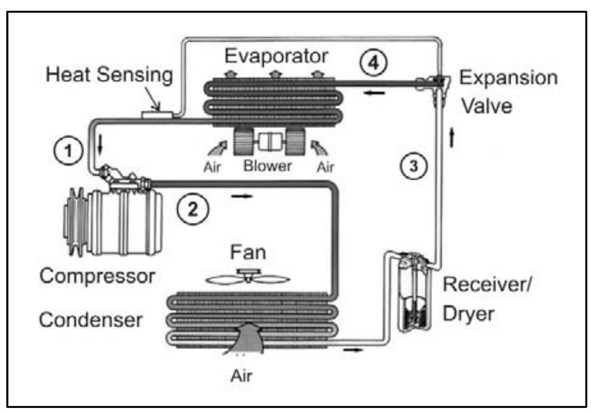

Figure-1. Basic of automotive AC cycle [17].

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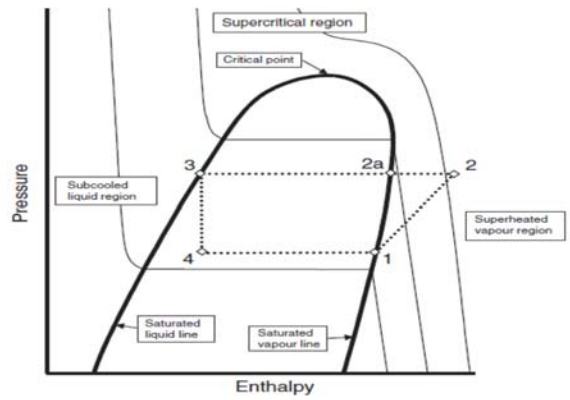

Figure-2. *P-h* diagram of vapor-compression AC systems.

Figure-2 shows a diagram of the pressure and the enthalpy of a vapor compression cycle. Refrigerant enters the compressor in a vapor phase is saturated at point 1. The refrigerant is compressed adiabatically and becomes superheated steam due to an increase in pressure, temperature, and enthalpy as indicated by point 2. Refrigerant at this point is above the temperature of the outside air. Then, the refrigerant is leaving for the condenser. During the condensers, heat from the refrigerant released into the outside air so that the change of superheated refrigerant into the saturated vapor at the point 2a.

Then, the refrigerant condenses into a liquid by releasing the latent heat of condensation. Condensation continues until all the liquid vapor becomes saturated at point 3. Subsequently, the refrigerant is expanded in iso-enthalpy through the expansion valve. When expanded, the pressure and the temperature will drop to below 0 °C. As a result, the heat of absorption will occur around the mouth of the expansion valve. Refrigerant flows through the evaporator which acts as a heat exchanger. The liquid refrigerant evaporates until it becomes saturated vapor then goes to the compressor to begin the cycle again [17].

As is known, one of the parameters for measuring the performance of air conditioning system is COP [18–23] . COP compares the refrigerating effect generating by evaporator to the compressor work. In the simplest analysis, the losses that occur in the expansion valve is not considerable. In reality, the ice formation layer phenomenon is formed around the expansion valve during air conditioning system operation (Figure-3).

In a thermodynamic analysis of air conditioning system, generally discusses in detail the heat exchange in the evaporator, condenser, and compressor work. The expansion process that occurs in the expansion valve is assumed to be an iso-enthalpy process [24]. In fact, during the expansion process the refrigerant taking the heat. Ideally, the process of heat exchange in the air-conditioning system fully occurs in the evaporator. From field observations, almost the entire expansion valve made of a metal material, usually aluminum alloy or cast iron. Both aluminum alloy and cast iron have a high thermal conductivity, 247 W/m·K and 80 W/m·K, respectively. As a result, very cold temperature refrigerant after expanded will be discharged into the environment through the body of the expansion valve.

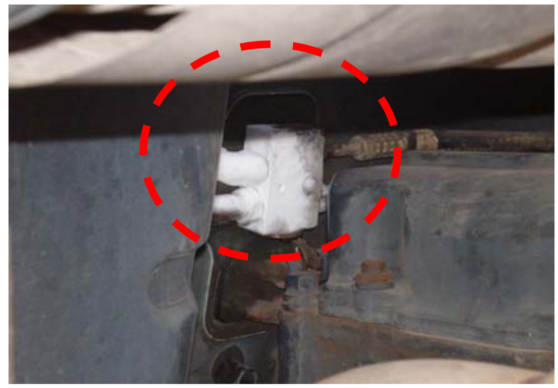

Figure-3. Ice formation layer around the expansion valve.

Meanwhile, PTFE is a material that has a very low thermal conductivity compared to aluminum and cast iron, about 0.25 W/m·K. PTFE is widely known as a heat insulating material that is widely used in industry, engineering, tribology, electricity, medicine, to the household sector. PTFE has many unique properties, which makes it valuable in a number of applications [25]. PTFE has a very high melting point, and also stable at very low temperatures. Teflon is very heat resistant and corrosion resistant. The most recognized brand of formula-based PTFE is Teflon. The chemical formula and atomic structure of PTFE are presented in Figure-4 and Figure-5, respectively.

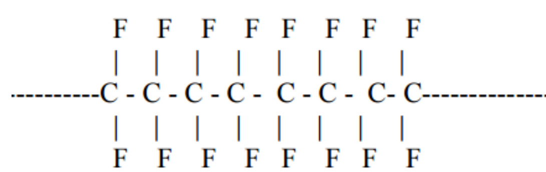

Figure-4. Chemical formula of PTFE [26].

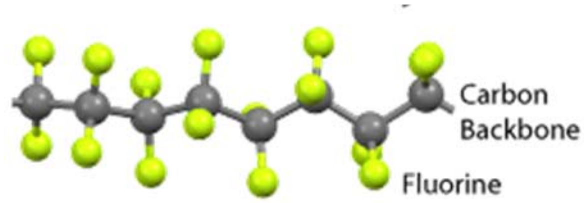

Figure-5. Atomic structure (C-F bonds) of PTFE [27].

Recent studies have shown that polytetrafluoroethylene (PTFE) is an effective material for tribology applications due to the mechanical properties and friction uniques, high chemical resistance, low coefficient of friction, and outstanding thermal stability

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[28]. Therefore, this study examines the use of PTFE as an expansion valve on the air conditioning system. Distribution temperature before and after the expansion valve is presented and compared to the expansion valve made of aluminum.

2. METRIAL AND METHODS

2.1 The expansion valve

This study uses two pieces of the expansion valve that made of PTFE and aluminum. Expansion valve made of aluminum is original from the vehicle. Meanwhile, the expansion valve of PTFE is made by machining with the same size as the original. Visualization of aluminum and PTVE expansion valve is presented in Figure-6 as follows.

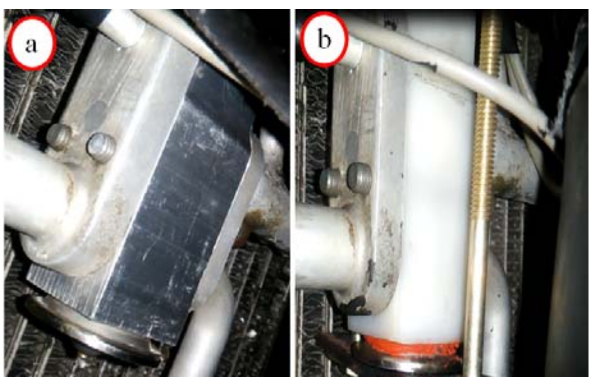

Figure-6. Aluminum (a) and PTFE (b) of expansion valve materials.

2.2 Set up experiment and apparatus

The AC system used in this study is a car air conditioning system that is removed from the car and driven by an electric motor. Configuration major components and measuring instruments used as shown in Figure-7. P_{in} is high pressure before the expansion valve and P_{out} is low pressure after the expansion valve. P_{in} and P_{out} are measured with a pressure gauge CLASSE REFCD 1.6. T_{in} is the temperature before the expansion valve and T_{out} is the temperature after the expansion valve. T_{in} and T_{out} are measured by a parts of PT-100 thermocouples. The temperature of the thermocouple then displayed using the temperature displayer OMRON E5CSL-RP. Subsequently, the temperature was recorded using a camera phone XIOMI REDMINOTE. Data collection is done at ambient temperature of 27.4°C and relative humidity of 71.3%. Refrigerant pressure is in 1585 kPa for two types of expansion valve, read by manifold gauge.

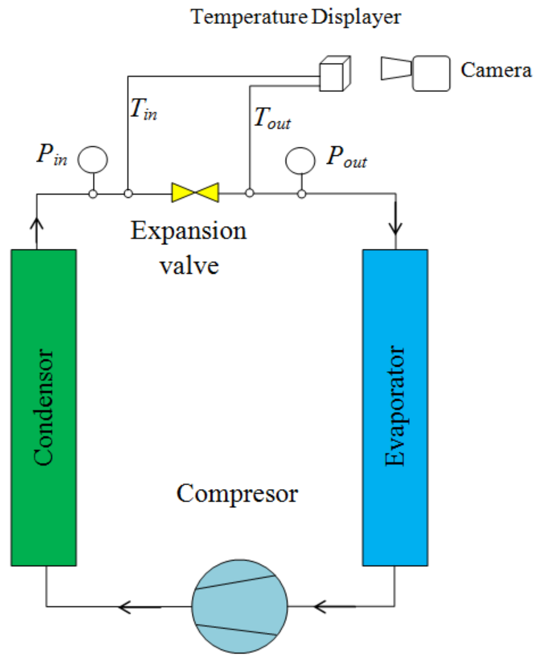

Figure-7. Set up experiment and apparatus.

Inspection of Figure-7, the temperature difference before and after the expansion valve observed for 5 minutes on the expansion valve made of PTFE and aluminum, respectively. Changes in temperature are recorded by a camera. Finally, the data recording is divided into 100 parts of figure and processed with excel.

3. RESULTS AND DISCUSSIONS

3.1 Temperature distribution

During the test, the temperature obtained on two types of expansion valve is presented in Figure-8.

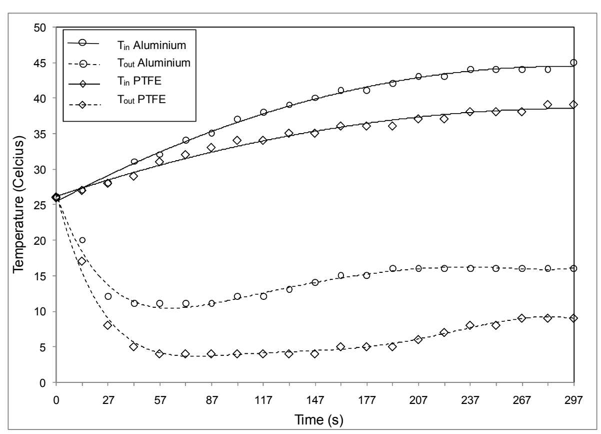

Figure-8. Temperature distribution on aluminum and PTFE expansion valve.

Noting of Figure-8, a group of curves with a straight line is the temperature at high pressure before the expansion valve and groups of curves with a dashed line is the temperature at low pressure after the expansion valve. The symbol (○) indicates expansion valves made from aluminum, while the symbol (◊) indicates expansion valve made of PTFE. The expansion valve made of aluminum give a higher temperature than the expansion valve made of PTFE, both on the high-pressure and low-pressure cycles.

3.2 Predicting on cooling effect

By using R134a refrigerant, it is known pressure-enthalpy diagram (P-h diagram) for each point as specific state point of the expansion valve (Figure-9). At the time of testing, the high pressure is 230 psi (1585 kPa) and the low pressure is 35 psi (241 kPa) for aluminum and PTFE, respectively.

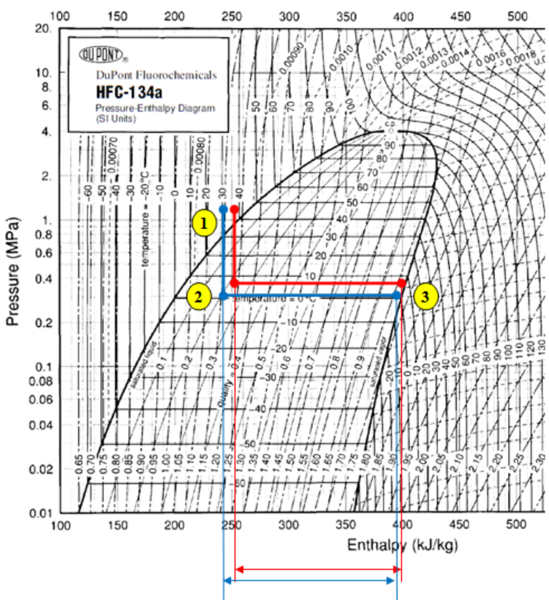

Figure-9. Specific state points on aluminum and PTFE expansion valve.

From Figure-8, the red line is the expansion valves made of aluminum and the blue line is the expansion valve made of PTFE. Enthalpy difference produced by expansion valve made of PTFE is greater than the expansion valve made of aluminum. At point 1 (40 °C and 1585 kPa), enthalpy for expansion valve made of aluminum is 256.31 kJ/kg. Given the expansion valve works is in iso-enthalpy process, point 2 is the same as point 1 (h_2=h_1). Finally, at the point 3 (10 °C), it is obtained that the enthalpy is 408.77 kJ/kg. The results of numerical simulations with REFPROP for the expansion valve made of aluminum are shown in Table-1.

Table-1. Specific state points of aluminium expansion valve.

5: R134a: Specified state points

	Temperature (°C)	Pressure (kPa)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)
1	40,000	1585,0	1151,4	256,31	1,1886
2	10,000	241,00	11,128	408,77	1,7783
3					

Meanwhile, for the expansion valve made of PTFE, the enthalpy at point 1 (1585 kPa and 35°C) is 241.00 kJ/kg. By h_2 = h_1, enthalpy at point 2 is 241.00 kJ/kg. At point 3 (5 °C and 241 kPa), the enthalpy values is 404.43kJ/kg. The results of numerical simulations with REFPROP for the expansion valve made of PTFE are shown in Table-2.

Table-2. Specific state points of PTFE expansion valve.

5: R134a: Specified state points

	Temperature (°C)	Pressure (kPa)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)
1	35,000	1585,0	1172,6	248,94	1,1649
2	5,0000	241,00	11,384	404,43	1,7629
3					

From Table-1 and Table-2, the enthalpy difference (Δh) in the expansion valve made of aluminum is 152.46 kJ/kg (408.77 kJ/kg - 256.31 kJ/kg). Meanwhile, the enthalpy difference (Δh) in the expansion valve made of PTFE is 155.49 kJ/kg (404.43 kJ/kg – 248.94 kJ/kg). With the same refrigerant mass flow, this means the expansion valve made of PTFE generates potential heat absorption greater than the expansion valve made of aluminum (3.03 kJ/kg). Approaches for explaining this condition, PTFE has a very low thermal conductivity, so the heat loss in the expansion process can be reduced.

4. CONCLUSIONS

By reviewing the research activities that have been performed, it is obtained fact that: (1) the temperature before and after the expansion valve made of PTFE is lower than the expansion valve made of aluminum, and (2) the potential het absorption from refrigerant using the expansion valve made of PTFE is greater than the expansion valve made of aluminum. In conclusion, PTFE is promising to be developed as an expansion valve on car air conditioning system applications.

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