JnUJSci

Jagannath University Journal of Science
Volume 09, Number II, December 2022, pp. 85-91
https://jnu.ac.bd/journal/portal/archies/science.jsp
ISSN 2224-1698

Thermodynamic and Environmental Effect of Widely Used Refrigerants in Domestic Air-Condition

Research Article

Mehedi Hasan and Kutub Uddin*

Department of Physics, Jagannath University, Dhaka-1100, Bangladesh

Received: 23 March 2023, Accepted: 22 May 2023

ABSTRACT

Among the sources of greenhouse gas emission, air-conditioning and refrigeration systems are now playing a vital role. These systems use refrigerants which have very high global warming potential (GWP) and consume huge amount of electricity. In this study, the environmental effects of different refrigerants used in Bangladesh are studied employing their thermodynamic performance and GWP. The widely used refrigerants are namely R22, R32, R134a, R152a, R410a and R507a, respectively. The thermodynamic performance parameters of the refrigeration system are considered refrigeration effect, compressor work, coefficient of performance (COP), power per ton of refrigeration, compressor discharge temperature, volumetric capacity, direct and indirect emission of refrigerants, and finally total equivalent warming impact (TEWI). The operating conditions used for the cycle calculation are: condensation temperature 40°C and evaporating temperatures 7°C.The superheat and sub cooling effect are also taken into consideration. It is found that the COP of R152a refrigerant is higher among the six studied refrigerants though the volumetric capacity of R152a is lower. The cooling load for R32 is found better among the six studied refrigerants. TEWI for R507a is found 11.98 ton-CO_2 which is higher among the studied refrigerants. The above mention properties are essential for the development of environment friendly refrigerants.

Keywords: *Air conditioner, Global warming, Refrigerants, Volumetric capacity*

1. Introduction

Globally, the production of cooling and heating in living area is seen as a major energy challenge of this new century. The economic development of developing countries, located their majority in hot climates region, will lead to a growing demand of chilling requirements. Currently, the production of cooling is mainly based on the refrigeration systems, which is considered the major consumers of electrical energy in a building. The refrigerants used in this system associated with very high global warming potential. So the systems cause both the direct and indirect emission of greenhouse equivalent gases (Calm 2002). It is then necessary to find environment friendly and economically acceptable solutions to meet those needs without compromising the international commitments on the protection of the environment, particularly for

*Corresponding Author: Kutub Uddin
Email: mdkutub@phy.jnu.ac.bd

reducing greenhouse gas emissions(Parties to the Protocol 1998; EU MAC Directive 2006; UNEP Report of the Technology and Economic Assessment Panel 2016).Different types of refrigerants are studied for refrigeration and air conditioning applications over the century (Calm 2008). Recently some new type of refrigerants are studying in different laboratory considering its energy efficiency as well as the environmental safety (Pal et al. 2018; Uddin et al. 2021).Considering the thermodynamic properties of gas, different gas is used in a different system (Bolaji 2010; Koyama et al. 2010; Pham and Rajendran 2012). Hydrocarbon also started to use as refrigerant for small size refrigerator (Hammad and Alsaad 1999; Palm 2008).

Heating, air conditioning and refrigeration system contribute significantly to the increase of CO_2 level in atmosphere. Different study showed the equivalent amount of greenhouse gas emission from these systems(Choi et al. 2017; Islam et al. 2017). Both the direct and indirect emission is considered to calculate the total impact from the system. The direct emission comes from the leakage whereas the indirect emission comes from the electricity used, its overall efficiency and manufacture. Bangladesh is vulnerable country to the impacts of climate change and global warming. As a developing country, every year the use of cooling devise is increasing. The present study calculated the total equivalent warming impact for the widely used refrigerant in Bangladesh.

2. GWP and international regulations

The Intergovernmental Panel on Climate Change (IPCC) has, since its first scientific assessment in 1990, used the global warming potential (GWP) as a method for comparing the potential climate impact of emissions of different refrigerants. The potential climate impact of different refrigerants has been introduced in 1990 by the Intergovernmental Panel on Climate Change (IPCC). The term used is global warming potential (GWP) which is defined by the radiation energy that any gas can absorb, relative to carbon dioxide (GWP = 1). It is estimated using the integrated time interval over 20, 100 and 500 years. In this study the GWP_{100} is used which is the heat trap by the same mass of CO_2 over the 100-year horizon. For the case of refrigerant mixture, the mass-weighted average of GWPs of individual components in the blend are used.

As the climate change is affected by the global warming gases, several international protocol and agreement has been adopted aiming to strengthen the global response to the of the climate change. Some of the important and successful international regulations are Montreal protocol, Kyoto Protocol, EU regulation, Paris agreement etc.

- The first international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion(UNEP 2016) is Montreal Protocol (signed in 1987). It is considered as the successful agreement for protecting the ozone layer. Later it has become a model for various multilateral environmental agreements. The Montreal Protocol now adopted HFCs refrigerants in its Kigali Amendment to ensure that industrialized countries will bring down their HFCs production and consumption by at least 85 per cent compared to their annual average values in the period 2011–2013.
- The Kyoto Protocol is signed in 1997, which extended the 1992 United Nations Framework Convention on Climate Change (UNFCCC),committed that state parties will reduce greenhouse gas emissions(Parties to the Protocol 1998). The GWP is the main concern in the Kyoto Protocol.
- EU regulation, signed in 2006 in the European Parliament set the GWP limit to use and produce certain fluorinated greenhouse gases (EU MAC Directive 2006).
- The Paris Agreement is signed in 2015. This agreement works for the mitigation, adaptation, and financing related to greenhouse gas

emission(UNFCC 2015). The long term goal of the Paris Agreement is to limit the increase in global average temperature to well below 2 °C above pre-industrial level. It will pursue its efforts to limit the increase to 1.5 °C. Besides these, some develop countries set their own GWP limit and goal to achieve the target. Industries in the developed country are working hard to find the low GWP refrigerants for the cooling industry. Bangladesh usually imports refrigerants from different countries. Based on the imported data, this study found some refrigerants imported with a large quantity for the last few years, shown in **Table 1**.

Table 1: Features of widely used refrigerants according to IPCC 5th assessment report 2014.

Compositional group	**Refrigerant number**	**Chemical formula**	**Ozone depletion potential (ODP)**	**Global warming potential (GWP)**	**Safety group**
HCFCs	R22	$CHClF_2$	0.055	1760	A1
	R123	$CHCl2CF_3$	0.02	79	B1
	R124	$CHClFCF_3$	0.022	527	A1
	R142b	CH_3CClF_2	0.065	1980	A2
HFCs	R23	CHF_3	0	12400	A1
	R32	CH_2F_2	0	677	A2L
	R125	CHF_2CF_3	0	3170	A1
	R134a	CF_3CH_2F	0	1300	A1
	R143a	CH_3CF_3	0	4800	A2
	R152a	CH_3CHF_2	0	138	A2
	R410A	R32 (50%) R125 (50%)	0	1900	A1

3. Thermophysical Properties of refrigerants

Six widely used refrigerants, namely, R22, R32, R134a, R152a, R410a and R507a are considered for this study. The thermodynamic properties of these refrigerants are required for the thermodynamic analysis of refrigeration system. The basic properties of six refrigerants are shown in **Table 2** which is found in ASHRAE hand book.

Table 2: Basic properties of refrigerants.

Refrigerant	M (kg/mol)	T_b (Kelvin)	P_c (MPa)	T_c (Kelvin)
R22	86.5	232.19	4.99	369.3
R32	52.024	221.5	5.782	351.26
R134a	102.03	247.08	4.0593	374.21
R410a	72.585	224.5	4.9012	344.49
R507a	98.859	226.3	3.7049	343.77
R152a	66.051	249.13	4.5168	386.41

4. Thermodynamic cycle of the refrigerants

Fig. 1(a) shows the four main parts; evaporator, compressor, condenser and expansion or throttling valve, of the heating, air-conditioning and refrigeration systems. Refrigerant is the working fluid which transfers heat from one section to another. Usually liquid refrigerant evaporates in the evaporator by taking heat from the space which needs to be cooled; the compressor the compresses the refrigerant vapor and send to the condenser where the vapor refrigerant is condensed. The liquid refrigerant then again comes back to the evaporator through the throttling valve. To ensure the complete vapor state and liquid state, superheat and sub-cooling, respectively, are used in the system. **Fig. 1(b)** shows the enthalpy change at different stage of the refrigerants in a thermodynamic cycle.

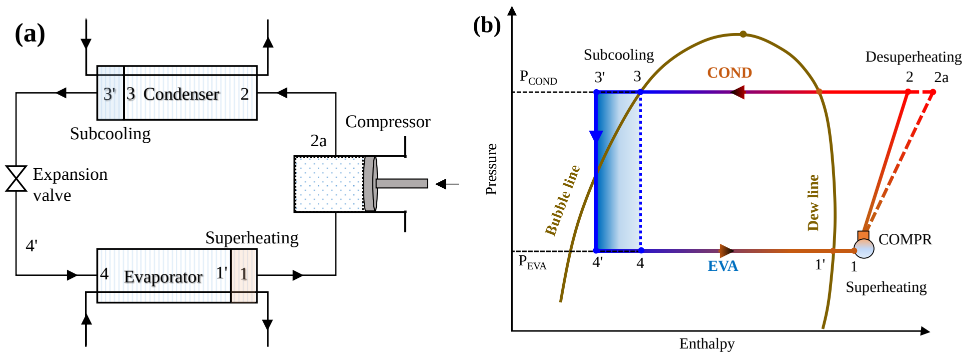

Fig. 1: The refrigeration cycle; (a) schematic, (b) corresponding p-h diagram.

5. Mathematical computations

The thermodynamic analysis is performed using the following equations where the subscript shows in the point in **Fig. 1(b)**.

$h_{2a}$is calculated by the following equations

$$h_{2a} = \frac{h_2 - h_1}{0.85} + h_1 \quad (1)$$

Isentropic compressor work is computed as

$$w_c = h_{2a} - h_1 \quad (2)$$

Refrigerating effect (RE) is calculated as

$$RE = h_1 - h_4 \quad (3)$$

COP is calculated as

$$COP = \frac{RE}{W_c} \quad (4)$$

Volumetric capacity (VRC) is calculated as

$$VRC = \rho_1 * RE \quad (5)$$

The compressor discharge temperature (T_{2a}) is computed at point 2a in **Fig. 1(b)**.

6. Results and discussion

(i) Thermodynamic analysis

Fig. 2 shows the *p-h* diagram of the studied refrigerants where a thermodynamic cycle for each refrigerant is super imposed. The similar operational condition is applied for all cycle. The thermos-physical properties are taken from REFPROP V9.1 database. Condensation, the degree of subcooling, evaporation and degree of superheat temperature are chosen at 35°C, 10°C, 7°C, and 4°C, respectively. Adiabatic compression efficiency is assumed to 0.85. The thermodynamic cycle for each refrigerant found in different places though their operation condition is similar. That is why for different system different refrigerant is chosen to get better performance.

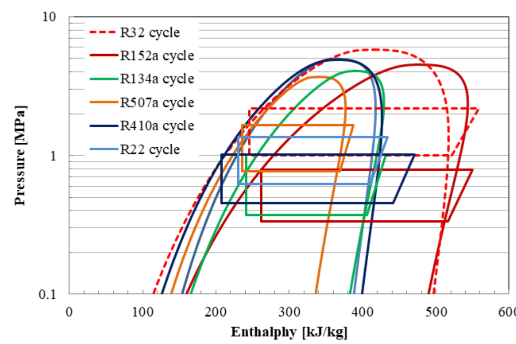

Fig. 2: Thermodynamic cycle for the studied refrigerants.

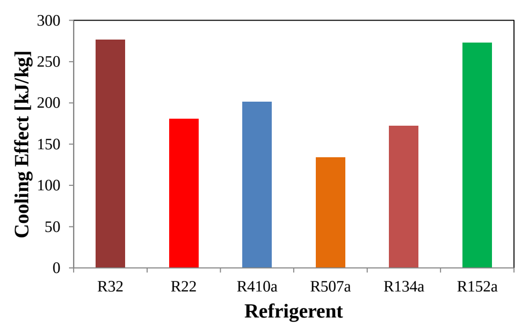

Fig. 3: Cooling effect for different refrigerants.

Fig. 3 shows the cooling effect (refrigeration effect) of various refrigerants. The refrigerant R32 shows highest amount of cooling load which is 276.38kJ/kg whereas the R507a shows the lowest value which is 133.57kJ/kg. It is also noticed that cooling effect decreases with the increasing condenser temperature keeping other parameters constant.

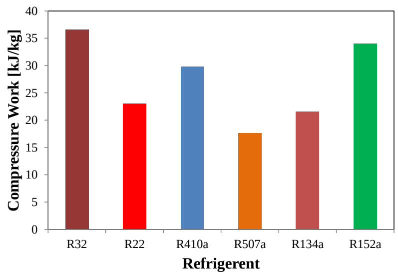

Fig. 4: Compressor work of various refrigerants.

Fig. 4 shows that the compressor work for R32 is higher which is found 36.54kJ/kg. The lowest compressor work is observed for R507a. The compressor discharge temperature for R32 is also higher.

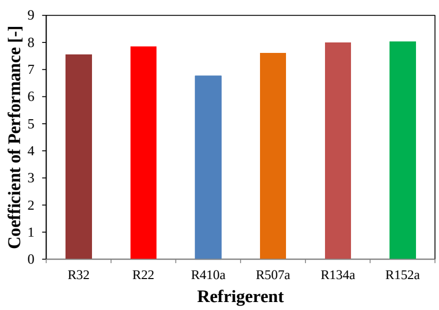

Fig. 5: Coefficient of performance of various refrigerants.

Fig. 5 shows the comparison of ideal cycle performance of selected refrigerants. COP of R152a is 8.025 which is the highest among the studied refrigerants. Lower COP is observed for R410a. COP found decreases with the increase of condenser temperature.

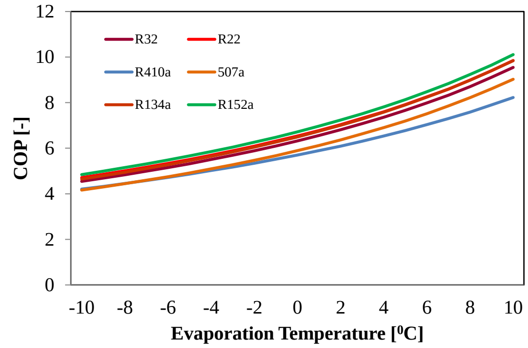

Fig. 6: Coefficient of performance of different refrigerants at various Evaporation temperatures.

Fig. 6 shows the variation of COPs with different evaporation temperature. It is found that the changes of COPs with evaporation temperature are similar for each refrigerant. R410a shows lower COP at higher evaporation temperature compared to other refrigerants.

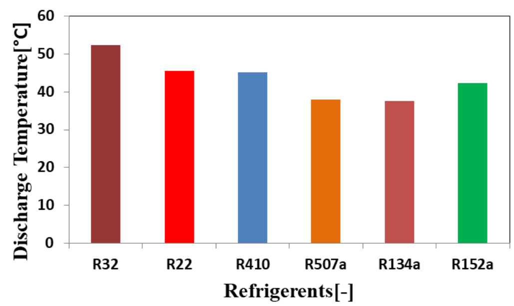

Fig. 7: Discharge temperature of various refrigerants.

It can be seen form **Fig. 7**that the discharge temperature for R32 is found higher and R134a is found lower. The lower compressor discharge temperature is always favorable from the stand point of durability of the compressor life. Here both R134a and R507a fluids exhibits better reliability and lifespan of compressor motor.

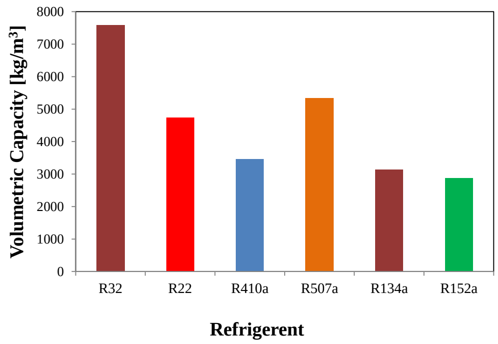

Fig. 8: Volumetric capacity of different refrigerants.

The volumetric capacity of different refrigerants is shown in **Fig. 8**. It is calculated using cooling capacity per unit volume of vapor refrigerant at the outlet of evaporator. The volumetric capacity also denotes the amount of refrigerant pumped by the compressor. The volumetric refrigeration capacity of R134a and R152a are found lower than R22 and hence these refrigerants require larger size of compressor. On the other hand, R32 require smaller size of compressor.

(ii) Total equivalent warming impact (TEWI)

TEWI or LCCP (Life Cycle Climate performance) are two parameter used to find the lifetime environmental impacts of the air-conditioning and refrigeration system. TEWI is the resultant amount of direct and indirect emissions. The direct emissions is calculated from GWP data for each refrigerant shown in **Fig. 9**. The indirect part comes from its manufacturing to the daily use of the system. The electricity required to drive the cooling system comes from the burning of fossil fuel (such as coal, natural gas).The power plants releases global warming gases like CO_2 during the production of electricity. The contribution of other types of alternative electricity, generated in nuclear, solar, windmill plant, are very small. Coefficient of performances of the cooling system affect the indirect emissions. Different operating system and different refrigerants show different COP. Refrigerant leakage is another source of emissions which is very serious in supermarket. The levels of leakage recently found in domestic air conditioning system is nearly 2%. This study the TEWI value of R22, R32, R134a, R152a, R410a and R507a calculated using the following equations.

$$TEWI = Direct\ Emission(DE) + Indirect\ Emission(IDE) \quad (6)$$

$$DE = GWP \times M \times \left[1 - (1 - \frac{a}{100})^Y\right] + GWP \times M \times (1 - \frac{a}{100})^Y \times (1 - \frac{b}{100}) \quad (7)$$

$$IDE = c \times Y \times \left(HC \times \frac{t_h}{COP_h} + CC \times \frac{t_c}{COP_c}\right) \quad (8)$$

For this calculation we used data from the following Table 3. Indirect emission and direct emission have been calculated and combined to get the total equivalent warming impact. System lifetime is considered 15 years. System use in heating mode 1183 hours and in cooling mode 1108 hours per year. Refrigerant charge amount was 0.85 kg for all refrigerants. Leakage rate 2 percent per year and recovery rate was 30 percent. CO_2 emission per kW was used 0.599 kg per kWh. COP was used 5.282490626 and 4.405622084 for heating and cooling mood respectively for all studied refrigerants except R32 and for R32 COP was used 5.429585025 and 4.487368679 heating and cooling mood respectively. Rated cooling and heating capacity was used 2 and 2.4 kw respectively for all refrigerants. Among six studied refrigerants direct emission of R507 is higher than all of refrigerants and R152a refrigerants has the lowest value shown in **Fig. 9**.TEWI is highest for Refrigerants R507a as shown in **Fig. 10**.

Table 3: Refrigerants GWP and Leakage during disposal and operation data table.

Refrigerant name	GWP	Leakage during disposal[kg]	Leakage during operation[kg]
R22	1810	795.4019951	402.2114356
R32	675	296.6278158	149.9959774
R134a	1430	628.411521	317.7692557
R152a	140	61.52280625	31.52280625
R410a	2088	917.5687104	463.9875566
R507	3985	1751.202735	885.5318071

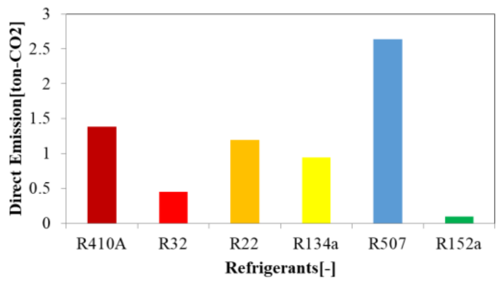

Fig. 9: Direct CO_2 equivalent emission for pure and mixture refrigerants.

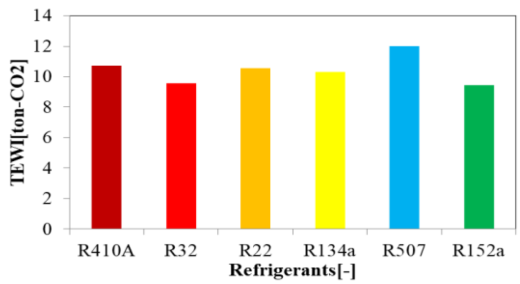

Fig. 10: TEWI for the studied refrigerants.

(i) Conclusions

Due to their different thermophysical properties, each refrigerant shows different level of performance at different stages of system operation. Some refrigerants show higher COP but lower volumetric capacity. Some refrigerants were low cost but their warming impact is higher. In this study, refrigerant R507 shows TEWI is 12 ton equivalent-CO_2 when it is used for a medium size air conditioner. Refrigerant R32 is found good in terms of performance and GWP but it shows higher temperature at the compressor outlet. Also the flammability of R32 is considerable (A2L). The volumetric refrigeration capacity for R32 is also higher where as for R134a and R152a it is lower. Higher volumetric capacity requires smaller size compressor to drive the refrigerants.

Acknowledgement

The work is supported by the project "Low-grade heat powered cooling system- a green technology towards low carbon society" of Bangladesh Climate Change Trust (BCCT-581), Ministry of Environment, Forest and Climate Change, Peoples Republic of Bangladesh.

(ii) References

Bolaji BO (2010) Experimental study of R152a and R32 to replace R134a in a domestic refrigerator. Energy 35:3793–3798. https://doi.org/10.1016/j.energy.2010.05.031

Calm JM (2002) Emissions and environmental impacts from air-conditioning and refrigeration systems. Int J Refrig 25:293–305. https://doi.org/10.1016/S0140-7007(01)000676

Calm JM (2008) The next generation of refrigerants - Historical review, considerations, and outlook. Int J Refrig 31:1123–1133. https://doi.org/10.1016/j.ijrefrig.2008.01.013

Choi S, Oh J, Hwang Y, Lee H (2017) Life cycle climate performance evaluation (LCCP) on cooling and heating systems in South Korea. Appl Therm Eng 120:88–98. https://doi.org/10.1016/j.applthermaleng.2017.03.105

EU MAC Directive (2006) Directive 2006/40/EC of the European Parliament and the Council of the European Union. Off J Eur Union L 161:

Hammad MA, Alsaad MA (1999) Use of hydrocarbon mixtures as refrigerants in domestic refrigerators. Appl Therm Eng 19:1181–1189. https://doi.org/10.1016/S1359-4311(98)00116-1

Islam MA, Srinivasan K, Thu K, Saha BB (2017) Assessment of total equivalent warming impact (TEWI) of supermarket refrigeration systems. Int J Hydrogen Energy 42:26973–26983. https://doi.org/10.1016/j.ijhydene.2017.07.035

Koyama S, Takata N, Matsuo Y, et al (2010) Possibility to introduce HFO-1234ze(E) and its mixture with HFC-32 as low-GWP alternatives for heat pump/refrigeration systems SYSTEMS. In: International Symposium on Next-generation Air Conditioning and Refrigeration Technology. Tokyo, pp 1–10

Pal A, Uddin K, Thu K, Saha BB (2018) Environmental assessment and characteristics of next generation refrigerants. Evergr Jt J Nov Carbon Resour Sci Green Asia Strateg 5:58–66

Palm B (2008) Hydrocarbons as refrigerants in small heat pump and refrigeration systems - A review. Int J Refrig 31:552–563. https://doi.org/10.1016/j.ijrefrig.2007.11.016

Parties to the Protocol (1998) Kyoto Protocol to the United Nations Framework Convention on Climate Change

Pham H, Rajendran R (2012) R32 And HFOs As Low-GWP Refrigerants For Air Conditioning. In: International Refrigeration and Air Conditioning Conference at Purdue. Indiana, pp 1–10

Uddin K, Arakaki S, Saha BB (2021) Thermodynamic analysis of low-GWP blends to replace R410A for residential building air conditioning applications. Environ Sci Pollut Res 28:2934–2947. https://doi.org/10.1007/s11356-020-10656-9

Uddin K, Saha BB (2022) An Overview of Environment-Friendly Refrigerants for Domestic Air Conditioning Applications Energies 2022, 15(21), 8082; https://doi.org/10.3390/en15218082

UNEP (2016) Montreal Protocol On Substances that Deplete the Ozone Layer (Report of the Technology and Economic Assessment Panel)

UNEP Report of the Technology and Economic Assessment Panel (2016) Montreal Protocol On Substances that Deplete the Ozone Layer

UNFCC (2015) United Nations/Framework Convention on Climate Change. Paris Agreem (21st Conf Parties) 27. https://doi.org/FCCC/CP/2015/L.9