An Experiment on a CO_2 Air Conditioning System with Copper Heat Exchangers

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Abstract— *This paper presented an experiment on a CO_2 air conditioning system with copper heat exchangers. In this study, the compressor and cooler were tested with hydraulic method to determine the deformed and torn temperatures. The results show that conventional compressor is not suitable for using high pressure, due to the COP of cycle is very low (0.5 only). With CO_2 compressor, the cycle can be achieved COP of 3.07 at the evaporative temperature of 10℃. This value equals with COP of commercial air conditioning system presently.*

Keywords— air conditioning system, heat exchanger, cooler, evaporator, CO_2 refrigerant.

I. INTRODUCTION

With conventional refrigeration systems, most of the HCFC and HFC refrigerants are already affecting the ozone depletion and global warming. To solve this problem, CO_2 is as a refrigerant replacement for the current refrigerant fluorocarbon. When CO_2 is commonly used in refrigeration systems, amount of Fluorocarbon refrigerant emits into the atmosphere that will be reduced. Regarding to CO_2 air conditioning systems, Ngo et al. [1] investigated heat transfer and pressure drop correlations of microchannel heat exchangers with S-shaped and zigzag fins for carbon dioxide cycles. Experimental results show that the pressure-drop factor of the MCHE with S-shaped fins is 4–5 times less than that of MCHE with zigzag fins, although Nuis 24–34% less, depending on the Re within its range. Elbel and Hrnjak [2] researched about the performance of R744 transcritical systems with direct expansion (DX) can be significantly improved by implementing a Flash Gas Bypass (FGB). The idea behind the concept is to bypass refrigerant vapor in the evaporator during the isenthalpic expansion process. Yun et al. [3] numerically analyzed a microchannel evaporator designed for CO_2 air-conditioning systems. The performance of the microchannel evaporator for CO_2 systems can be improved by varying the refrigerant flow rate to each slab and changing fin space to increase the two-phase region in the microchannel. Cheng et al. [4-7] studied the models of CO_2 boiling heat transfer tubes that placed horizontally in size from mini to micro. However, authors did not mention completed CO_2 air-conditioning systems.

Sato et al. [8] announced patent on a hot water supply systems and CO_2 air conditioners system. Dienhart et al. [9] announced patent on the optimal operation of CO_2 air conditioners system. Dube [10] announced patent on CO_2 air conditioners system for skating surface. However, the heat exchangers in the [8-10] were used traditional sizes rather compact types. Jin et al. [11] presented an analysis/computer model to predict the performance of an evaporator for a CO_2 mobile air-conditioning system. The errors of root mean square (RMS) for cooling capacities and refrigerant-side pressure drops were 1.9% and 12.3%, respectively. Lee et al. [12] studied on the performance of a CO_2 air conditioning system using an ejector as an expansion device. The cooling capacity and COP in the air-conditioning system using an ejector are higher than those in the conventional system at an entrainment ratio greater than 0.76. Huang et al. [13] investigated for the effect of axial heat conduction on the heat transfer analysis in microchannel flow. In this study, more than half of the temperature increase occurs within 1/8 of channel length from the entrance at a Reynolds number of 15. Baheta et al. [14] studied the performance of transcritical carbon dioxide refrigeration cycle. In this study, the highest COP was 3.24 at 10MPa gas cooler pressure. Chen et al. [15] analyzed and optimized a hybrid CO_2 transcritical mechanical compression – ejector cooling cycle. The hybrid cooling cycle is a combination of a CO_2 transcritical mechanical compression refrigeration machine (MCRM) powered by electricity, and an ejector cooling machine (ECM) driven by heat rejected from the CO_2 cooling cycle. Refrigerants R245ca, R601b (neopentane) and R717 (ammonia) are investigated as the working fluids of ECM in the present study. In this study, using the ejector cooling cycle for subcooling the CO_2 gas after gas cooler allows increasing the efficiency of the CO_2 transcritical cooling cycle up to 25-30% depending on the refrigerant type of the ejector cooling cycle. However, the investigations in [14, 15] were done by theoretical methods only.

From literature reviews above, there are no more experimental studies on air conditioning system with CO_2 as the working refrigerant. They did not indicate thermodynamic parameters of CO_2 air conditioning cycle clearly. So, it is essential to investigate CO_2 air conditioning system experimentally. In this study, copper tubes were used in the evaporator and the cooler of this system.

II. EXPERIMENTAL SETUP

The Fig. 1 indicates the experimental test loop for CO_2 air conditioning system. This system has four main components: a CO_2 compressor, a copper cooler, a thermal expansion valve, and a copper evaporator. The CO_2 refrigerant enters the compressor in superheated vapor state and then it is compressed to a higher pressure corresponding higher temperature state. The superheated vapor is routed through a cooler where it is cooled by flowing inside tubes with cooler air flowing across the tubes. The cooled refrigerant continues to move to an expansion valve.

When it runs through an expansion valve, the pressure is dropped dramatically because of the adiabatic evaporation of a part of the liquid refrigerant. Therefore, after flowing through the expansion valve, the refrigerant is a mixture of liquid and vapor. That mixture has lower temperature than the temperature of the enclosed space. The cold mixture is routed through the tubes in the evaporator where it refrigerates the enclosed space. A fan blows the warm air in the enclosed space across the tubes, so the warm air (the room-temperature air) is cooled. Meanwhile, the liquid part of the cold refrigerant mixture is also heated to evaporate by the warm air. To complete the refrigeration cycle, the refrigerant vapor from the evaporator with saturated vapor state is superheated and is routed back into the compressor.

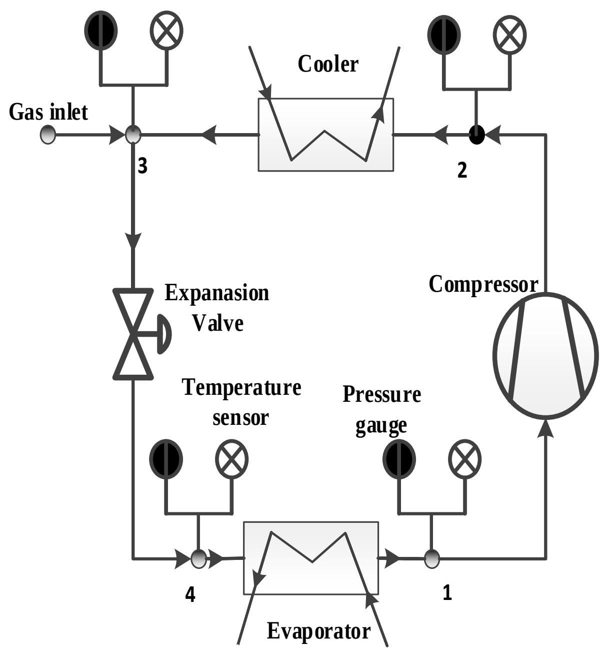

Fig. 1: Schematic of the test loop for CO2 air conditioning system

For four main points of this system, four temperature sensors and pressure gauges were installed to get thermodynamic parameters. The CO_2 air conditioning cycle was done with transcritical mode. This cycle on p-h diagram is shown in Fig. 2. The superheat is around 5°C.

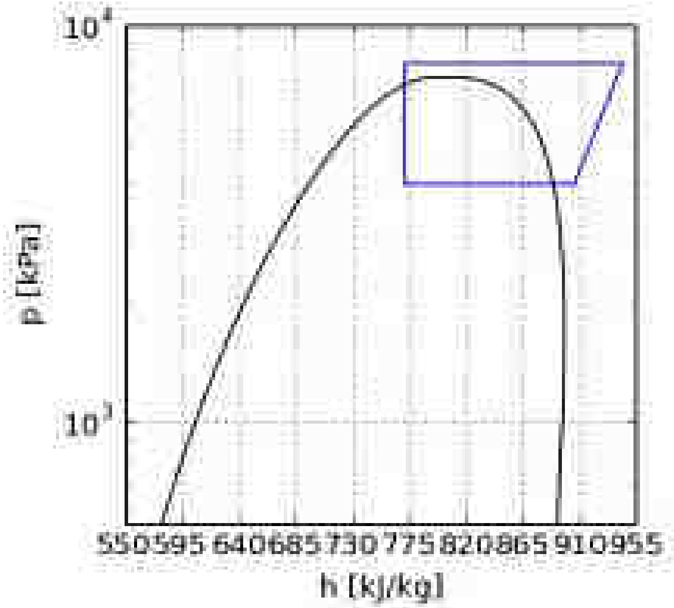

Fig. 2: The CO2 air conditioning cycle on p-h diagram

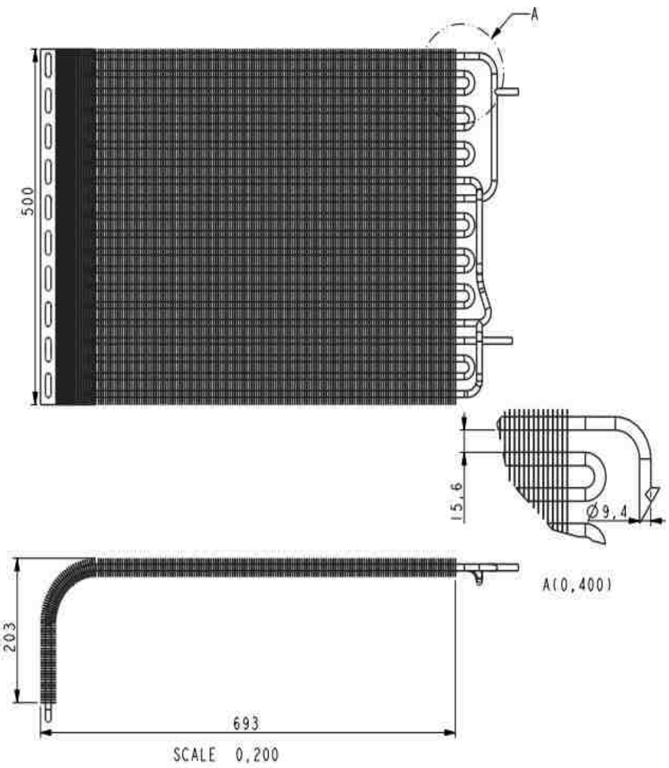

Fig. 3: Dimensions of the cooler

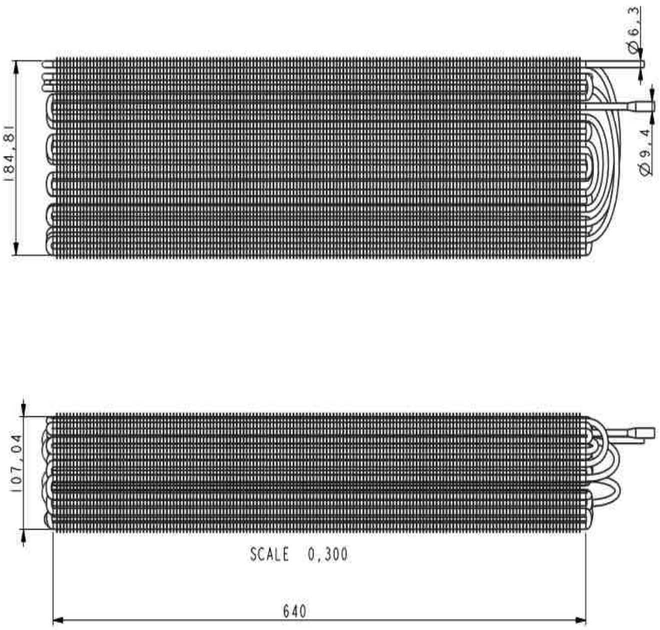

Fig. 4: Dimensions of the evaporator

Copper tubes were used in the cooler, as shown in Fig. 3. The refrigerant ran in the tubes of this cooler with 12 passes (including eight parallel passes). The tube pitch is 15.6 mm and these tubes have outside diameter of 9.4 mm. Fig. 4 shows dimensions of the evaporator. Copper is also used in this heat exchanger. Outside diameter of tubes is 6.3 mm. The thickness of the tubes is 0.9 mm. The cooler and evaporator were tested with the hydraulic testing method. The two heat exchangers did not tear or deform at the pressure of 150 bars. Accuracies and ranges of testing apparatus are listed in Table 1 and equipments used for the experiments are listed as follows:

- Thermometer, made by Daewon
- Thermostat, EW – 181 H, made by Ewelly
- Infrared thermometer, AT 430L2, made by APECH
- Infrared thermometer, Raynger@ST, made by Raytek
- Pressure gauge, made by Pro - Instrument
- Anemometer, AVM-03, made by Prova
- Clamp meter, Kyoritsu 2017, made by Kyoritsu.

Table.1: Accuracies and ranges of testing apparatuses

Testing apparatus	**Accuracy**	**Range**
Thermometer	± 0.5 °C	0 ~100 °C
Infrared thermometer	± 1 °C of reading	- 32 ~ 400 °C
Pressure gauge	± 1 FS	0~100 kgf/cm^2
Clamp meter	± 1.5 % rdg	0 ~ 200 A
Anemometer	± 3 %	0 ~ 45 m/s

III. RESULTS AND DISCUSSION

3.1 Working with conventional compressor

By the hydraulic testing method, a reciprocating compressor using for the R410 refrigerant was tested. The compressor has the absorbed power of ¼ HP. The results shown that the compressor body was slight deformed at the pressure value of 140 bar. Up to 197 bar, the compressor was torn at the suction port. Based on the results, the same compressor was used in this test loop to get the thermodynamic parameters. Experimental data for the air conditioning system were obtained under the ambient temperature of 29.5ºC. The temperature difference between the refrigerant and the air is 2ºC.

Table.2: Thermodynamic parameters of the CO_2 cycle with conventional compressor

p1 (bar)	**t1 (°C)**	**p2 (bar)**	**t2 (°C)**	**p3 (bar)**	**t3 (°C)**	**p4 (bar)**	**t4 (°C)**
20	20.2	45	83.2	45	31.5	20	0
19.5	20.4	44.5	82.7	45	31.2	20.5	0.2
20	20.1	45	83.2	45	31.1	20.5	0.1
20.5	20.6	45	82.8	45	31.4	21	0.2
20	19.7	45	83.3	44.5	31.1	20.5	0.5

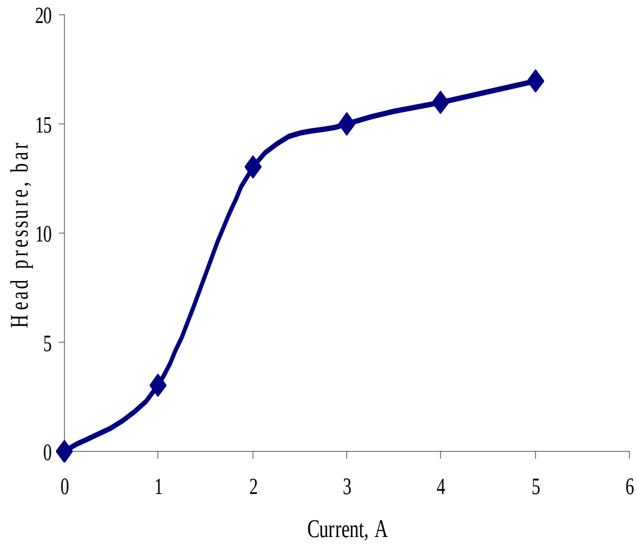

Fig. 5: Head pressure vs. current

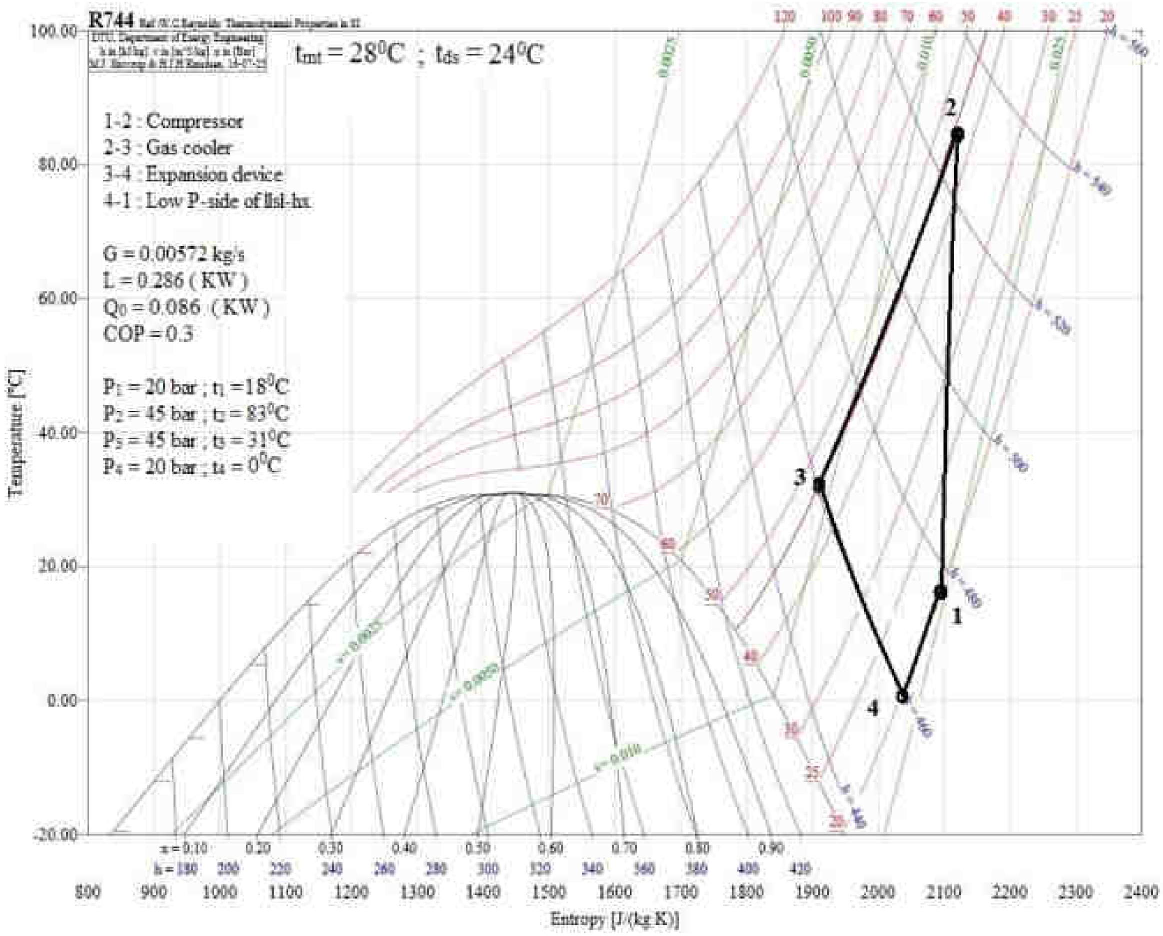

Fig. 6: Experimental point of the cycle on T-s diagram

Table 2 shows several thermodynamic parameters at four main points of this system. The pressure drops of the cooler and the evaporator are negligibly small. The pressure value at point no. 1 is lower than pressure value at point no.4. This means the process is not isothermal; in fact, the pressure at outlet of evaporator is lower than the pressure at inlet of evaporator by suction pressure at compressor. A relationship between the head pressure and current is shown in Fig. 5. The process was obtained by adjusting expansion valve. The head pressure by suction pressure and discharge pressure increases as increasing current. However, when the current was over 5A, the compressor was out of work.

The experiments of four main points of the cycle on T-s diagram are shown in Fig. 6. The results show that the cycle was done following the principle of a refrigeration cycle. However, the conventional compressor is not suitable for using high pressure. So, the cycle runs within the superheat region, leading to the COP (Coefficient of Performance) is very low (0.3 only). This is important key to investigate a CO_2 air conditioning system which depends on the compressor as well as the expansion method.

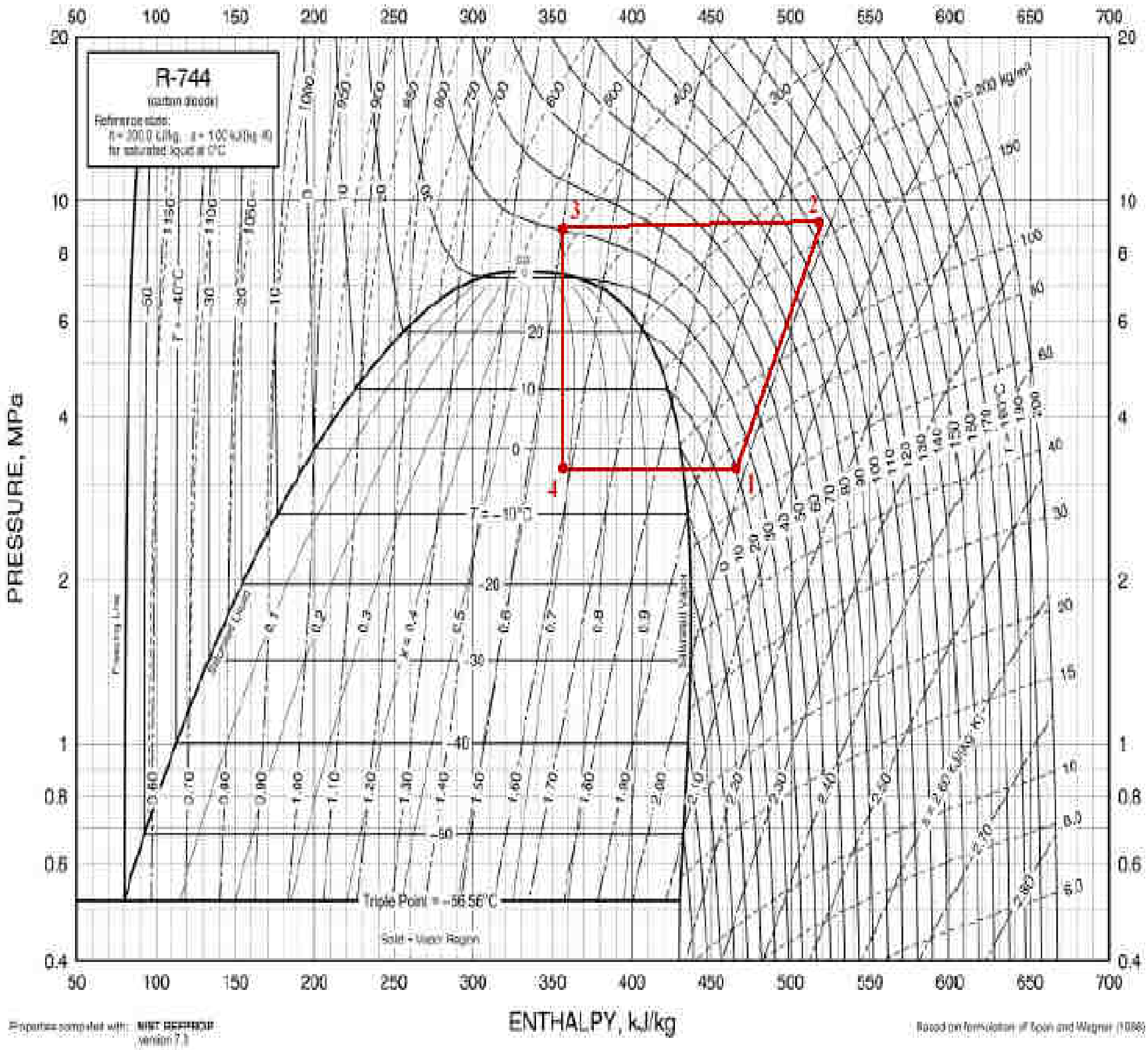

Fig. 7: Experimental point of the cycle on p-h diagram

3.2 Working with CO_2 compressor

For this section, a CO_2 compressor was used to supersede for the conventional R410 compressor above. This compressor was made by DORIN – Italy. The thermodynamic parameters of the CO_2 cycle with DORIN compressor are listed in Table 3. Experimental data for the air conditioning system were obtained under the ambient temperature of 32.5ºC. The temperature difference between the refrigerant and the air is 7ºC. It was observed that the cycle belongs to saturated state, as shown in Fig. 7.

Due to pressure drop of the cooler and evaporator, so the pressure value at the outlets of these heat exchangers are lower than those obtained from the inlet ones. So, isothermal and isobaric processes in this cycle are quasi with theory. The cycle can perform at the evaporative temperature lower than 0°C (at -2.5°C). It leads the COP of this cycle is low, with COP of 2.01. However, the COP of this cycle was 3.07 at the evaporative temperature of 10 °C. The experimental results are in good agreement with the results from [14, 15]. These values equal with COP of commercial air conditioning system presently. The experimental results are important for investigate CO_2 air conditioning system.

Table.3: Thermodynamic parameters of the CO_2 cycle with DORIN compressor

p1 (bar)	t1 (°C)	p2 (bar)	t2 (°C)	p3 (bar)	t3 (°C)	p4 (bar)	t4 (°C)
34	20.8	86	105	85	40.2	35	-3.1
33.5	21.1	85.5	104	85	39.5	34.5	-3.2
34	21.2	85.5	105	85.5	39.7	35	-2.8
34	21.3	86	105	85	39.2	35	- 2.7
33.5	20.9	86	104	85.5	39.8	34	- 2.5

IV. CONCLUSION

An experiment on a CO_2 air conditioning system with copper heat exchangers was done. In this study, the compressor and cooler were tested with hydraulic method to determine the deformed and torn temperatures.

The conventional compressor is not suitable for using high pressure, the cycle runs within the superheat region, leading to the COP (Coefficient of Performance) is very low (0.3 only). This is important key to investigate a CO_2 air conditioning system which depends on the compressor as well as the expansion method.

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REFERENCES

[1] T.L. Ngo, Y. Kato, K. Nikitin, T. Ishizuka, Heat transfer and pressure drop correlations of microchannel heat exchangers with S-shaped and zigzag fins for carbon dioxide cycles, Experimental Thermal and Fluid Science, Vol. 32, 2007, pp. 560-570

[2] Elbel and Hrnjak, Flash gas bypass for improving the performance of transcritical R744 systems that use microchannel evaporators, International Journal of Refrigeration, Vol. 27, 2004, pp. 724-735

[3] R. Yun, Y. Kim and C. Park, Numerical analysis on a microchannel evaporator designed for CO2 air-conditioning systems, Applied Thermal Engineering, Vol. 27, 2007, pp. 1320-1326

[4] Lixin Cheng, Gherhardt Ribatski and John R. Thome, Analysis of Supercritical CO2 Cooling in Macro- and Micro Channels, In. J. Refrig., Vol. 31, 2008, pp. 1301-1316

[5] Lixin Cheng, GherhardtRibatski, Jesus Moreno Quibén, and John R. Thome, New Prediction Methods for CO2 Evaporation inside Tubes: Part I-A Two-phase Flow Pattern Map and a Flow Pattern Based Phenomenological Model for Two-Phase Flow Frictional Pressure drops, Int. J. Heat Mass Transfer, Vol. 51, 2008, pp. 111-124

[6] Lixin Cheng, GherhardtRibatski and John R. Thome, New Prediction Methods for CO2 Evaporation inside Tubes: Part II-An Updated General Flow Boiling Heat Transfer Model Based on Flow Patterns, Int. J. Heat Mass Transfer, Vol.51, 2008, pp. 51, 125-135

[7] Lixin Cheng, GherhardtRibatski, LeszekWojtan and John R. Thome, New Flow Boiling Heat Transfer Model and Flow Pattern Map for Carbon Dioxide Evaporating inside Horizontal Tubes, Int. J. Heat Mass Transfer, Vol. 49, 2006, pp. 4082-4094

[8] Kazuyoshi Sato, Youichi Kawazu, Tooru Saitou, Hot water supply and air conditioning system using co2 heat pump, Patent No. CA2586676 C, Mar 12, 2013

[9] Bernd Dienhart, Hans-Joachim Krauss, Hagen Mittelstrass, Karl-Heinz Staffa, Christoph Walter, Jürgen Fischer, Michael Katzenberger, Karl Lochmahr, Optimized CO2 operated air-conditioning system, Patent No. US6588223 B2, Jul 8, 2013

[10] Serge Dubé, Co2 refrigeration system for ice-playing surface, Patent No. US20120247148 A1, Oct 4, 2012

[11] Jifeng Jin, Jiangping Chen, and Zhijiu Chen, Development and validation of a microchannel evaporator model for a CO2 air-conditioning system, Applied Thermal Engineering, Vol. 31 (2011), pp 137-146

[12] Jae Seung Lee, Mo Se Kim, and Min Soo Kim, Studies on the performance of a CO2 air conditioning system using an ejector as an expansion device, International Journal of Refrigeration, Vol. 38 (2014), pp 140-152

[13] Chih-Yung Huang, Cheng-Min Wu, Ying-Nung Chen, and Tong-Miin Liou, The experimental investigation of axial heat conduction effect on the heat transfer analysis in microchannel flow, International Journal of Heat and Mass Transfer 70 (2014) 169–173

[14] Aklilu Tesfamichael Baheta, Suhaimi Hassan, Allya Radzihan B Reduan, and Abraham D. Woldeyohannes, Performance investigation of transcritical carbon dioxide refrigeration cycle, Procedia CIRP, Vol. 26, 2015, pp. 482 –485

[15] Guangming Chen, Oleksii Volovyk, Daibin Zhu, Volodymyr Ierin, Kostyantyn Shestopalov, Theoretical analysis and optimization of a hybrid CO2 transcritical mechanical compression – ejector cooling cycle, Vol. 74, 2017, pp.84 – 92.