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Araçlar için Yenilikçi Soğuk Depolamalı İklimlendirme Sistemi Geliştirilmesi

Innovative Cold Storage Air Conditioning System Development For Vehicles

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Abstract

The conventional vapor compression air conditioning systems, which consist of air compressor from the engine shaft, condenser, expansion valve and evaporator are used in the today's automotive industry. These systems are quite prone to development and to improvement in terms of energy consumption, cost competitiveness and weight reduction. The variable waste energy, which is generated during driving of the vehicles, can be stored and used inside the vehicle cabin interior in the form of latent heat at a constant temperature. Thus an environmental lightweight and improved air conditioning system can be developed instead of complex, heavy, expensive and energy consuming current systems. In this study, the electrical energy obtained during the braking of the vehicle alternator, electricity produced by thermoelectric module from the exhaust heat and receiving variable electrical energy from engine on the vehicle-induced vibration (piezoelectric generator), the rough roads of the induced vibrations (electromagnetic generator); Peltier heat pump was used to aid the vehicle interior cabin air-conditioning using liquid to solid phase change fluids. Thus, all waste energy can be stored at constant temperature so that it can be used the air conditioning system.

Keywords: *Peltier heat pump, waste heat, air conditioning*

Öz

Günümüzde otomotiv sektöründeki araç iklimlendirmesinde motor milinden tahrik alan kompresör, kondanser, genleşme valfi ve eveparatörden oluşan buhar sıkıştırmalı konvansiyonel soğutma sistemleri kullanılmaktadır. Bu sistemler, enerji tüketimi, maliyet ve ağırlık açısından geliştirilmeye açıktır. Araçlarda sürüş esnasında ortaya çıkan değişken atık enerjiler sabit sıcaklıkta gizli ısı şeklinde depolanarak araç kabin içi iklimlendirmesinde kullanılabilir. Bu sayede karmaşık, ağır, pahalı ve fazla enerji tüketen mevcut iklimlendirme sistemleri yerine hafif ve çevreci bir iklimlendirme sistemi geliştirilebilir. Bu çalışma kapsamında, aracın alternatöründen frenleme esnasında alınan elektrik enerjisi, egzoz ısısından termoelektrik modül ile üretilen elektrik enerjisi ve araç üzerindeki motor kaynaklı titreşim (piezoelektrik jenaratör) ile, bozuk yol kaynaklı titreşimlerden (Elektromanyetik jeneratör) alınan değişken elektrik enerjileri; sıvı katı faz değiştiren akışkanlar kullanılarak peltier ısı pompası yardımıyla araç kabin iklimlendirilmesinde kullanılmıştır. Bu sayede tüm değişken atık enerjiler sabit sıcaklıkta depolanarak iklimlendirme sisteminde kullanılabilmektedir.

Anahtar Kelimeler: *Peltier ısı pompası, atık ısı, iklimlendirme*

1. Introduction

Upon examining the cooling function used in current air conditioning systems of vehicles, we can see that it is composed of the mechanical compressor driven from engine shaft; condenser that allows hot gas to shift into liquid phase by discharging the heat to outer environment; expansion valve that allows gas to expand by dropping its pressure; and evaporators that allows heat absorption through gas evaporation. Figure 1 shows the air conditioning system used in current vehicles.

Coefficient of performance (COP) is calculated by dividing cooling load ($Q_{cooling}$) to total energy consumed (Equation 1).

$$COP = \frac{Q_{cooling}}{W_{compressor} + Fan_1 + Fan_2} \quad (1)$$

Known air conditioning systems in vehicles generally use two separate systems for heating and cooling functions. Cooling systems use a condenser in the same position as a radiator, while the compressor is generally attached to belt and pulley system and engine shaft. Evaporator and expansion valve is located in an integrated way within cabin HVAC module. Figure 2 shows the cooling group of a vehicle's air conditioning system.

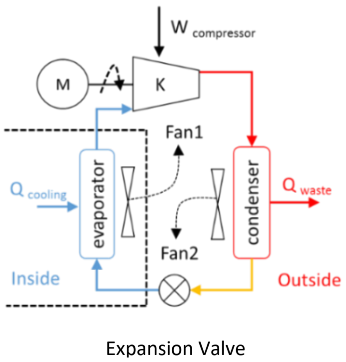

Figure 1. Air conditioning system used in current vehicles

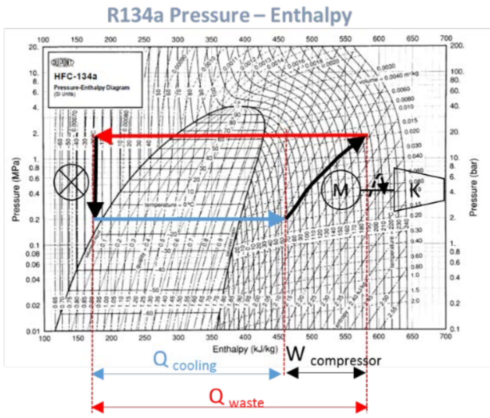

Figure 1. Air conditioning system used in current vehicles (continued)

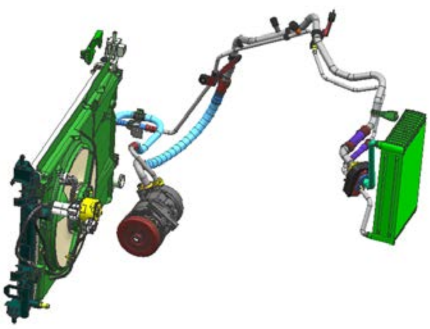

Figure 2. Current air conditioning cooling group

In the literature, many experimental and numerical studies have been found to develop more efficient vehicle air conditioning system [1-4]. Selvam et al. present a novel technique to increase peltier performance with phase change materials [5]. Manikandan et al. studied on designing of the actual annular thermoelectric cooling (ATEC) systems [6]. Said et al. proposed a new technique of using phase change material on air condition system. COP of air conditioning system is increasing about 14% [7].

Cooling load of a passenger car is 3.7 kW ($Q_{cooling}$). Power of the in-cabin circulation fan (Fan 1) is 0.4 kW, while the power of radiator fan (Fan 2) used for cooling the condenser is 0.43 kW. Although COP value of the compressor varies depending on the vehicle's number of revolutions, it is averagely 2.6. Compressor's isentropic efficiency is 0.7 while its mechanical efficiency is 0.85. In this case, 2.39 W ($W_{compressor}$) load is drawn from engine shaft. This value is 3.22 when the vehicle is working at maximum capacity (including the fans). If we consider that a passenger car going at 100 km/h steady speed consumes 20 kW energy, fuel consumption increases by 16.1 %.

Maximum capacity for vehicle air conditioning cooling group design is calculated as 35 °C air intake temperature and 50 % relative humidity, 18 °C air discharge temperature and 100 % relative humidity, 400 m^3/h fan flow rate. Thus, perceptible heat load and latent heat load required for cooling the air are 17.85 kJ/kg and 15.25 kJ/kg respectively. We can see that 1.68 kW of 3.7 kW cooling load is latent heat. In order for latent heat to be absorbed from the environment, 5 g of water per 1 kg of air is condensed and expelled to outer environment. All of these calculations are displayed in Figure 3.

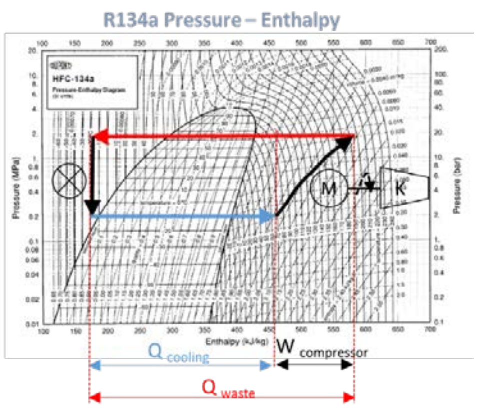

Figure 3. Current vehicle air conditioning system cooling group design

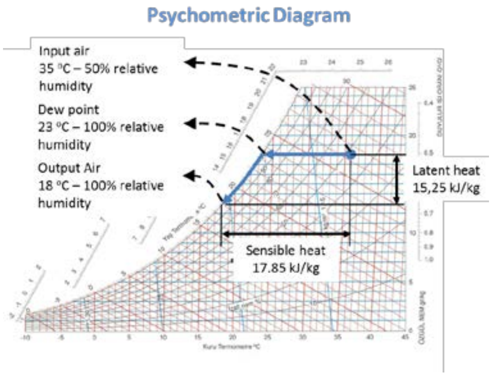

Figure 3. Current vehicle air conditioning system cooling group design (continued)

If the condensed and expelled water is regained as latent heat, cabin cooling load is expected to drop from 3.7 kW to 2 kW.

2. Material and Method

Thermoelectric coolers (Peltier) shown in Figure 4 are the most basic heat pumps that can transfer the heat in one environment to another by connecting P and N type semi-conductors together and conducting electricity over them. Temperature difference between cooled environment and outer environment is a very important parameter in calculating thermoelectric cooler's (TEC, Peltier) cooling coefficient of performance (COP). As can be seen in Figure 5, COP value is 3.4 when temperature difference is 9.5°C, while it drops to 1.4 when temperature difference increases to 19°C. In terms of values in Figure 3, outer environment was 35 °C and air discharge temperature was 18 °C. When a thermoelectric cooler is used for this 17°C temperature difference, COP value rises to 3.5 in this new situation from the previous 1.5.

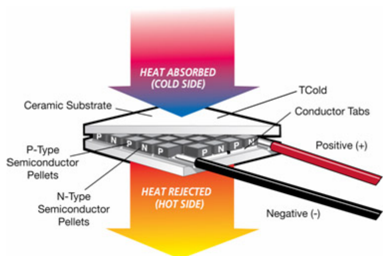

Figure 4. Thermoelectric cooler (Peltier heat pump) [8]

This difference is caused by evaporating the water condensed in the cabin on the hot surface of thermoelectric cooler using evaporative cooling method. Existing situation and the new developed system is shown on a psychometric diagram in Figure 6.

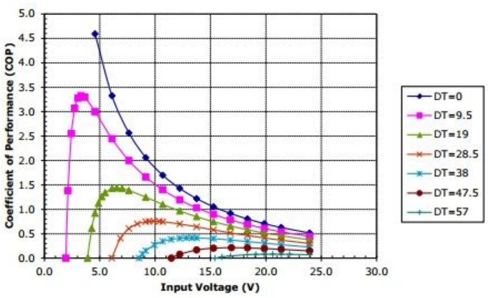

Figure 5. Thermoelectric cooler COP value/potential difference for different temperatures [9]

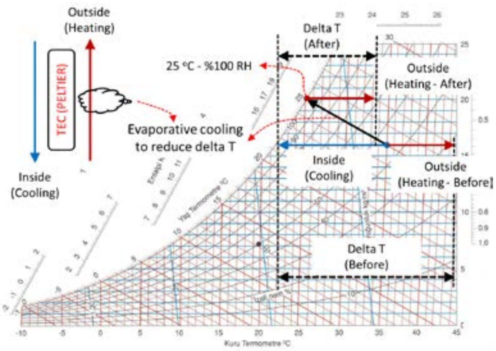

Figure 6. Existing situation and the new developed system on a psychometric diagram

Thermoelectric coolers can be manufactured in plate or cylindrical types, as shown in Figure 7. A cylindrical cooler was used for in this study.

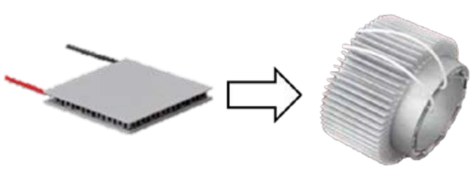

Figure 7. Plate and cylindrical type thermoelectric coolers

Cooling load at varying temperatures can be stored at a steady temperature and used later through phase shifting material. Figure 8 shows how phase shifting materials store cool air at fixed temperature as latent heat. This study used 22TM / 22°C as phase shifting material.

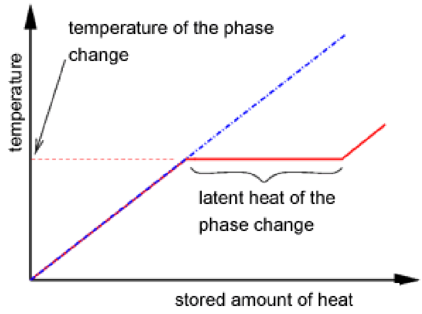

Figure 8. Storing heat at steady temperature [10]

By using cylindrical thermoelectric coolers with the cool air storage system we designed, compressor, condenser, expansion valve and evaporator components that form the current vehicle cooling group have been eliminated. Temperature difference is reduced, with the help of a piezoelectric atomizer, by diffusing the condensed water from the air in the cabin in external air passing over the hot surface of cylindrical thermoelectric cooler. This enabled the development of a cold storage system with better COP value compared to the eliminated expensive, heavy and complex cooling system. By using phase shifting material, cooling load at varying temperatures were able to be stored and used at a steady temperature. Figure 9 shows the new cold storage system [11].

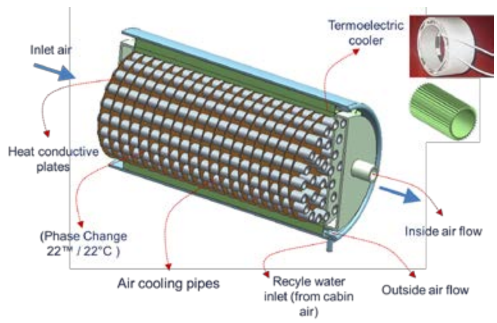

Figure 9. Newly developed cold storage system

Cooling load at varying temperatures is the electricity energy in varying powers, which is the source of a peltier heat pump. This energy is generated through the waste energy of a vehicle. Figure 10 displays 3 types of waste energy. These are; varying electricity power during braking, varying electricity power generated by the thermoelectric generator (TEG) placed on exhaust system and varying electricity power generated by piezo electric generator and magnetic generator using vehicle's engine and road vibrations.

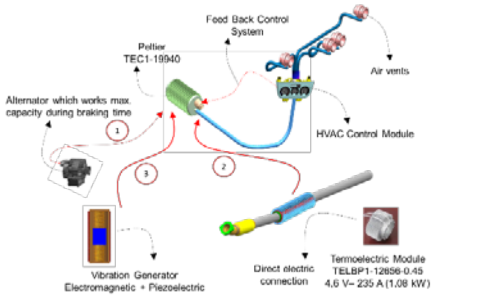

Figure 10. Varying electricity generators used in the developed system

3. Result and Discussion

Within the scope of this study, an innovative cold storage system was developed instead of an expensive, heavy, complex and high energy-consuming cooling system. This allowed the design of a cooling system that is 8.5 kg lighter per vehicle, and provides fuel economy by supplying all its power requirements from vehicle's waste energy. In addition, cooler liquids with high global warming potential (R136a or R1234YF) are eliminated. Works carried out in terms of weight reduction are shown in Figure 11.

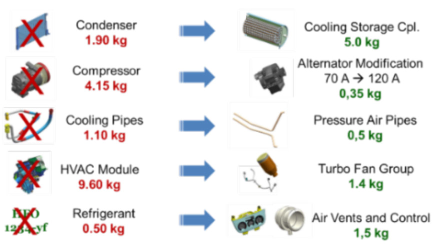

Figure 11. Current and developed system components and weigh

4. Conclusion

Within the scope of this study, electricity energy obtained from the vehicle's alternator during braking, electricity energy generated by thermoelectric module using exhaust heat and electricity energy obtained from vibrations on the vehicle due to engine movements (piezoelectric generator) and uneven road (electromagnetic generator) have been used for vehicle cabin air conditioning by utilizing liquid solid phase shifting material with the help of peltier heat pump. In this way, all varying waste energies can be stored at a steady temperature and used in air conditioning system. This new cooling system has resulted in approximately 8.5 kg weight reduction per vehicle. It also has positive effects on global warming and reducing CO2 emissions.

Acknowledgment

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References

[1] Ayartürk, H., Doruk, E., Durgun, İ., Ekbic, K., 2016. New Heating System Development Working With Waste Heat For Electric Vehicles, Transportation Research Procedia, Vol. 14, pp. 1080-1086. DOI: 10.1016/j.trpro.2016.05.178.

[2] Irshad, K., Habib, K., Kareem, M.W., Basrawi, F., Saha, B.B., 2017. Evaluation of Thermal Comfort in a Test Room Equipped with a Photovoltaic Assisted Thermo-electric Air Duct Cooling System, International Journal of Hydrogen Energy, Vol. 42, pp. 26956 -26972. DOI: 10.1016/j.ijhydene.2 017.05.247.

[3] Baik, Y.J, Heo, J., Koo, J., Kim, M., 2014. The Effect of Storage Temperature on the Performance of a Therm o-electric Energy Storage Using a Transcritical CO2 Cycle, Energy, Vol. 75, pp. 204-215. DOI: 10.1016/j.energy.2014.07.0 48.

[4] Zou, T., Fu, W., Liang, X., Wang, S., Gao, X., Zhang, Z., Fang, Y., 2018. Preparation and Performance of Modified Calcium Chloride Hexahydrate Composite Phase Change Material for Air-conditioning Cold Storage, International Journal of Refrigeration, Vol. 95, pp. 175-181. DOI: 10.1016/j.ijrefrig.2018.08.001.

[5] Selvam, C., Manikandan, S., Kaushik, S.C., Lamba, R., Harish, S., 2019. Transient Performance of a Peltier Super Cooler Under Varied Electric Pulse Conditions With Phase Change Material, Energy Conversion and Management, Vol. 198, pp. 1-10. DOI: 10.1016/j.enconman.2019.111822.

[6] Manikandan, S., Kaushik, S.C., 2015. Energy and exergy analysis of an annular thermoelectric cooler, Energy Conversion and Mana gemen t, Vol. 106, pp. 804-814. DOI: 10.1016/j.enconman.2015.10.029.

[7] Said, M.A., Hassan, H., 2018. Parametric Study on the Effect of Using Cold Thermal Storage Energy of Phase Change Material on the Performance of Air-conditioning Unit, Applied Energy, Vol. 230, pp. 1380-1402. DOI: 10.1016/j.apenergy.2018.09.048.

[8] Thermoelectric cooler (Peltier heat pump). http://blogs.cas.suffolk.edu/rjfedak2/files/2014/03/peltier-figure-9.jpg (available online at: January 15, 2020).

[9] Thermoelectric cooler COP value/potential difference for different temperatures. http://cdn.overclock.net/b/bc/500x1000px-LL-bcc5d13a_Untitled.jpeg (available online at: January 15, 2020).

[10] Storing heat at steady temperature. http://195.20.235.12/grafiken/en-vergleich.gif (available online at: January 15, 2020).

[11] Innovative Cold Storage Air Conditioning System Development for Vehicles, Ayarturk Hasan et al., Patent Pending. TR 2015/07901.