Frontiers in Heat and Mass Transfer (FHMT), 19, 15 (2022)
DOI: 10.5098/hmt.19.15

Global Digital Central
ISSN: 2151-8629

Frontiers in Heat and Mass Transfer

Available at www.ThermalFluidsCentral.org

EXERGY ANALYSIS OF A REFRIGERATION SYSTEM WITH A MINICHANNEL CONDENSER USING R134A REFRIGERANT

Vijay W. Bhatkar[a,*], Anirban Sur[b,*], Anindita Roy[b]

[a] Associate Professor, Marathwada Mitra Mandal's College of Engineering, Pune-411052, Maharashtra, India
[b] Associate Professor, Symbiosis Institute of Technology, Symbiosis International (Deemed) University, Pune-412115, Maharashtra, India

ABSTRACT

Versatile vapor compression refrigeration system is designed, developed and fabricated such that desired condensing and evaporating temperatures can be obtained by providing different electronic controls for superheating, subcooling, fan speed, air heaters and water heaters to use alternative refrigerants to R134a such as R1234ze, R152a, R600a, R290 and R290/R600a (50/50%) with conventional and minichannel condenser. All the refrigerant are tested for condensing temperature ranging from 40 °C to 55 °C while evaporating temperature changes from -10 °C to 15 °C for both condensers. The total exergy loss for main system components such as compressor, condenser, expansion valve and evaporator are calculated. It is found that condenser represented maximum exergy loss in all refrigerants for conventional and minichannel condenser. The total exergy loss is more for conventional condenser than minichannel condenser for all refrigerants while R1234ze represented minimum exergy loss. Exergy efficiency for minichannel condenser is more than conventional condenser for R1234ze over other refrigerants at all condensing and evaporating temperatures. The condensation temperature reduced by 3 °C with the minichannel condenser over conventional condenser resulted into increase in coefficient of performance (COP) by 10% to 15% for different evaporating temperatures. Thus, it is concluded that R1234ze is direct drop-in substitute to R134a as compared to R152a, R600a, R290 and R290/R600a (50/50%) considering exergy loss, exergy efficiency and COP with minichannel condenser over conventional condenser.

Keywords: *Exergy, efficiency, condensers, COP, minichannel, refrigerants*

1. INTRODUCTION

Refrigeration and air conditioning industries are consuming large quantity of high-grade energy for heating, cooling and ventilation applications in different fields. The selection of refrigerant is one of the important aspects in view of environmental consideration. The global warming potential (GWP), ozone depletion potential (ODP), carbon emission and green-house gases are major factors in environmental degradation. In most of heating, ventilating, air conditioning and refrigeration (HVACR) industries, R134a refrigerant is used which is having GWP of 1300 much more than ecological norms. Bhatkar *et al.* (2013, 2015, 2021) found that there is no ideal refrigerant for any specific application. While selecting the refrigerant, compromise between thermodynamic, chemical, physical, operating and environmental properties are to be considered. Ammonia is good refrigerant as per the thermodynamic properties are considered but it cannot be used in the household applications due to its pungent odour. In the present research, versatile refrigerant system is designed, developed and fabricated for 1TR (3.52 kW) refrigeration capacity with conventional round tube plate fin and minichannel condenser. The system fabricated is an experimental tutor like virtual platform which can control various parameters such as condensing and evaporating pressure, different alternative refrigerants can be tested as drop-in substitute, subcooling and superheating temperatures can be controlled due to heaters provided and flow rate can be varied with the help of manual expansion valve. In experimentation, different refrigerants such as R134a. R1234ze, R152a, R600a, R290 and R290/R600a (50/50%) are used for varying condensing temperature from 40 °C to 55 °C while evaporating temperature changing from -10 °C to +15 °C. The refrigerant R152a and R1234ze are mild flammable whereas R600a and R290 are flammable as per ASHRAE classification. It was investigated that zeotropic mixtures of hydro carbon (HC) refrigerants have potential to enhance the performance and efficiency of vapor compression refrigeration (VCR) system due to temperature gliding effect. Mini/micro-channel condensers reduces ODP due to smaller amount of environmentally harmful refrigerants and reduces green-house gas emissions by improving component and system energy efficiencies. Minichannel geometry and size have significant impact on the performance of heat exchanger. As hydraulic diameter of minichannel is reduced, heat transfer coefficient (HTC) increases but pressure drop also increases which need to be controlled by providing proper location and size of inlet and outlet to condenser, headers, receiver and number of passes along condenser, Kandlikar *et al.* (2006).

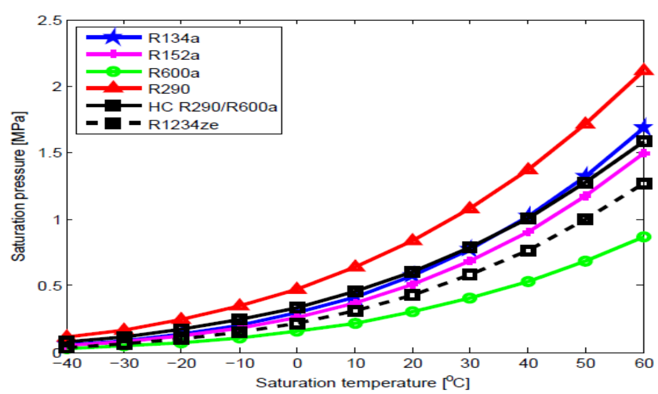


Fig. 1 Saturation pressure vs. saturation temperature

The selection of alternative refrigerant for refrigeration system depends on the saturation pressure and temperature properties for extensive range from initial to final temperature. Figure 1 indicates saturation pressure and temperature for R134a, R1234ze, R152a, R290,

* Corresponding author. Email: vijaybhatkar2009@gmail.com (VWB), anirban.sur@sitpune.edu.in (AS)

DOI: 10.5098/hmt.19.15
ISSN: 2151-8629

R600a and mixture of R290/R600a (50/50%) from - 40 °C to + 60 °C which is drawn from refrigerant property values. It is seen from Figure 1 that R1234ze, R152a, HC mixture of R290/R600a can be considered as direct replacement to R134a as saturation pressure and temperature characteristics are same as R134a.

Hydrocarbon as refrigerants have motivating environmental properties like zero ODP, negligible GWP, non-toxicity, high miscibility with mineral oils and good compatibility with materials used in refrigerating systems. If safety measures are taken to prevent refrigerant leakage from system, then flammable refrigerant may be as safe as other conventional refrigerants. (Calm, 2008; Mani and Selladurai, 2008; Richards, 1992; Ritter, 1996). Fernando et al. (2008) studied performance of minichannel condenser with 6 parallel channels for hydraulic diameter 1.42 mm at constant condensation temperature of 30 °C to 50 °C and developed correlation for two phase heat transfer coefficients. Thus, most of researchers studied performance of HC refrigerants in existing system by replacing R134a with alternative refrigerants. In present study, versatile VCR system is built specifically to study performance of different refrigerants with conventional and minichannel condenser using electronic controls to achieve desired conditions.

2. EXPERIMENTAL SETUP

In the experimentation, one ton of refrigeration (1 TR = 3.52 kW) system is designed, developed and fabricated for trial of alternative refrigerants to R134a along with different control parameters for condenser and evaporator temperature using forced convection air-cooled minichannel parallel flow and conventional round tube plate fin condenser. Figure 2 shows schematic diagram of VCR system with different controls. The heat rejected by condenser is equivalent to heat absorbed in evaporator in addition to heat released due to mechanical compression in compressor. Thus, condenser designed is almost 20% larger capacity than evaporator. The conventional round tube plate fin condenser is replaced by compact and efficient minichannel condenser with four passes considering heat transfer enhancement and pressure drop. Table 1 shows components used in VCR system setup.

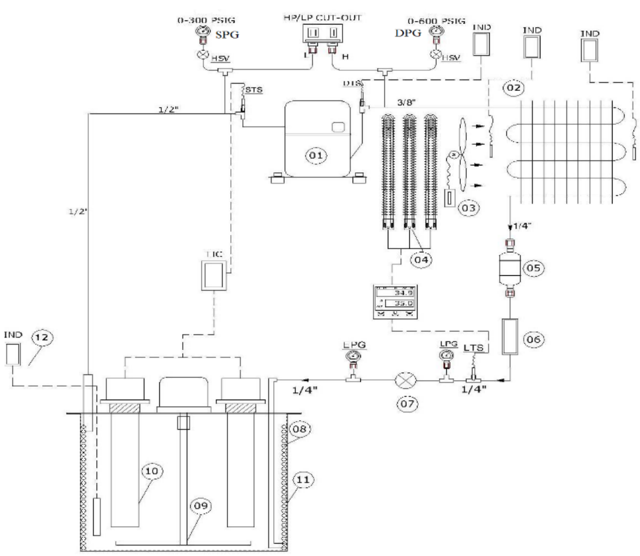


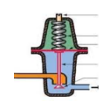
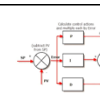
Fig. 2 Schematic diagram of VCR system

The system is designed in such way that condenser temperature can be controlled due to provision of air heaters and multispeed fan, suction temperature can be controlled due to water heaters in the evaporator. Ethylene glycol is used in evaporator to achieve temperatures below freezing point of water. Manual controlled expansion valve is provided so that alternative refrigerants can be utilized in the same system. The pressure gauges are provided across condenser and evaporator to find pressure drop during phase change process. Table 1 and Table 2 shows components and instruments used in VCR system respectively.

Table 1 Components used in the setup

Sr.No.	*Description*	*Quantity*
1	Compressor	1
2	Air Cooled Condenser	1
3	Condenser Fan	1
4	Air Heater	3
5	Drier	1
6	Rotameter	1
7	Expansion Valve	1
8	Evaporator	1
9	Stirrer	1
10	Water Heater	2
11	S.S. Tank	1
12	TIC	5
13	PID	1
14	Pressure Gauge	4
15	Temp. Sensor	5
16	HP/LP Cut-Out	1

Table 2 Instruments used in the setup

SN	*Description*	*Symbol*	*Quantity*
1	Pressure gauge		4
2	Temperature sensor		5
3	Expansion valve		1
4	PID		1
5	TIC		5

Minichannel and conventional condensers are designed for R134a as per geometrical considerations for 1 TR refrigerating capacity. Conventional condenser is with round copper tubes and aluminium plate fins whereas minichannel condenser is designed with aluminium rectangular tubes and louvered fins. The pass optimization is carried out for different number of tubes in each pass for two phase heat transfer and pressure drop analysis as per Copetti *et al.* (2009). A

DOI: 10.5098/hmt.19.15 ISSN: 2151-8629

rectangular tube contains 10 minichannels of 0.914 mm hydraulic diameter. The minichannel condenser is designed with four passes containing 14, 10, 4 and 3 number of tubes in each pass respectively. Minichannel and conventional condenser is designed for condensation temperature of 50 °C and evaporation temperature of 0 °C with R134a. The superheating at the entry to compressor is considered as 10 °C and subcooling at exit of condenser as 7 °C. Total condenser is divided into de-superheating, two phase region and subcooling section. Figure 3 shows cut-section of minichannel parallel flow condenser with header, minichannels and louver fins as per Shah (2009) and Friedel (1980).

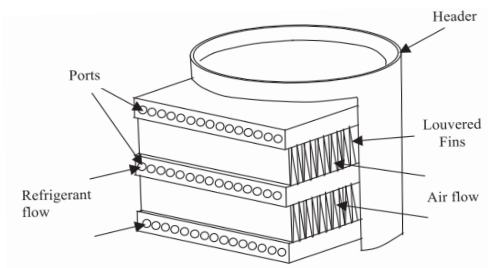


Fig. 3 Cut section view of minichannel condenser

Table 3 shows range and accuracy of instruments used in the experimentation. The uncertainty analysis is carried out using formulae mentioned in ASHRAE (1986).

Table 3 Range and accuracy of the equipment's used

Equipment	Range	Accuracy
Temperature sensors	-100 to 100 °C	± 0.1 °C
Pressure gauge 1	0 to 2 MPa	± 0.007 MPa
Pressure gauge 2	0 to 4 MPa	± 0.007 MPa
Rotameter	0 to 138 kg hr^{-1}	± 1 kg hr^{-1}
Power meters	0 to 99999999 k	± 0.01 kW
Anemometer	0 to 25 m s^{-1}	± 0.1 m s^{-1}
Thermometer	-20 to 500 °C	± 0.5 °C
Weight balance	0 to 10 kg	± 1 g
Voltmeter	0 to 500 V	± 1 V
Ammeter	0 to 200 A	± 1 A

As density of hydrocarbon refrigerants is nearly 40% less than R134a, refrigerant charge reduces 40% to 50% with minichannel condenser. Various refrigerants charged in existing refrigeration system with conventional and minichannel condenser are shown in Table 4. It is found that R1234ze have nearly same density as R134a at operating temperature range. The refrigerant charged in the minichannel condenser is less than conventional condenser due to compact structure.

Table 4 Refrigerant charged in VCR system

SN	Refrigerant	Conventional Condenser (g)	Minichannel Condenser (g)
1	R134a	1000	900
2	R1234ze	950	840
3	R152a	800	650
4	R600a	450	400
5	R290	485	408
6	R290/R600a (50/50%)	480	410

3. ENERGY AND EXERGY

The useful or available portion of energy of system is exergy. Exergy analysis is more significant than energy analysis for predicting the performance of system. Jian Sun *et al.* (2020) studied exergy analysis of refrigeration system with R513a and R134a. They found performance differences in cooling capacity, COP, exergy destruction rate and exergy efficiency for both the refrigerants. They studied that the capacity of R513a is decreased by 12% for same operating parameters. Exergy is an indicator of energy degradation of system and detects available energy of the system. Exergy efficiency is calculated to understand potential of efficiency with available resources. Ali *et al.* (2022) studied refrigeration system with 11 ecological refrigerants such as R134a, R450A, R513A, R515A, R515B, R516A, R152a, R444A, R1234ze(E), R1234yf, R290 and R1243zf. Berkah Fajar *et al.* (2020) investigated performance of R410A and R290 in VCR system by calculating capacity, COP and exergy. They found that exergy destruction and exergy efficiencies were 524 W, 0.24 for R410A and 336, 0.2 for R290 respectively. The exergy analysis of refrigeration plant signifies thermodynamic limitations as exergy destructions or energy loss. Exergy efficiency is an indication of degree of reversibility. Exergy combines first and second law of thermodynamics. Exergy destruction take place in irreversible processes due to friction and other irregularities in the system. Rosen and Dincer (1997) stated that exergy is the main criteria for energy and environment. Dincer and Rosen (2007) stated different environmental, thermodynamic and sustainability for risk assessment methods. They studied different risk finding methods such as environmental performance indicators, environmental impact assessment and ecological footprints. They found that exergy analysis and material flux analysis are thermodynamic risk methods while life cycle assessment, sustainable process index and industrial ecology are sustainability risk methods. Sur *et al.* (2019, 2021, 2022) studied performance of microchannel heat exchanger with numerical approach.

When Carnot engine working at 600 K and 300 K as source and sink temperature respectively, efficiency is only 50% although Carnot cycle is reversible cycle but exergy is 100% mentioning correct nature of system. Yumruta *et al.* (2002) studied consequences of condensation and evaporation temperature on exergy loss, second law efficiency and coefficient of performance of system. Shabgarda and Faghri (2019) applied exergy analysis to energy storage systems, different heat exchangers, fuel cells and heat desalination systems. The VCR cycle consists of compressor, condenser, expansion valve and evaporator as the basic components along with accessories and instruments for measuring temperature, velocity, flowmeter, thermostat, air and water heaters etc. Zheng, Z. and Cao, J. (2020) investigated performance of VCR system components separately and concluded that exergy loss is more for condenser as compared to compressor, expansion valve, evaporator, pump and fan.

The versatile experimental setup is designed, developed and manufactured for testing different refrigerants with minichannel and conventional condensers for same input parameters. In the setup, different parameters such as superheating at entry to compressor, subcooling at the exit of condenser, evaporator and condenser pressure, surrounding air temperature for condensation, condenser fan speed etc. are controlled with the help of PID controllers. The experimentation is performed alternately for both the condensers keeping same parameters for all the refrigerants used as shown in Fig. 4. Table 5 shows geometrical designed parameters for conventional and minichannel condensers. Table 6 shows uncertainty analysis of different performance parameters as per experimental methods studied in Holman (1998).

Frontiers in Heat and Mass Transfer (FHMT), 19, 15 (2022)
DOI: 10.5098/hmt.19.15

Global Digital Central
ISSN: 2151-8629

Fig. 4 Experimental setup

Table 5 Geometrical Parameters

Geometrical Parameters	*Conventional Condenser*	*Minichannel Condenser*
Face area (mm^2)	470 x 360 =0.169	470 x 350 = 0.165
Tube material	Copper	Aluminium
Fin material	Aluminium	Aluminium
Dimensions (mm)	470 x 360 x 90	470 x 315 x 15
Internal volume (cm^3)	1864	382.5
Weight (kg)	5.6	1.6
Fin density	1 fin / 2 mm	1fin / mm
Fin height (mm)	25	8
Fin width(mm)	90	15
Fin thickness (mm)	0.5	0.3
Hydraulic dia. (mm)	9.525	0.914
Total no. of rows	(7x4) x 2 = 56	31
Air side area (m²)	11.741	4.936
Inside area (m²)	0.925	0.418
No of ports	1	10
No of passes	2 Rows, 28 turns	4 (14,10,4,3)

The exergy loss is calculated for conventional and minichannel condenser at condensing temperature of 40 °C to 55 °C while evaporating temperature changes from -10 °C to 15 °C using NIST Standard version 10. The properties of new refrigerants such as R1123, R1224yd(Z), R1233zd(E), R1234ze(Z), R1243zf, and R1336mzz(Z) are used from NIST software to calculate various performance parameters in terms of compressor power, condenser capacity, refrigeration capacity, COP and exergy losses for evaporator, condenser, expansion valve and evaporator.

Table 6 Uncertainty analysis

Sr Nr	*Parameters*	*Uncertainty (%)*
1	Surface area of condenser	± 1.3
2	Refrigerant mass flow rate	± 2.05
3	Heat rejected by condenser	± 3.5
4	Refrigeration capacity	± 4.5
5	Power consumption	± 1.0
6	COP	± 3.6
7	Heat transfer coefficient	± 10.64
8	Temperature	± 2.8
9	Pressure	± 5.0

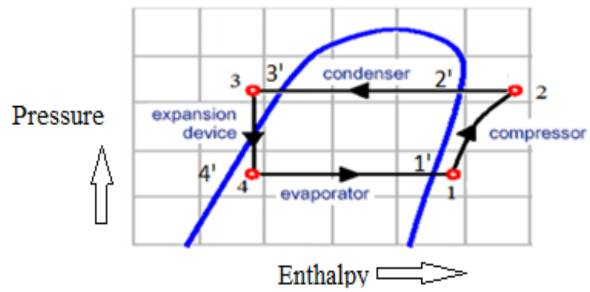


Fig. 5 P-h diagram of VCR system

The following expressions are used for energy and exergy loss calculation with reference to Fig. 5.

$$Compressor\ Power = mr\left(h_2 - h_1\right) \quad (1)$$

$$Compressor\ Exergy\ Destruction = mr\ To\left(S_2 - S_1\right) \quad (2)$$

$$Condenser\ capacity = mr\left(h_2 - h_3\right) \quad (3)$$

$$Condenser\ Exergy\ Destruction = mr\left[\left(h_2 - h_3\right) - To\left(S_2 - S_3\right)\right] \quad (4)$$

$$Expansion\ valve\ exergy\ loss = mr\ To\left(S_4 - S_3\right) \quad (5)$$

$$Refrigeration\ capacity = mr\left(h_1 - h_4\right) \quad (6)$$

$$Evaporator\ exergy\ loss = mr\left[\left(h_1 - h_4\right) - To\left(S_1 - S_4\right)\right] \quad (7)$$

Total exergy loss is addition of exergy loss in compressor, condenser, expansion valve and evaporator.

$$Exergy\ efficiency = COP\left(1 - \frac{To}{Te}\right) \quad (8)$$

Where mr is mass flow rate of refrigerant (kg/s), S is entropy (kJ/kgK), h is enthalpy (kJ/kg), To and Te are environment and evaporation temperature respectively.

Initially trials are performed for conventional condenser and then minichannel condenser using R134a, R1234ze, R152a, R600a, R290 and mixture of R290/R600a (50/50%) respectively for different condensing and evaporating temperatures. In all trials, for each condenser temperature, evaporator temperature is varied from -10 °C to 15 °C. For all refrigerants, exergy loss is plotted at condensation

Frontiers in Heat and Mass Transfer (FHMT), 19, 15 (2022)
DOI: 10.5098/hmt.19.15

Global Digital Central
ISSN: 2151-8629

temperature of 44 °C (normal condensing temperature corresponding to ambient temperature) using conventional and minichannel condenser for ambient temperature of 25 °C. It is observed that exergy loss is more for conventional condenser than minichannel condenser for all refrigerants used in VCR system. Thus, minichannel condenser is better than conventional condenser with exergy analysis. From Fig. 6 it is seen that R1234ze shows minimum exergy loss for both condensers. It is found that R1234ze is drop-in refrigerant for R134a while R290 shows highest exergy loss, thus, it is to be retrofitted with high pressure refrigerant in VCR system. It is investigated that total exergy loss increases as evaporation temperature increases from -10 °C to 15 °C at condensing temperature of 44 °C. The exergy loss for condenser is more than evaporator, compressor and expansion valve. Thus, condenser is second prime component over compressor in VCR system.

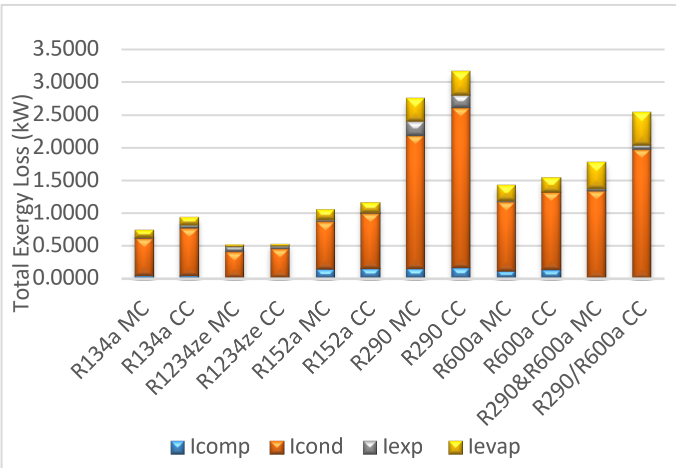


Fig. 6 Total exergy loss for all refrigerants with MC and CC

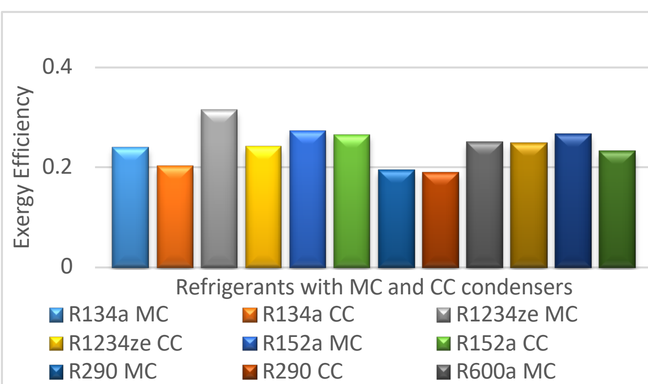


Fig. 7 Exergy efficiency for all refrigerants with MC and CC

Exergy efficiency is calculated for all refrigerants using Eq. (8) for conventional and minichannel condenser. Exergy efficiency is one of the parameter for predicting the performance of specific component in the system. It is observed from Fig. 7 that exergy efficiency is more for minichannel condenser than conventional condenser for all refrigerants at all condenser temperatures. It is found that R1234ze indicated maximum exergy efficiency among all refrigerants for minichannel condenser while R290 with conventional condenser indicated least exergy efficiency. Thus, R1234ze is direct drop-in substitute to R134a from exergy efficacy considerations and R290 is retrofit refrigerant.

COP is measure of energy efficiency for refrigerating and air conditioning system. COP depends on the condenser temperature and evaporator temperature for specific applications in refrigeration and air conditioning. It is observed that as the condensation temperature drops by 3 °C with the minichannel condenser over conventional condenser for same operating conditions, COP for minichannel condenser is more than 10% to 15% than conventional condenser. It is experimentally observed that COP for R1234ze is maximum among all refrigerants with minichannel condenser. Thus, minichannel condenser is efficient over conventional round tube plate fin condenser for HVACR applications. Figure 8 shows COP values of all refrigerants for evaporating temperature varying from -10 °C to +15 °C at condensation temperature of 44 °C with minichannel condenser.

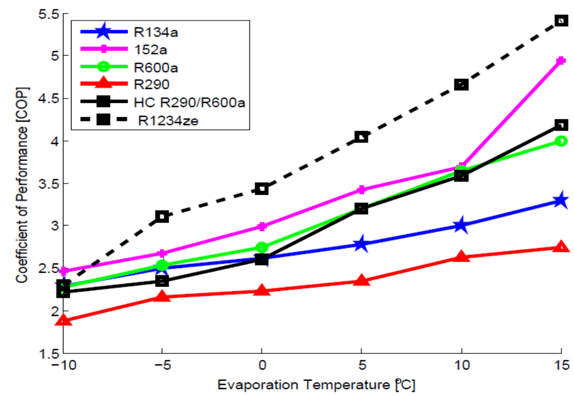


Fig. 8 COP for all refrigerants

4. CONCLUSIONS

In the experimental study of substitute refrigerants to R134a, different refrigerants such as R1234ze, R152a, R600a, R290 and R290/R600a (50/50%) are tested with conventional and minichannel condenser alternately in refrigeration system. The versatile refrigeration test rig made is capable of achieving different condensation and evaporation temperatures due to air/water heaters, desired superheating and subcooling temperatures due to PID controllers, drop in refrigerants due to provision of expansion valve and pressure drop across the condenser due to pressure gauges. The refrigerants such as R134a, R1234ze, R152a, R290, R600a and mixture of R290/R600a (50/50%) are tested with the innovative system for same input parameters using conventional and minichannel condenser for performance comparison. The refrigerant charge reduced by around 40% with the minichannel condenser over conventional condenser. The energy and exergy analysis of all refrigerants is carried out for conventional and minichannel condenser with condensing temperature varying from 40 °C to 55 °C while evaporating temperature ranging from -10 °C to 15 °C for constant condensing temperature. It is concluded from total exergy loss and exergy efficiency that R1234ze is direct drop-in substitute to R134a. It is concluded that COP of VCR system with minichannel condenser for all the refrigerant is more than 10% to 15% over conventional condenser at all condensation temperatures. COP of R1234ze is found to be the highest among all refrigerants tested for same conditions.

ACKNOWLEDGEMENTS

The author is thankful to Dassault Systemes, LaFondation for funding project titled "Virtual design and simulation of environmentally friendly combined flow evaporative condenser for cold storage plants" with No: 40/2020.

NOMENCLATURE

CC	Conventional Condenser
COP	Coefficient of Performance
DPG	Discharge Pressure Gauge
DTS	Discharge Temperature Sensor
EPG	Evaporator Pressure Gauge
ETS	Evaporator Temperature Sensor
IND	Indicator
LPG	Liquid Pressure Gauge
LTS	Liquid Temperature Sensor
MC	Minichannel Condenser
PID	Proportional Integral Derivative
SPG	Suction Pressure Gauge
STS	Suction Temperature Sensor
To	Ambient Temperature (K)
Te	Evaporating Temperature (K)

REFERENCES

Ali, K.S., Joaquín, N-E, Adri, M. B., 2022, "Energy, exergy, and environmental (3E) analysis of a compound ejector-heat pump with low GWP refrigerants for simultaneous data center cooling and district heating" *Int. Journal of Refrigeration,* **133,** 61–72. https://doi.org/10.1016/j.ijrefrig.2021.09.036

ASHRAE guidelines 2, Engineering analysis of experimental data, Atlanta, GA, ASHRAE 1986. http://www.ce.utexas.edu/prof/novoselac/classes/ce397/handouts/ashrae_guideline_2.pdf

Berkah Fajar, T.K., Bagas, R., Ukhi, S., Alhamid, M.I., Lubis, A., 2020, "Energy and exergy analysis of an R410A small vapor compression system retrofitted with R290" *Case Studies in Thermal Engineering,* **21,** 100671. https://doi.org/10.1016/j.csite.2020.100671

Bhatkar, V.W., Kriplani, V.M., Awari, G.K., 2013, "Alternative refrigerants in vapour compression refrigeration cycle for sustainable environment: a review of recent research" *Int. Journal of Environmental Science and Technology,* **10**, 871-880. http://dx.doi.org/10.1007/s13762-013-0202-7

Bhatkar, V.W., Kriplani, V. M., Awari, G. K., 2013, "Numerical simulations of an aluminium microchannel condenser for household air conditioner" *Int. Review of Mech. Engineering,* **7** (1), 181-188. https://www.researchgate.net/publication/286345173_Numerical_simulations_of_a_aluminium_microchannel_condenser_for_household_air_conditioner

Bhatkar, V.W., Kriplani, V. M., Awari, G. K., 2015, Experimental performance of R134a and R152a using microchannel condenser, *Journal of Thermal Engineering*, **1** (7), 575-582 https://doi.org/10.18186/jte.55930

Bhatkar, V.W., Sur A, 2021, "An experimental analysis of liquid air jet pump" *Frontiers in Heat and Mass Transfer*, **17** (12), 1-5. http://dx.doi.org/10.5098/hmt.17.12

Calm, J.M., 2008, "The next generation of refrigerants–historical review, considerations, and outlook" *Int. Journal of Refrigeration*, **31**, 1123-1133. http://dx.doi.org/10.1016/j.ijrefrig.2008.01.013

Copetti, J.B., Macagnan, M.H., Figueiredo, C.O., 2009, "Design and optimization of minichannel parallel flow condensers" Seventh Int. Conference on *Enhanced, Compact and Ultra-Compact Heat Exchangers: From Micro scale Phenomena to Industrial Applications.* https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.468.1363&rep=rep1&type=pdf

Dincer I., Rosen M.A., 2007, "Exergy-Energy, Environment and Sustainability" *Elsevier Publication*

Fernando, P., Palm, B., Ameel, T., Lundqvist, P., Granryd, E., 2008, "A minichannel aluminium tube heat exchanger-Part-III, condenser performance with propane" *Int. Journal of Refrigeration*, **31**, 696-708. http://dx.doi.org/10.1016/j.ijrefrig.2008.02.011

Friedel, L., 1980, "Pressure drop during gas/vapor–liquid flow in pipes" *Int. Chemical Engineering*, **20** (3), 352–367.

Gulia, V., Sur, 2022, A., **"**A comprehensive review on microchannel heat exchangers, heat sink, and polymer heat exchangers: current state of the art" *Frontiers in Heat and Mass Transfer*, **18** (40) (2022) http://dx.doi.org/10.5098/hmt.18.40

Holman J. P. 1998, "*Experimental Methods for Engineers,"* Seventh Edition, Tata McGraw Hill Education Private Limited, India. http://103.47.12.35/bitstream/handle/1/3182/PK63-2_5195431417516917247.pdf?sequence=1&isAllowed=y

Kandlikar, S., Garimella, S., Li, D., Colin, S., King, M.R., 2005, "Heat transfer and fluid flow in minichannels and microchannels, First edition, *Elsevier Publication,* U.K. eBook ISBN: 9780080456188

Mani, K., Selladurai, V., 2008, "Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC 12 and HFC134a" *Int. Journal of Thermal Science,* **47**, 1490-1495. https://doi.org/10.1016/j.ijthermalsci.2007.11.008

Narkhede, S., Sur, A., 2021, Performance prediction of hollow micro-lattice cross-flow heat exchanger using a numerical approach, *Int. Journal of Ambient Energy* http://dx.doi/10.1080/01430750.2021.1927835

Richardson, R.N., Butterworth, J.S., 1995, "The performance of propane/isobutane mixtures in a vapour compression refrigeration system" *Int. Journal of Refrigeration*, **18**, 58–62 http://dx.doi.org/10.1016/0140-7007(94)P3712-A

Ritter, T.J. 1996, "Flammability-hydrocarbon refrigerants" *Proc. of the Institute of Refrigeration Conference,* London.

Rosen M.A., Dincer I., 1997, "On exergy and environmental impact" *Int. Journal of Energy Research,* **21**, 643–654. https://doi.org/10.1002/(SICI)1099-114X(19970610)21:7%3C643::AID-ER284%3E3.0.CO;2-I

Shabgarda, H., Faghri, A. 2019, "Exergy analysis in energy systems: fundamentals and application" *Frontiers in Heat and Mass Transfer*, **12** (9), 1 to 22. https://doi.org/10.5098/hmt.12.9

Sur, A., Narkhede, S., Darvekar, S. 2019, "Applications, manufacturing and thermal characteristics of micro-lattice structures: current state of the art", *Engineering Journal*, **23** (6), 419-431. https://doi.org/10.4186/ej.2019.23.6.419

Sur, A., Pandya, S., Sah, R.P., Kotecha, K., Narkhede, S. 2021, "Influence of bed temperature on performance of silica gel/methanol adsorption refrigeration system at adsorption equilibrium" *Particulate Science and Technology,* **39** (5), 624-631, https://doi.org/10.1080/02726351.2020.1778145

Sun, J., Li, W., Cui, B., 2019, "Energy and exergy analyses of R513a as a R134a drop-in replacement in a vapor compression refrigeration system" *Int. Journal of Refrigeration*, **112** (12), 348-356. http://dx.doi.org/10.1016/j.ijrefrig.2019.12.014

Shah, M.M., 2009, "An improved and extended general correlation for heat transfer during condensation in plain tubes" *HVAC&R research,* **15**, 1-26. https://doczz.biz.tr/doc/219728/otomotiv-klima-yo%C4%9Fu%C5%9Fturucusunda-kullan%C4%B1lan-t%C3%BCplerde-is%C4%B1

Thermodynamic properties of refrigerants and refrigerant mixtures, *NIST Standard Reference Database version 10, Gaithersburg*. https://www.nist.gov/srd/refprop

Yumruta R., Kunduz, M., Kanoglu, M., 2002, "Exergy analysis of vapor compression refrigeration systems" *Exergy, an Int. Journal,* **2,** 266–272. https://doi.org/10.1016/S1164-0235(02)00079-1