PERFORMANCE ANALYSIS OF R-22
AND ITS
ALTERNATE REFRIGERANTS

A major thesis submitted
In partial fulfillment for the requirements of the award of the degree of

Master of Engineering

In

Thermal Engineering

By
HIRA LAL SACHDEV
ROLL NO. 8565

(Session 2004-06)

Under the Guidance of

Prof. AKHILESH ARORA **Prof. B.B.ARORA**

Department of Mechanical Engineering,
Delhi College of Engineering, University of Delhi
DELHI 110042 INDIA

Candidate’s Declaration

I hereby declare that the work which being present in the major thesis entitled “**PERFORMANCE ANALYSIS OF R-22 AND ITS ALTERNATE REFRIGERANTS**” in the partial fulfillment for the award of degree of **MASTER of ENGINEERING** with specialization in “**THERMAL ENGINEERING”** submitted to **Delhi College of Engineering, University of Delhi,** is an authentic record of my own work carried out under the supervisions of Prof. B.B.ARORA and Prof. A. ARORA, Department of Mechanical Engineering Delhi College of Engineering, University of Delhi. I have not submitted the matter in this dissertation for the award of any other Degree or Diploma or any other purpose whatever.

(HIRA LAL SACHDEV)

College Roll No.20/THERMAL/2004

University Roll No: 8565

Certificate

This is to certify that the above statement made by HIRA LAL SACHDEV is true to the best of our knowledge and belief.

(A.ARORA) (B.B.ARORA)

Lecturer
Department of Mechanical Engg.
Delhi College of Engineering, Delhi

Asst. Professor
Department of Mechanical Engg
Delhi College of Engineering, Delhi

Acknowledgement

It is a great pleasure to have the opportunity to extent my heartiest felt gratitude to everybody who helped me throughout the course of this dissertation.

It is distinct pleasure to express my deep sense of gratitude and indebtedness to my learned supervisors Prof.. B.B.ARORA and Prof. A.ARORA**,** Department of Mechanical Engineering, Delhi College of Engineering, for their invaluable guidance, encouragement and patient review. Their continuous inspiration only has made me complete this dissertation. .

I would also like to take this opportunity to present my sincere regards to my teachers for their kind support and encouragement.

I am thankful to my friends and classmates for their unconditional support and motivation for this dissertation..

(Hira LaL Sachdev)
Roll No. 8565

CONTENTS

List of Figures

List of Tables

Nomenclature

COP	Coefficient of performance
ED	Exergy destruction (W)
EES	Engineering Equation Solver
EF	Exergy of fuel (W)
EDR	Exergy destruction ratio
EP	Exergy of product (W)
Q	Heat flow rate (W)
R	Refrigerant
T	Temperature (°C)
TR	Ton of Refrigeration
W	Work (W)
e_x	Exergy of fluid (W)
h	Enthalpy
m	Mass (Kg.)
s	Entropy
η	Efficiency
δ	Efficiency Defect

Subscript

c.	Compressor
cs	Isentropic compression
cond.	Condenser
e	Evaporator
ex	Exergetic
i	Irreversibility
iss	Isentropic
t	Throttle
r	Room

vg Specific volume at inlet to compressor

T_c Condenser temperature

ABSTRACT

The chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) refrigerants are being replaced by hydro fluorocarbon (HFC) and HFC mixtures due to environmental concerns about depletion of the ozone layer and global warming. Various researchers have suggested different alternative to R-22 such as R-290, R-502, R407C, R-410A, and R-417A etc. R-22 has ozone depletion potential 0.055,which have harmful effect on ozone layer; hence R-22 is required to be phased out by year 2030 in developed countries and by year 2040 in developing countries. An air conditioning system using alternative refrigerants needs to be modified or alternatively designed due to variation in the physical properties of these alternative refrigerants with R-22.R-290 is flammable and R-502 is azeotropes refrigerant.

In the present work exergy analysis along with energy analysis of vapour compression refrigeration cycle for R-22 and its alternate refrigerant R407C, R410A and R417A has been carried out by varying evaporator temperature between -38 °C to 7°C and condenser temperature between 35 °C to 60°C, with the help of Engineering Equation Solver (EES). The parametric investigation such as coefficient of performance, volumetric cooling capacity, pressure ratio, exergy destruction ratio, exergetic efficiency, and efficiency defect in individual components for R-22, R-407C, R-410A and R-417A have been carried out theoretically and have been compared with the experimental available data.

The results indicate that evaporating and condensing temperatures have pronounced effect on exergy destruction in the air-conditioner components such as compressor, condenser, and throttle valve where as in the evaporator it is negligible. The exergetic efficiency and COP of the cycle change to large extent with the variation in evaporator and condenser temperatures. The computational analysis has allowed the determination of the best energetic and exergetic performances of R-22 and its substitute refrigerant R-407C, R410A and R417A.

INTRODUCTION

The continuous depletion of the ozone layer, which shields the earth's surface from UV radiation, has resulted in a series of international treaties demanding a gradual phase out of halogenated fluids. The chlorofluorocarbons (CFCs) have been banned since 1996, and also the partially halogenated hydro chlorofluorocarbons (HCFCs) are bound to be prohibited in the near future. The HFCs (hydro fluorocarbons) are candidates for the definite substitution of both CFCs and HCFCs, as they do not contain chlorine. A further problem is the greenhouse effect, stemming from the infrared radiation capture by some components of the atmosphere. Human activities have considerably increased the concentration of greenhouse gases (CFC, HCFC, carbon dioxide, methane, nitrous oxide) that determine the earth's surface and atmosphere warming that might adversely affect the natural ecosystem. Over the last hundred years, the mean temperatures have increased by 0.3°C –0.6°C, and doubling the amount of carbon dioxide in the atmosphere is likely to yield a further temperature increase from 1.5°C to 4.5°C. In particular, it is well known that the greenhouse effect resulting from an operating plant is not a secondary matter. Recent estimates indicate that the overall contribution, both direct and indirect, to the green house effect of HCFCs and CFCs exceeds 24% **[Houghton(1995), Engler , Mobner, Oellrich(1995)].** So, the choice of the working fluids in the vapour compression plant must depend on both the absence of chlorine atoms in the molecule (ozone depletion potential (ODP) equal to 0) and their low contribution to the greenhouse effect (low global warming potential (GWP) and high energy efficiency). The phase out of fully halogenated CFCs and the partially halogenated HCFCs is an irreversible process in the industrialized world, but the problems of their replacement have been only partially solved.

As for R22, there is no unanimous solution for its substitution. The various alternates reported by various researchers are R-407C (a zeotropic blend of R-32 / R-134a/ R-125- 23%/52%/25% by weight), R-410A (a zeotropic mixture of R-32/R-125 in the equal ratio of 50% by weight), R-417A (a zeotropic mixture of R-134a/R-125/R-600 in the ratio of 50%/46.6%/3.4% by weight) and R-290 (propane).

However to switch over to alternate refrigerant, the first step is to carry out the performance analysis of alternate refrigerant based on energy and exergy so as to optimise the refrigeration system.

Thermodynamic processes in refrigeration systems release large amounts of heat to the environment. Heat transfer between the system and the surrounding environment takes place at a finite temperature difference, which is a major source of irreversibility for the cycle. Irreversibility causes the system performance to degrade. The losses in the cycle need to be evaluated considering individual thermodynamic processes that make up the cycle. Energy (first law) analysis is still the most commonly used method in the analysis of thermal systems. The first law is concerned only with the conservation of energy, and it gives no information on how, where, and how much the system performance is degraded. Exergy analysis is a powerful tool in the design, optimization, and performance evaluation of energy systems.

The principles and methodologies of exergy analysis are well established **[Bejan (1982), Moran (1982), Bejan (1988), Wark (1995)]**. An exergy analysis is usually aimed to determine the maximum performance of the system and identify the sites of exergy destruction. Analyzing the components of the system separately can perform exergy analysis of a complex system. Identifying the main sites of exergy destruction shows the direction for potential improvements. An important object of exergy analysis is for systems that consume work such as refrigeration; liquefaction of gases, and distillation of water is finding the minimum work required for a certain desired result **[Çerçi, Çengel and Wood (2000), Kanoglu (2002)].**

There have been several studies on the R-22 and its various substitute refrigerant on the basis of energy and exergy analysis of refrigeration systems .

The conventional view expressed by **Strobridge (1974)** that the exergetic efficiency of the actual refrigeration cycles does not depend on the refrigeration temperature was questioned by **Bejan** (1989) .He showed that the exergetic efficiencies decrease as the refrigeration temperature decreases.

Said and Ismail (1994) assessed the theoretical performances of HCFC123, HFC134a, CFC11, and CFC12 as coolants. It is established that for a specific amount of desired exergy, more compression work is required for HCFC123 and HFC134a than for CFC11 and CFC12. The differences are not very significant at high evaporation temperatures and hence HCFC123 and HFC134a should not be excluded as alternative coolants. There is an optimum evaporation temperature for each condensation temperature, which yields the highest exergetic efficiency.

Nikolaidis and Probert (1998) used exergy method to examine the behavior of two-stage compound compression-cycle, with flash inter cooling, using refrigerant R22. The condenser's saturation-temperature was varied from 298 to 308 K and the evaporator's saturation-temperature from 238 to 228 K. The effects of temperature changes in the condenser and evaporator on the plant's irreversibility rate were determined. It is established that greater the temperature difference between either (i) the condenser and the environment, or (ii) the evaporator and the cold room, the higher the irreversibility rate. Any reduction in the irreversibility rate of the condenser gives approximately 2.40 times greater reduction in the irreversibility rate for the whole plant, and any reduction in the evaporator's irreversibility rate gives a 2.87 times greater mean reduction in the irreversibility rate of the whole plant. Because the changes in the temperatures in the condenser and the evaporator contribute so significantly to the plant's overall irreversibility. They pointed out that there is considerable scope for optimizing the conditions imposed upon the condenser and evaporator.

Aziz and Alexandria Eng.(1998) used the first law and the second law efficiency to evaluate the system behavior for refrigerants CFC R-12,HCFC R-22 and HFC R-134a, based on the thermodynamic properties. Test results showed that the system-cooling COP for R-134a is 8% and 22% higher than the COP of R-12 and R-22, respectively. Based on the second law analysis, the irreversibility of the components varies considerably, in such a way that the main source of exergy loss is due to the heat transfer in the evaporator, condenser and suction line for which effective measures should be taken. This analysis indicates that the exergetic efficiency of R-134a is 20% and 8% higher than that of R-12 and R-22, respectively.

Yan *Nanjing Ligong Da-we Xuehao.(*1999) used cubical equation of state to calculate the thermodynamic properties of R-290 and R-22. Their theoretical cool circulation properties are compared under the standardized working conditions of the conditioners. A test was made on substituting R-290 for R-22 in a KF-22GM air conditioner. The test results showed that R-290 and R-22 have almost the equal refrigerant capacity without any change of the conditioner and with the proper amount of refrigerant.

Aprea and Greco (2002) suggested the substitution of R-22 in an experimental vapour compression plant with the most widely used drop-in substitute, i.e. the zeotropic mixture R-407C. A comparative exergetic analysis was carried on with experimental tests. The experimental tests were performed in a vapour compression plant working with water and air as secondary fluids in the condenser and in the evaporator, respectively. The overall exergetic performance of the plant working with R-22 is consistently better than that of its candidate substitute R407C. The performance of the individual components of the plant had been analyzed; in order to pinpoint those contributing most to the decrease in the exergetic performance of R407C.The parameter considered for analysis was condenser outlet temperature for working fluid. The result shows that the overall exergetic performance of R22 is significantly better than that of R407C. The difference ranges between a maximum of 45% to a minimum of 7%.

Aprea and Greco (2002) compared the performed between R22 and R407C and suggested that R407C is a promising drop-in substitute for R22. Experimental tests were performed in a vapour compression plant with a reciprocating compressor. The objective of this study was to evaluate the compressor performance using R-407C in comparison to R-22.The plant overall energetic performance was also evaluated and revealed that R22 performance is consistently better than that of its candidate substitute R-407C. The overall energetic performance of the experimental plant has been evaluated. R22 performance has been consistently better than that of its candidate substitute (by 8–14%).

Stegou-Sagia, **(2003)** carried the studied to describe irreversibility's in one stage refrigerating process for vapour compression cycle with refrigerant mixtures R-404A, R-410A, R-410B and R-507 as working fluids. They are calculated as exergy losses by an algorithm developed on the basis of thermodynamics. The proposed relationships have been derived from exergy balances on the system components. Emphasis was placed on parameters influencing the losses and the related results were presented through Grassmann diagrams (diagrams of exergy fluxes).

Aprea and Renno (2003) studies the performances of a vapour compression refrigeration plant using as working fluids R22 and its substitute R417A experimentally This type of plant is applied to a commercially available cold store, generally adopted for preservation of foodstuff. Its working was regulated by on/off cycles of the compressor, operating at the nominal frequency of 50 Hz, imposed by the classical thermostatic control. They revealed that for R22, there is no unanimous solution for its substitution. In this study, the refrigerant fluid experimentally tested as a substitute for R22 is the non-azeotropic mixture R417A.The substitute is a non-ozone depleting long term replacement for R22, which can be used in new and existing direct expansion systems using traditional R22 lubricants

Mark W. Spatz1, Samuel F. Yana Motta* (2004) Theirs study focuses on a thorough evaluation of the R-22 replacement options for medium-temperature refrigeration applications. It includes a thermodynamic analysis, comparison of heat transfer and pressure drop characteristics, system performance comparisons using a validated detailed system model, safety issues, and determination of the environmental impact of refrigerant selection. Three potential alternatives to the R-22 were studied: two HFCs (404A and R-410A) and one HC (R-290). An HFC refrigerant, R-410A, is shown to be an efficient and environmentally acceptable option to replace R-22 in medium temperature applications.

Stegou-Sagia and Paignigiannis (2005) In their article, the mixtures were considered: R-401B, R-401C, R-402A, R-404A, R-406A, R-408A, R-409A,R-410A, R-410B and R-507. Some of them do not have zero ODP, but they are in use due to their low ODP. Focused on performance comparisons of these working fluids in vapor compression refrigerating cycles was on the basis of exergy aspects.

Erol Arcaklioglu and Abdullah Ali (2005) In this study, they formed an algorithm to find refrigerant mixtures of equal volumetric cooling capacity (VCC) when compared to CFC based refrigerants in vapor compression refrigeration systems. To achieve this aim the point properties of the refrigerants were obtained from REFPROP where appropriate. They used replacement mixture ratios—of varying mass percentages—suggested by various authors along with our newly formed mixture ratios. In other words, they tried to see the effect of changing mass percentages of the suggested (i.e. in the literature) replacement refrigerants on the VCC of the cooling system. Secondly, they used this algorithm to calculate the coefficient of performance (COP) of the same refrigeration system. This mechanism has provided the ability to compare the COP of the suggested refrigerant mixtures and newly formed mixture ratios with the conventional CFC based ones. According to their results, for R12 R290/R600a (56/44) mixture, for R22 R32/R125/R134a (32.5/5/62.5) mixture, and for R502 R32/R125/R134a (43/5/52) mixture are appropriate and can be used as replacements.

Zhang Chuan, Ma Shanwei, Chen Jiangpin,Chen Zhijiu (2005) The objective of this study is to present test results and to develop a dimensionless correlation on the basis of experimental data to predict the mass flow rate of R22 and its alternative refrigerant R407C through an electronic expansion valve (EEV). The mass flow rate was measured at a series of condensing temperatures, evaporating temperatures and degrees of subcooling at the EEV inlet with five opening setting degrees of the EEV. The experimental results were analyzed, and it was found that the operation condition, flow area and the thermo physical properties of the refrigerant would affect the mass flow rate through the EEV.

A new correlation based on the Buckingham p theorem was developed to predict the mass flow rate of refrigerants through the EEV. The relative deviations of the predicted value by using this correlation are from -10.74% to 9.26% for R22 and from -14.20% to 22.10% for R407C. The average deviations and standard deviations are -0.79% and 5.02% for R22 and 0.67% and 8.08% for R407c, respectively. The relative deviation was analyzed in terms of the operation condition and flow area of the EEV. This correlation can be used to predict the mass flow rate through EEVs whose largest flow area is less than 2.544 mm^2.

Muhmmad Ali Khalid (2006) compared the performance analysis of R22 and its substitute refrigerants R407C, R410A and R417A on the basis of first law. He revealed that COP of R417A is 12% higher than R22. But for R407C and R410A COP is 5% lowered as compared to R22. R417A can be used in existing system without any modification.

From the literature review R-290, R-502, R-407C, R-410A and R-417A emerged out as alternatives to R-22. R-290 is flammable refrigerant, R-502 is azeotropic mixture and are generally formed when the difference in the boiling points of the two components is not very large, where as R-407C, R-410A and R-417A are zeotropic mixture and are formed with the large variation in boiling point of different components. Further experimental work has been done with small variation in evaporator and condenser temperature. The present work is carried with large variation in evaporator and condenser temperatures. Present work also helped not only to compare the R-407C, R-410A and R-417A with R-22 but also with each other.

ENERGY AND EXERGY ANALYSIS

1. Vapour compression refrigeration cycle composed of a condenser, an evaporator, a compressor, and a capillary tube as shown in figure 1.

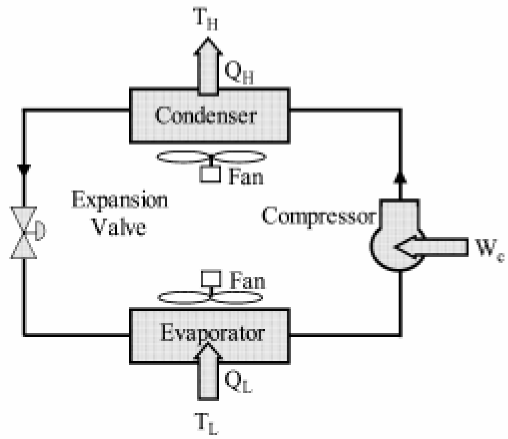


Figure 1. Simple vapour compression refrigeration cycle

2. R-22 is a chief refrigerant since the inception of refrigeration and air-conditioning.

3. R-22 has an ozone depletion potential (ODP) of 0.055, hence it is required to be phased it out by the year 2030.

4. As reported by various researchers R-407C (a zeotropic blend of R-32 / R-134a/ R-125-23%/52%/25% by weight), R-410A (a zeotropic mixture of R-32/R-125 in the equal ratio of 50% by weight), R-417A (a zeotropic mixture of R-134a/R-125/R-600 in the ratio of 50%/46.6%/3.4% by weight) have zero ODP are alternates to R-22.

5. Table 1.shows comparisons of thermodynamic properties of R-32, R-125, and R-134a and R-600.

6. Table 1A shows comparisons of thermodynamic properties of R-22, R-407C, R-410A and R-417A.

Table 1: Comparison of refrigerants properties R-32, R-125, and R-134a and R-600.

REFRIGERANT	R32	R125	R134a	R600
Refrigerant chemical formula	CH_2F_2	C_2HF_5	CF_3CH_2F	C_4H_{10}
Name	DIFLURO METHANE	PENTAFLURAO ETHANE	TETRA FLURO ETHANE	ISOBUTANE
Molecular weight [kg/kmol]	52.02	120	102	58.13
Normal boiling point (°C)	-51.91	-48.42	-26.37	-0.8605
Pressure critical (bar)	57.84	36.18	40.59	37.96
Temperature critical (°C)	78.11	66.02	101	152
Viscosity [kg/m-s]	0.00001151	0.00001236	0.00001113	0.000007076
Conductivity [W/m-K]	0.01311	0.01256	0.01248	0.01444
Surface Tension [N/m]	.009767	.006015	.01058	.01402
Density [kg/m^3]	2.269	5.251	4.496	2.592
Cp[kJ/kg-K]	.83	.7699	.8248	1.666

Table 1A: Comparison of refrigerants properties R-22, R-407C, R-410A and R-417A.

REFRIGERANT	R22	R407C	R410A	R417A
Refrigerant chemical formula	$CHCLF_2$	MIXTURE	MIXTURE	MIXTURE
GWP	1700	1530	1730	N/A
Molecular weight [kg/kmol]	86.47	86.2	72.58	N/A
Normal boiling point	-41.09	-43.6	-50.5	-43.3

Pressure critical	49.89	45.97	49.25	N/A
Temperature critical	96.13	86.79	72.13	90.97
Viscosity [kg/m-s]	0.00001218	0.00001147	0.00001205	0.00001181
Conductivity [W/m-K]	0.009895	0.01187	0.012	0.01333
Surface Tension [N/m]	.0107	.009592	.008257	N/A
Density [kg/m^3]	3.78	3.766	3.171	4.546
Cp[kJ/kg-K]	0.6438	0.8004	0.8113	0.8342

7.Assumptions

An analysis is based on following relevant assumptions.

- Pressure losses due to friction and pipelines are considered to be negligible.
- Heat losses to the surroundings through the system components are negligible.
- Refrigerant leaving the condenser is assumed to be saturated at its respective

  saturation temperature.
- Refrigerant vapour leaving the evaporator is assumed to be saturated.
- Isentropic efficiency of compressor is 75%
- Room temperature is 5°C higher than evaporator temperature.
- The reference enthalpy (ho) and entropy (so) of the working fluids have been

determined corresponding to an environment temperature (To) 25°C.

8.ENERGY ANALYSIS

Energy changes in each component of vapour compression refrigeration system are as follows:

Evaporator: Evaporator abstracts the heat (Qe) from the cold room, which is given by

$$Qe = m_R (h_1 - h_4) \tag{1}$$

Compressor: The isentropic work input to compressor (Wcs) is expressed as

$$Wcs = m_R (h_{2s} - h_1) \tag{2}$$

and actual compressor work (Wc) is specified as

$$Wc = \frac{W_{cs}}{\eta_{is}}$$

or

$$Wc = m_R (h_2 - h_1) \tag{3}$$

Condenser: The heat rejected by the condenser (Qcond.) to the atmosphere is given as

$$Qcond. = m_R (h_2 - h_3) \tag{4}$$

Throttle valve: In throttle valve the enthalpy remains constant.

From the first law point of view, the measure of performance of the refrigeration cycle is the coefficient of performance (COP) and is defined as the net refrigeration effect produced per unit of work required. It is expressed as

$$COP = \frac{Q_e}{W_c} \tag{5}$$

Volumetric Cooling Capacity

The volumetric cooling capacity is the cooling capacity per unit volume flow rate at the inlet to the compressor.

$$\text{Volumetric cooling capacity} = \frac{Q_e}{(m_R x v_s)} \text{ kJ/m}^3 \qquad (6)$$

Where:
m_R = mass flow of refrigerants
v_s = specific volume at inlet to the compressor

Pressure Ratio

Compressor pressure ratio (Pr.) is given as:

$$Pr. = P_c/P_e \qquad (7)$$

where P_c = Condenser pressure at state 2
and P_e = Evaporator pressure at state 1

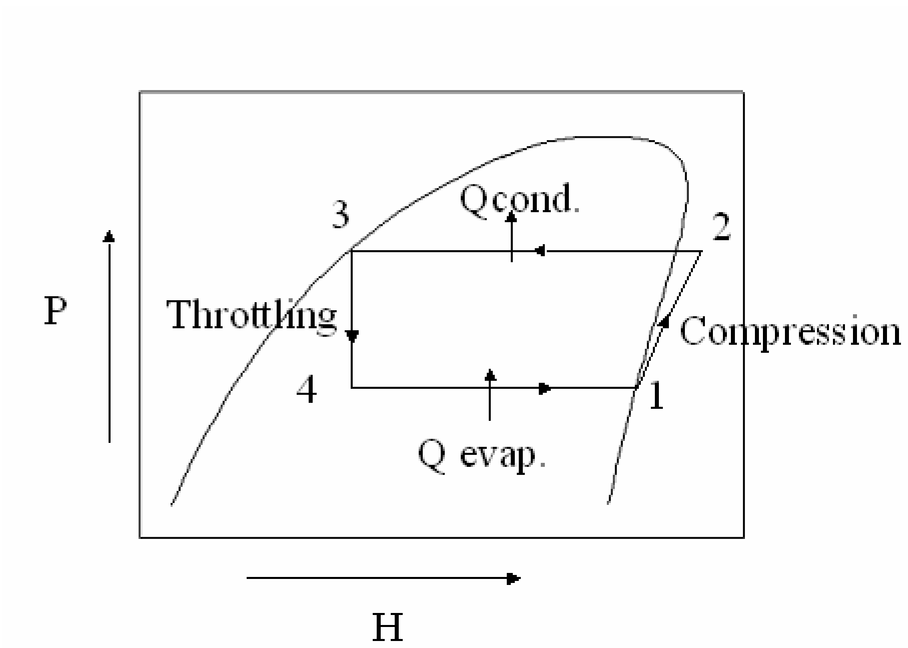


Figure 2. Simple vapour compression refrigeration cycle P-h diagram

9. EXERGY ANALYSIS

A reversible thermodynamic process can be reversed without leaving any trace on the surroundings. That is, the system and the surroundings are returned to their initial states at the end of the reverse process. This is possible only if the net heat and network exchange between the system and the surrounding is zero. All real processes are irreversible. Some factors causing irreversibility in a refrigeration cycle include friction and heat transfer across a finite temperature difference in the evaporator, compressor, condenser, and refrigerant lines, subcooling to ensure pure liquid at throttling valve inlet, superheating to ensure pure vapor at compressor inlet, pressure drops, and heat gains in refrigerant lines. The vapor-compression refrigeration cycle investigated is presented in Fig. 2 (p-h) diagram. The exergy destruction in system components is calculated as:

Evaporator

Exergy entering in the evaporator = $m_R\left(h_{4}\text{-}T_0s_4\right)+Q_e\left(1\text{-}\dfrac{T_0}{T_r}\right)$

Exergy leaving the evaporator = $m_R\left(h_1\text{-}T_0s_1\right)$

Exergy destruction (EDe) in evaporator is given as:

$$ED_e = m_R\left(h_{4}\text{-}T_0s_4\right)+Q_L\left(1\text{-}\frac{T_0}{T_r}\right)\text{-}m_R\left(h_1\text{-}T_0s_1\right) \tag{8}$$

where

m_R = mass flow of refrigerant (kg./sec)

Q_e = Refrigerating effect (kW)
h = enthalpy kJ/kg.
T = Temperature
s = entropy
0= reference state

Compressor

Exergy entering the compressor = $m_R(h_1 - T_0 s_1) + W_c$

Exergy leaving the compressor = $m_R(h_2 - T_0 s_2)$

Exergy destruction in compressor (Ed_c)

$$ED_c = m_R(h_1 - T_0 s_1) + W_c - m_R(h_2 - T_0 s_2) \qquad (9)$$

where
Wc =Compressor work

Condenser

Exergy entering the condenser = $m_R(h_2 - T_0 s_2)$

Exergy leaving the condenser = $m_R(h_3 - T_0 s_3)$

Exergy destruction in condenser ($ED_{cond.}$)

$$ED_{cond} = m_R(h_2 - T_0 s_2) - m_R(h_3 - T_0 s_3) \qquad (10)$$

Throttle valve

As enthalpy across the throttle valve remains constant. Hence exergy destruction across the throttle valve (ED_t) is given as:

$$ED_t = m_R(s_4 - s_3) \qquad (11)$$

Total exergy destruction

The total exergy destruction in the system is the sum of exergy destruction in the various components of the system and is given as follows

$$ED_{Total} = ED_e + ED_c + ED_{cond} + ED_t \tag{12}$$

Exergetic efficiency

The exergetic efficiency **(Bejan, 1996)** is defined the as :

$$\eta_{ex} = \frac{\text{Exergy equivalent of refrigerating effect}}{\text{Exergy of compressor work}} = \frac{EQ_e}{Ew_c}$$

$$\eta_{ex} = \frac{\left| Q_e \left(1 - \frac{T_0}{T_r} \right) \right|}{W_c} \tag{13}$$

Exergy destruction ratio (EDR)

Exergy destruction ratio **(Said and Ismail, 1994)** is defined as the ratio of total exergy destruction in system to exergy in the product and can be stated as follows

$$EDR = \frac{ED_{TOTAL}}{EP} \tag{14}$$

Efficiency defect

The efficiency defect **(Kotas 1985)** is the ratio between the exergy flow destroyed in each component and the exergy flow required to sustain the process, i.e. the electrical power supplied to the compressor:

$$\delta_i = \frac{ED_i}{w_c} \qquad (15)$$

where i stands for particular component.

The efficiency defects of the components are linked to the exergetic efficiency of the whole plant by means of the following relation:

$$\eta_{ex} = (1 - \sum_i \delta_i) \qquad (16)$$

Annexure 1 shows the computer programme in ENGINEERING EQUATION SOLVER (Klein and Alvardo 2002, academic version 6.548N) for energetic and exergetic performance of R-22 and its alternate refrigerants R-407C, R-410A and R-417A. The evaporator temperature varied between -38°C and 7°C in a step of 5°C .The reason behind such a large variation in evaporator temperature is to compare the performance for R-22 and its substitutes refrigerants R407C, R-410A and R-417A for the refrigeration and air-conditioning applications. The condenser temperature is varied between 35°C and 60°C in a step of 5°C. The thermodynamic properties of R-417A are calculated from NIST

THERMODYNAMIC PROPERTIES OF REFRIGERANTS AND REFRIGERANTS MIXTURES (REFPROP.VERSION 4.0).

RESULTS AND DISCUSSIONS

The comparative performance analysis of various parameters are given below:

3.1 Pressure Ratio

The figure 3, 4, 5 and 6 shows the variation of pressure ratio with varying evaporator or/and condenser temperature for R-22, R-407C, R-410A and R-417A respectively**.** The figures show that pressure ratio decreases with increase in evaporator temperature at particular condenser temperature, but pressure ratio increases with the increase in condenser temperature at particular evaporator temperature. The trends are similar for R-22 and its candidature substitutes. These results of varying pressure ratio are also presented in table 2,3,4,and 5 for R-22, R-407C, R-410A and R-417A respectively**.**

Fig. 7, 8, 9, 10, 11 and 12 represents the comparison of pressure ratio for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C.

Results shows that at condenser temperature 55°C and evaporator temperature –38°C pressure ratio required for R-407C and R-417A are 37.4% and 14.47% higher where as for R-410A pressure ratio is 5.4% lower than R-22.

At 7°C evaporator temperature and condenser temperature 55°C pressure ratio required for R-407C and R-417A are 22% and 4% higher than R-22 where as for R-410A pressure ratio is 0.914% lower than R-22, which means heavy compressor and higher compressor work is required while using R-407C, while for R-410A compressor required is lighter than R-22. The trends are similar for condenser temperature 35 °C, 40 °C, 45°C, 50°C and 60°C.

3.2 Volumetric Cooling Capacity

The figure 13, 14, 15 and 16 shows the variation of volumetric cooling capacity with varying evaporator or/and condenser temperature for R-22, R-407C, R-410A and R-417A respectively**.** The figures shows that the volumetric cooling capacity increases with increase in evaporator temperature at particular condenser temperature and decrease with increase in condenser temperature at particular evaporator temperature. The trends are similar for R-22 and its substitute R-407C, R-410A and R-417A. These results of varying volumetric cooling capacity are also presented in table 6,7,8,and 9 for R-22, R-407C, R-410A and R-417A respectively**.**

Fig. 17, 18, 19, 20, 21 and 22 represents the comparison of volumetric cooling capacity for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Results shows that at condenser temperature 55°C and evaporator temperature –38°C volumetric cooling capacity for R-407C, and R-417A are 31.2% and 40.5% lower where as for R-410A volumetric cooling capacity is 34.53% higher in comparison to R-22,

At 7°C evaporator temperature and condenser temperature 55°C volumetric cooling capacity for R-407C, and R-417A are 15.8% and 22% lower where as for R-410A volumetric cooling capacity is 34% higher in comparison to R-22, which means that size of compressor for R-22, is smaller than R-407C and R-417A. However the size of compressor when using R-410A is smaller as compared to R-22. The trends are similar for condenser temperature 35 °C, 40 °C, 45°C, 50°C and 60°C.

3.3 Coefficient of performance (COP)

Fig.23, 24, 25 and 26 shows the variation of COP with varying evaporator or/and condenser temperature for R-22, R-407C, R-410A and R-417A respectively. The figures shows that the COP increases with increase in evaporator temperature at particular condenser temperature and decrease with increase in condenser temperature at particular evaporator temperature. The trends are similar for R-22 and its substitute R-407C, R-410A and R-417A. These results of varying coefficient of performance are also presented in table 10,11,12,and 13 for R-22, R-407C, R-410A and R-417A respectively**.**

Fig. 27, 28, 29, 30, 31 and 32 shows the comparison of COP for R-22 and its substitute refrigerants with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Results show that at condenser temperature 55°C and evaporator temperature 7°C, coefficient of performance for R-407C, R-410A and R-417A are 19%, 13.5% and 6.3% lower in comparison to R-22. The difference decreases with decrease in evaporator temperature, which means that for per kg. of refrigerant flow in the system at any given evaporating temperature, R22 yields a greater refrigerating power at the expenses of a lower mechanical power at the compressor. Conversely, a plant working with R407C requires higher electric power consumption in order to provide the same refrigerating load. Apart from direct costs, this is disadvantageous in terms of overall environmental pollution, since more fuel must be burned and higher amounts of carbon dioxide are discharged in the atmosphere. Furthermore, R-407C, R-410A and R-417A are greenhouse gases in its own right related on the fraction of refrigerant charge released in the atmosphere (leakages etc.). Therefore, in terms of greenhouse effect, the use of R-407C, R-410A and R-417A might result in a higher, overall environmental impact than that of R22, even though the former is totally harmless to the ozone layer. The trends are similar for condenser temperature 35 °C, 40 °C, 45°C, 50°C and 60°C.

3.4 Exergy Destruction Ratio (EDR)

Variations of exergy destruction ratio with evaporator or/and condenser temperature are shown in fig. 33, 34, 35 and 36 for R-22, R-407C, R-410A and R-417A respectively. The figures show that EDR increases with increase in evaporator as well as condenser temperature. The increase is more at higher condenser temperature. The trends are similar for R-22 and its substitute R-407C, R-410A and R-417A. These results of varying EDR are also presented in table 14,15,16,and 17 for R-22, R-407C, R-410A and R-417A respectively**.**

Fig. 37, 38, 39, 40, 41 and 42 represents the comparison of exergy destruction ratio for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Figures shows that at -38°C EDR in R-417A is higher than R-410A, but as the evaporator temperature increases EDR for R-417A decreases at 7°C evaporator temperature R-417A has lower EDR in comparison to R-410A and R-407C. The trends are similar at condenser temperature 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C.

Results shows that at condenser temperature 55°C and evaporator temperature 7°C exergy destruction ratio in comparison to R-22 are 28.3%, 18.3% and 8% higher for R-407C, R-410A and R-417A respectively.

3.5 Exergetic Efficiency

Variations of exergetic efficiency with evaporator or/and condenser temperature are shown in fig. 43, 44, 45 and 46 for R-22, R-407C, R-410A and R-417A respectively. Exergetic efficiency decreases with increase in evaporator temperature and decrease in condenser temperature. The trends are similar for R-22 and its substitute R-407C, R-410A and R-417A. These results of varying exergetic efficiency are also presented in table 18,19,20,and 21 for R-22, R-407C, R-410A and R-417A respectively.

Fig. 47, 48, 49, 50, 51 and 52 represents the comparison of exergy destruction ratio for R-22 and its candidatures substitutes with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Results show that at condenser temperature 55°C and evaporator temperature 7°C, exergetic efficiency for R-407C, R-410A and R-417A are 19%, 13.5% and 6.3% lower in comparison to R-22.

Figures shows that at -38°C exergetic efficiency of R-417A is lower than R-410A, but as the evaporator temperature increases exergetic efficiency of R-417A increases, at 7°C evaporator temperature R-417A has higher exergetic efficiency in comparison to R-410A. The trends are similar at condenser temperature 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C.

3.6 Efficiency Defect (Compressor)

The effect of variation of evaporator or/and condenser temperature on efficiency defect in compressor is shown in fig. 53, 54, 55 and 56 for R-22, R-407C, R-410A and R-417A respectively. The figures show that efficiency defect in compressor increases with increase in evaporator temperature and decrease in condenser temperature. The trends are similar for R-22 and its substitute R-407C, R-410A and R-417A. These results of varying efficiency defect in compressor are also presented in table 22,23,24,and 25 for R-22, R-407C, R-410A and R-417A respectively.

Fig. 57, 58, 59, 60, 61 and 62 represents the comparison of efficiency defect in compressor for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C.

Figure 57 shows that R-417A has consistently higher efficiency defect in compressor. At -38°C R-407C has higher efficiency defect in comparison to R-22 and R-410A, with increase in evaporator temperature efficiency defect in compressor for R-407C decreases. At 7°C R-407C has lowest efficiency defect than R-22, R-410A and R-417A. The trends are similar at condenser temperature 35 °C, 40 °C and 45°C.

Results show that at condenser temperature 55°C and evaporator temperature 7°C efficiency defect in compressor is 0.19%, 0.8 % and 5.16% higher for R-407C, R-410A and R-417A respectively in comparison to R-22. At 60 °C condenser temperature trends is similar to 55°C. Whereas at 50°C efficiency defect (Compressor) in R-417A and R-22 are almost same.

3.7 Efficiency Defect (Condenser)

The effect of variation of evaporator or/and condenser temperature on efficiency defect in condenser is shown in fig. 63, 64, 65 and 66 for R-22, R-407C, R-410A and R-417A respectively. The figures show that efficiency defect in condenser increases with increase in evaporator as well as condenser temperature. The trends are similar for R-22 and its substitutes R-407C, R-410A and R-417A. These results of varying efficiency defect in condenser are also presented in table 26,27,28,and 29 for R-22, R-407C, R-410A and R-417A respectively.

Fig. 67, 68, 69, 70, 71 and 72 represents the comparison of efficiency defect in condenser for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Figures show that at –38 °C R-417A has lower efficiency defect in condenser in comparison to R-22, R407C and R-410A, with the increase in evaporator temperature efficiency defect in condenser for R-417A increases. At 7 °C evaporator temperature R-417A has efficiency defect (condenser), lower than

R-22 but higher than R-407C and almost similar to R-410A. The trends are similar at condenser temperature 35 °C, 40 °C, 45°C, 50°C, 55°C and 60c.

Results show that at condenser temperature 55°C and evaporator temperature 7°C efficiency defect in condenser is 14%, 8 % and 9% lower for R-407C, R-410A and R-417A respectively in comparison to R-22. The reason behind it is the temperature glide in zeotropic mixtures during condensation.

Transferring the heat at lower temperature difference can reduce efficiency defect in condenser.

3.8 Efficiency Defect Throttle Valve

The effects of variation of evaporator or/and condenser temperature on efficiency defect in throttle valve are shown in fig. 73, 74, 75 and 76 for R-22, R-407C, R-410A and R-417A respectively.

Efficiency defect in throttle valve decrease with increase in evaporator temperature and decrease in condenser temperature. The trends are similar for R-22 and its substitutes R-407C, R-410A and R-417A. These results of varying efficiency defect in throttle valve are also presented in table 30,31,32, and 33 for R-22, R-407C, R-410A and R-417A respectively**.**

Fig. 77, 78, 79, 80, 81 and 82 represents the comparison of efficiency defect in condenser for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Figures show that at -38 °C R-417A has higher efficiency defect in throttle valve in comparison to R-22 and R-410A, with the increase in evaporator temperature it decreases and at 7 °C evaporator temperature its value is lower than

R-407C and R-410A. The trends are similar at condenser temperature 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C.

Results also show that at condenser temperature 55°C and evaporator temperature 7°C efficiency defect in throttle valve is 6%, 4 % and 3.3% higher for R-407C, R-410A and R-417A respectively in comparison to R-22.Subcooling the liquid refrigerant can reduce efficiency defect in throttle valve.

3.9 Efficiency Defect Evaporator

The effect of variation of evaporator or/and condenser temperature on efficiency defect in evaporator are shown in shown in fig. 83, 84, 85 and 86 for R-22, R-407C, R-410A and R-417A respectively. Figures show that efficiency defect in evaporator increases with the increase in evaporator temperature and decrease in condenser temperature. These results of varying efficiency defect in evaporator are also presented in table 34,35,36,and 37 for R-22, R-407C, R-410A and R-417A respectively**.**

Fig. 87, 88, 89, 90, 91 and 92 represents the comparison of efficiency defect in condenser for R-22 and its substitutes candidatures with varying evaporator temperature and condenser temperature at 35 °C, 40 °C, 45°C, 50°C, 55°C and 60°C. Figures show that at 35°C, 40°C and 45°C condenser temperature R-407C has higher efficiency defect in evaporator further increasing the condenser temperature reduces the efficiency defect in evaporator for R-407C and R-22 has its value higher at condenser temperature 50°C, 55°C and 60°C. Further R-417A has consistently lower efficiency defect in evaporator in comparison to R-22, R-407C and R-410A.

Results show that at condenser temperature 55°C and evaporator temperature 7°C efficiency defect in evaporator is 10.2%, 13 % and 25% lower for R-407C, R-410A and R-417A respectively in comparison to R-22.

Efficiency defect in evaporator is marginal in comparison to the overall efficiency defect of the system. Transferring the heat at lower temperature difference can further reduce the efficiency defect in evaporator.

For acceptance of this work results obtained from theoretical analysis is compared with the experimental data obtained from the work done by C. Apera [4] at 0 °C cold air temperature and 32° C outside air temperature.

Coefficient of performance (COP) Figure 93 shows the comparison of experimental results with present work for COP. Results shows that R-22 has 13.6% higher COP than R-417A in experimental work done by C.Apera whereas its value is11.69% in present work.

Exergetic Efficiency Figure 94 shows the comparison of experimental results with present work for exergetic efficiency. Results show that R-22 has 5 % higher exergetic efficiency than R-417A in experimental work done by C.Apera whereas its value is 3% higher in present work.

CONCLUSIONS

In present work the comparative performance analysis of R-22 and its substitutes R-407C, R-410A and R-417A have been discussed.. The results obtained permit the following remarks:

1. The COP of R-417A is lower than R-22, but higher than R-407C,and R-410A .
2. R-22 has higher Volumetric Cooling Capacity than R-407C and R-417A respectively. Whereas volumetric cooling capacity for R-22 is lower than R-410A.
3. R-407C and R-417A requires higher compression ratio for same rise of condenser temperature as raised by R-22. Whereas for R-410A pressure ratio requires is lower.
4. The overall exergetic performance of the cycle working with R22 is consistently better than that of its candidate substitute. The exergetic efficiency of R-417A is lower than R-22, but higher than R-407C, and R-410A.
5. R-22 have lower exergy destruction ratio than R-407C, R-410A and R-417A respectively.

6. Efficiency defect in compressor is higher for R-407C, R-410A and R-417A respectively in comparison to R-22.
7. Efficiency defect in condenser is lower for R-407C, R-410A and R-417A respectively in comparison to R-22.
8. Efficiency defect in throttle valve is higher for R-407C, R-410A and R-417A respectively in comparison to R-22.
9. Efficiency defect in evaporator is lower for R-407C, R-410A and R-417A respectively in comparison to R-22.

In conclusion, there is no unanimous substitution for R-22. The results indicate that R-407C, R-410A and R-417A as the alternate refrigerants, when used as drop in replacement will not provide same performance as obtained in case of R-22.With regards to COP and exergy destruction ratio R-22 is superior refrigerant. Even exergetic efficiency of R-22 is better than its candidature substitutes. As the ODP for R-22 is higher, which is going to destruct the ozone layer and hence environment. It is therefore necessary to switch over to an alternate refrigerant, which is available in the form of R-417A. It has comparable COP, exergy destruction ratio and exergetic efficiency. R-417A does not require the change in compressor lubricant. Further improvement in the design of individual components may enhance the performance parameter for R-417A.

FUTURE WORK

- R-22 can also be compared with R-290 and R 502.
- Zeotropic mixture R-419A can also be compared with R-22 to find out better alternate.

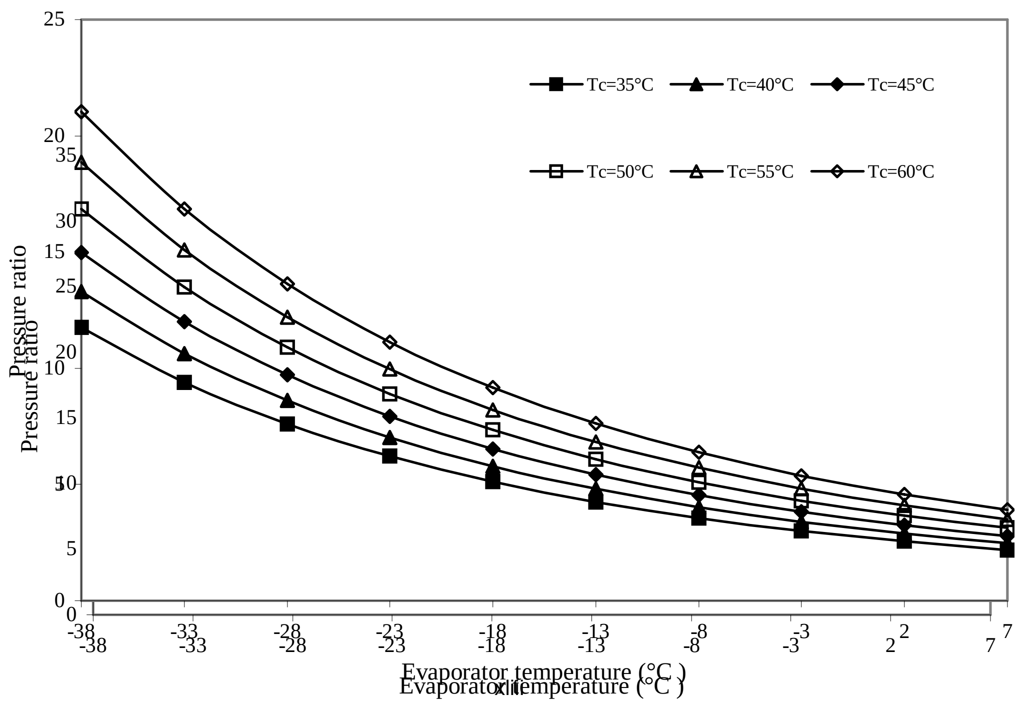


Figure 3: Variation of pressure ratio with varying evaporator temperature (R22)

Figure 4: Variation of pressure ratio with varying evaporator temperature (R407C)

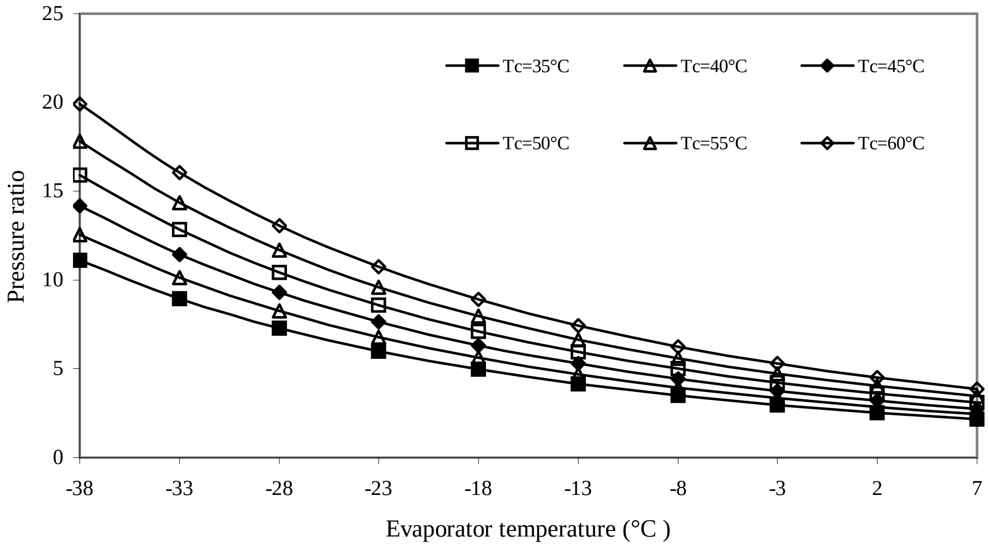


Figure 5. Variation of pressure ratio with varying evaporator temperature (R410A)

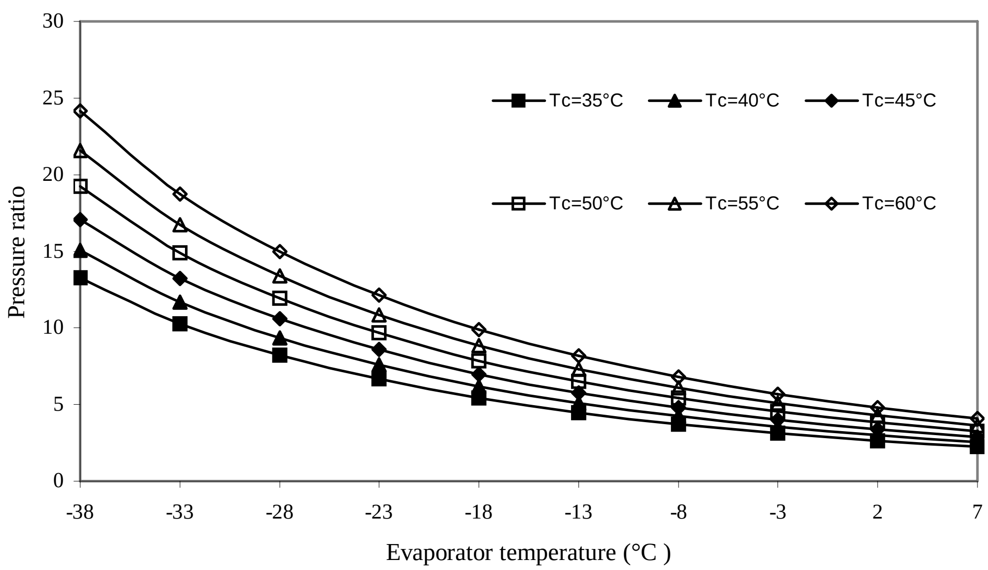


Figure 6. Variation of pressure ratio with varying evaporator temperature (R417A)

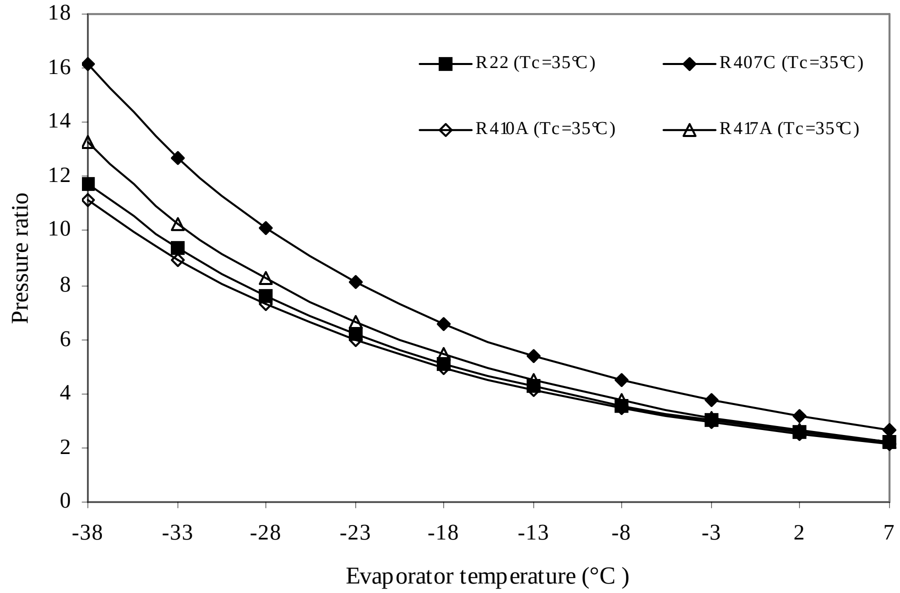


Figure 7. Comparison of pressure ratio with varying evaporator temperature (Tc=35°C)

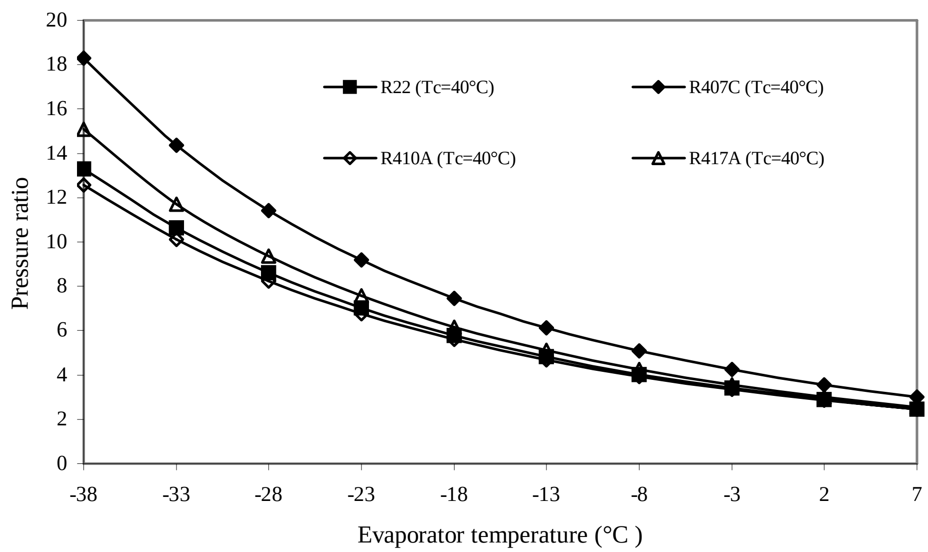


Figure 8. Comparison of pressure ratio with varying evaporator temperature (Tc=40°C)

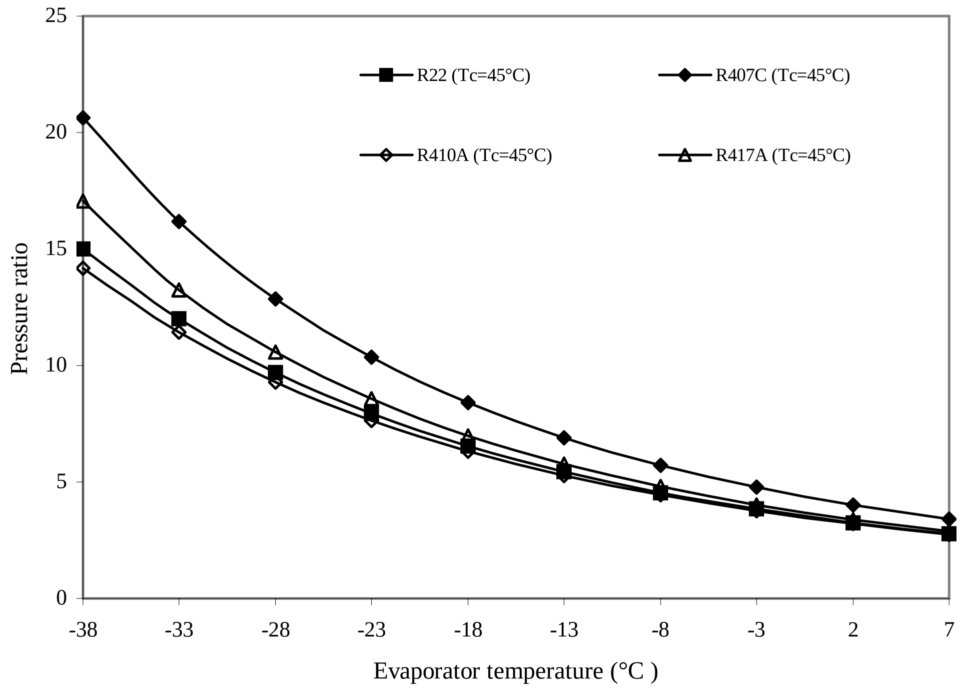


Figure 9.Comparison of pressure ratio with varying evaporator temperature (Tc=45°C)

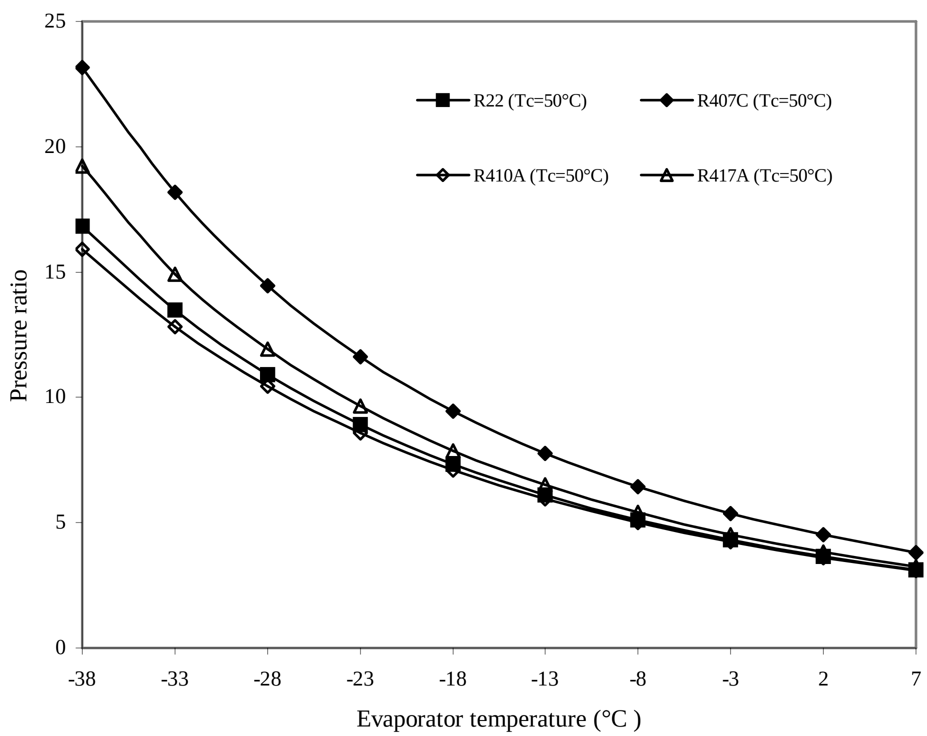


Figure 10.Comparison of pressure ratio with varying evaporator temperature (Tc=50°C)

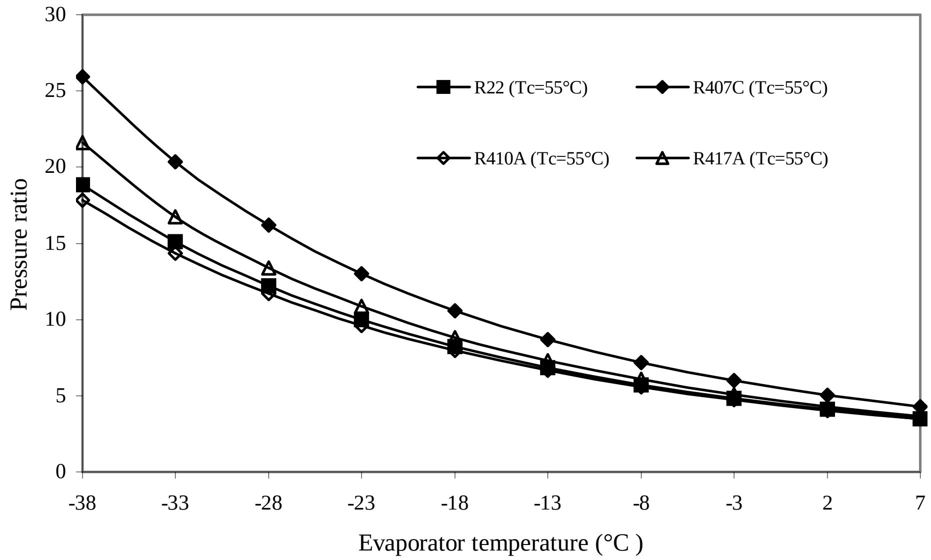


Figure 11. Comparison of pressure ratio with varying evaporator temperature (Tc=55°C)

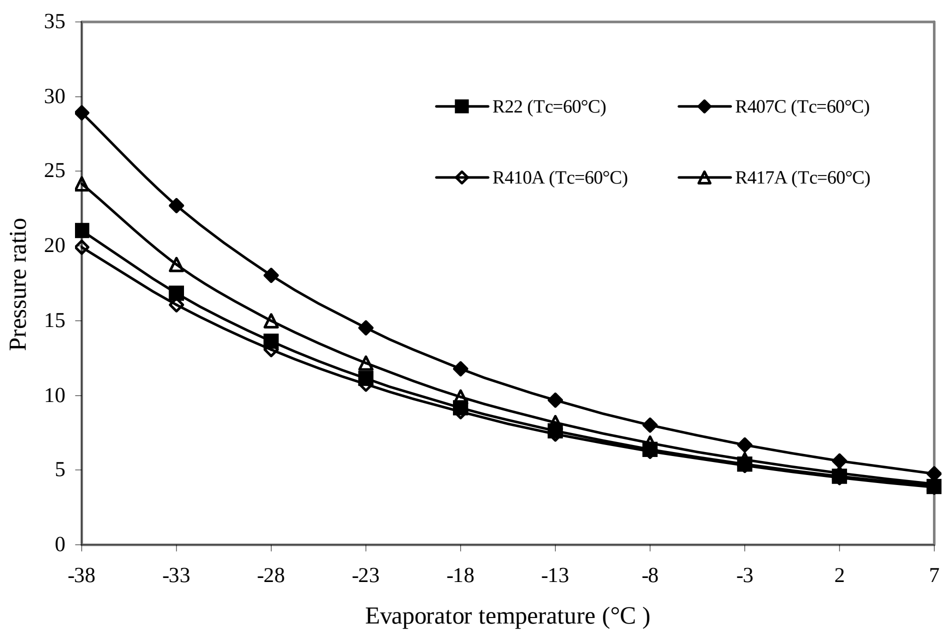


Figure 12. Comparison of pressure ratio with varying evaporator temperature (Tc=60°C)

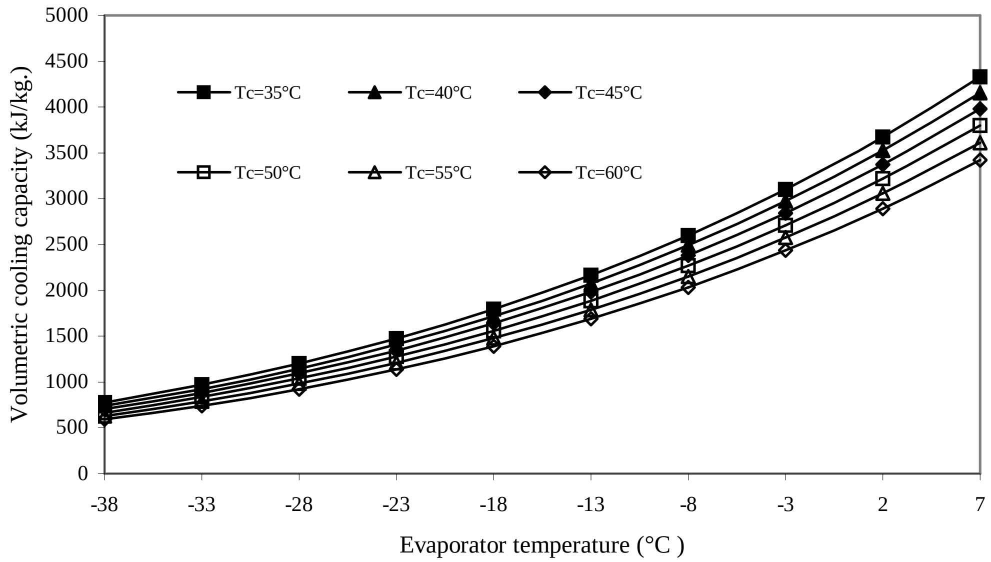


Figure 13. Variation of volumetric cooling capacity with varying evaporator temperature (R22)

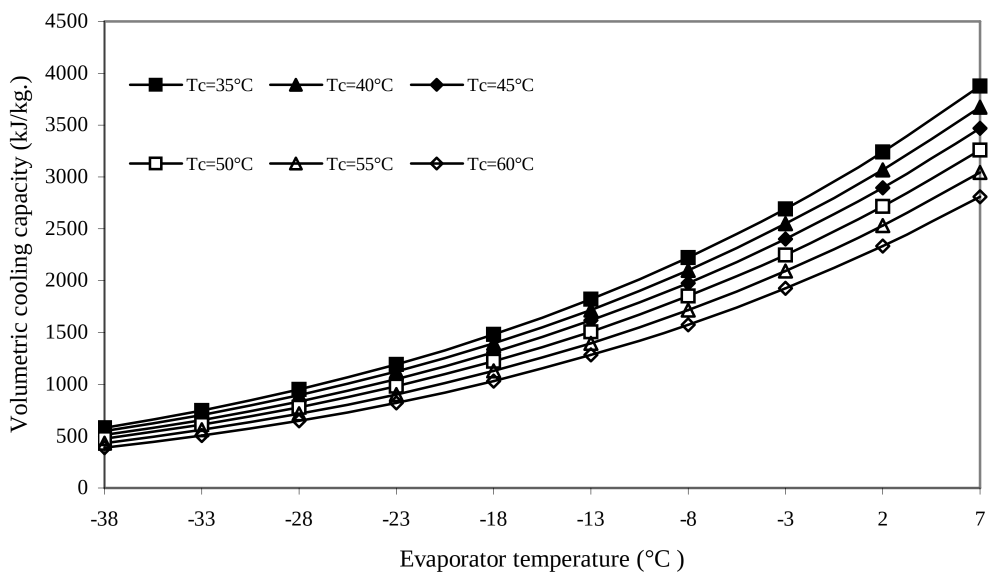


Figure 14. Variation of volumetric cooling capacity with varying evaporator temperature (R407C)

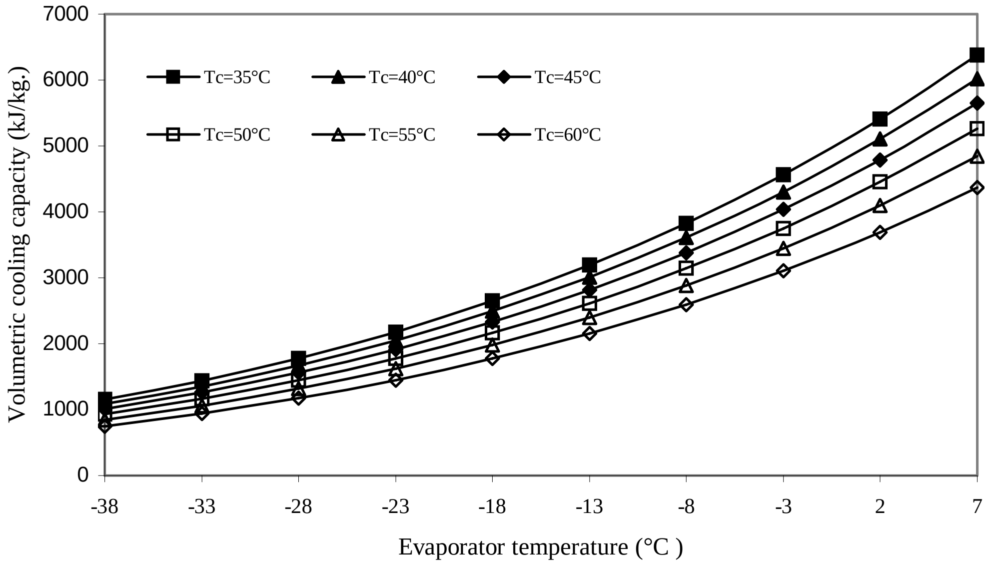


Figure 15. Variation of volumetric cooling capacity with varying evaporator temperature(R410A)

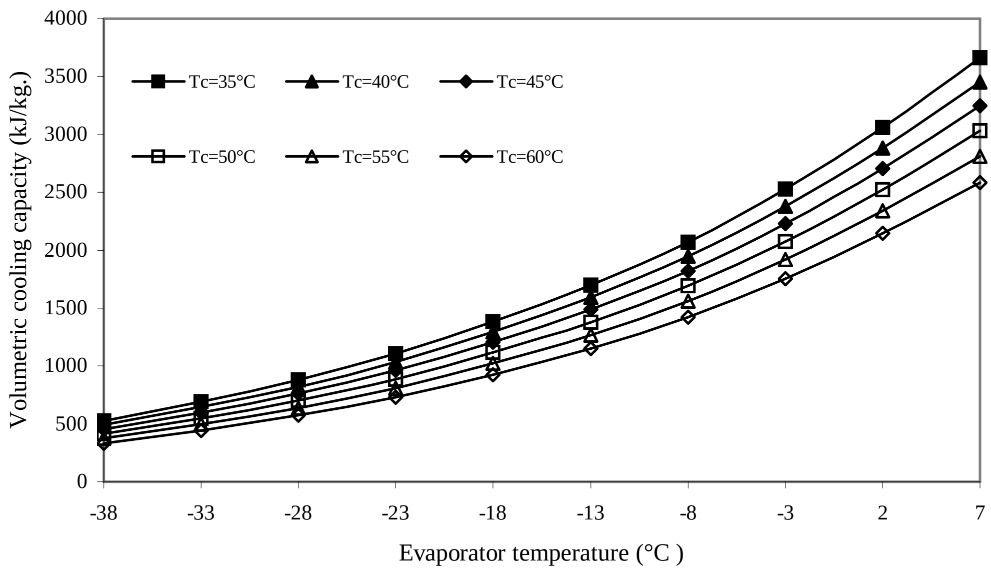


Figure 16. Variation of volumetric cooling capacity with varying evaporator temperature (R417A)

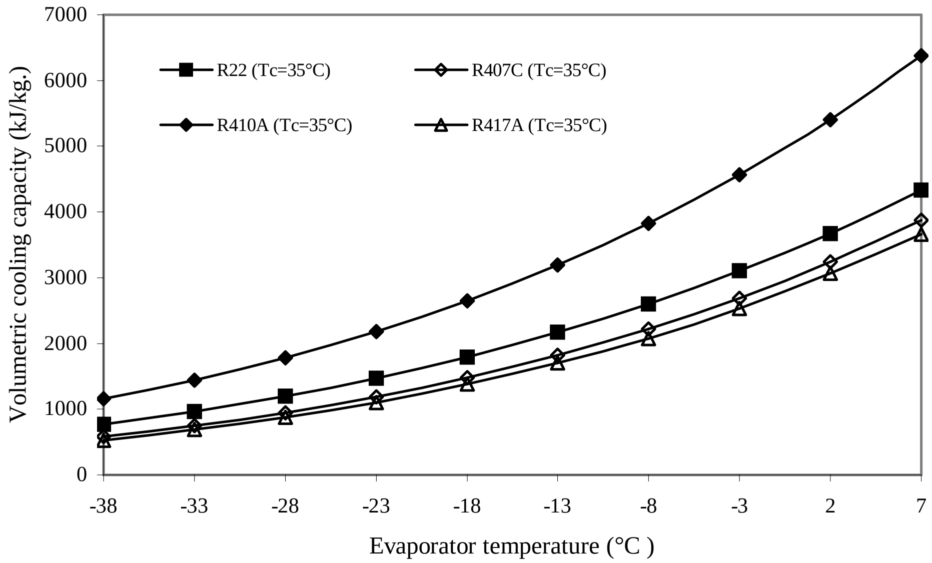


Figure 17. Comparison of volumetric cooling capacity with varying evaporator temperature (Tc=35°C)

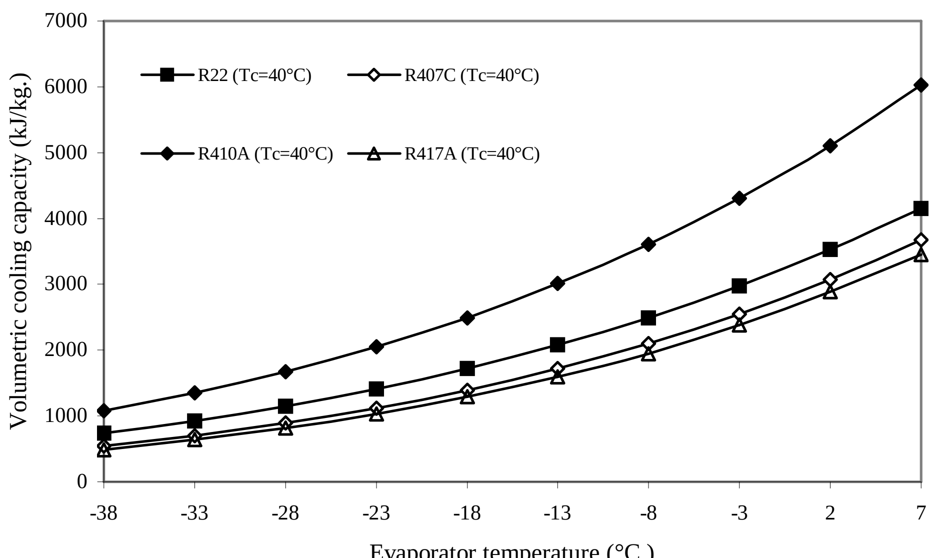


Figure 18. Comparison of volumetric cooling capacity with varying evaporator temperature (Tc=40°C)

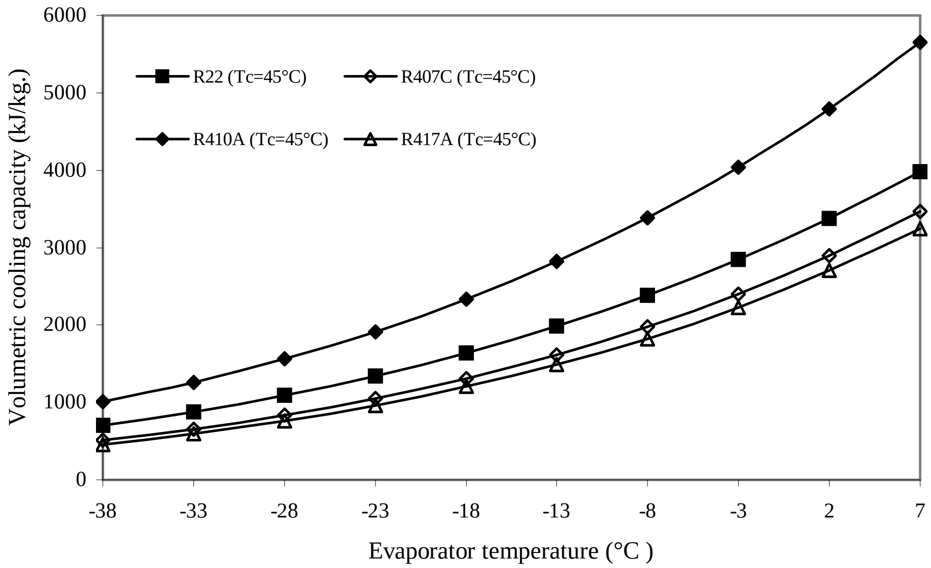


Figure 19. Comparison of volumetric cooling capacity with varying evaporator temperature (Tc=45°C)

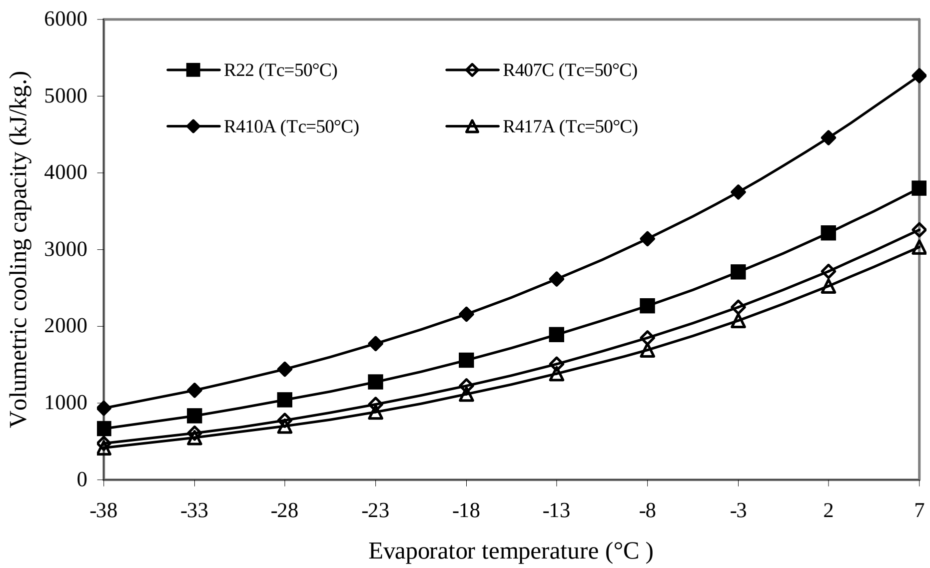


Figure 20. Comparison of volumetric cooling capacity with varying evaporator temperature (Tc=50°C)

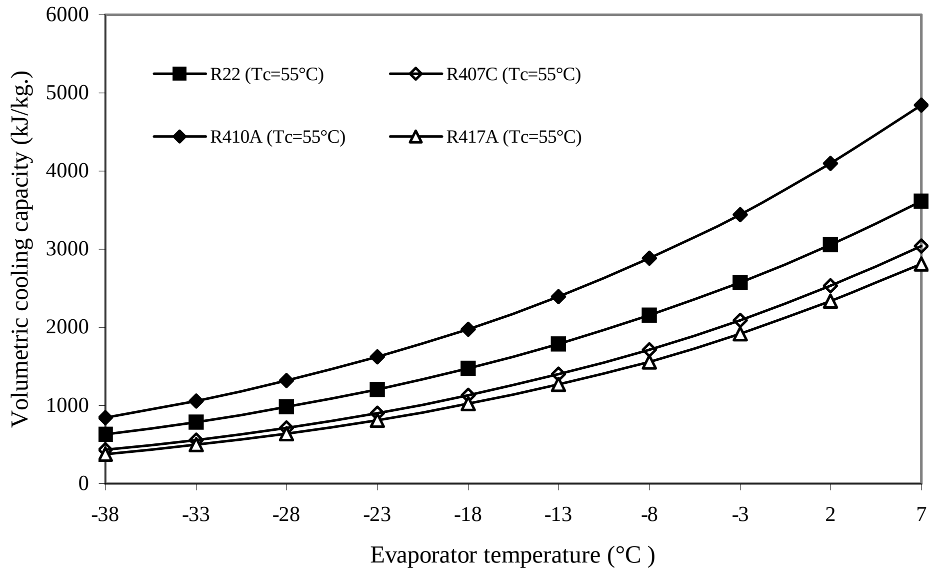


Figure 21. Comparison of volumetric cooling capacity with varying evaporator temperature (Tc=55°C)

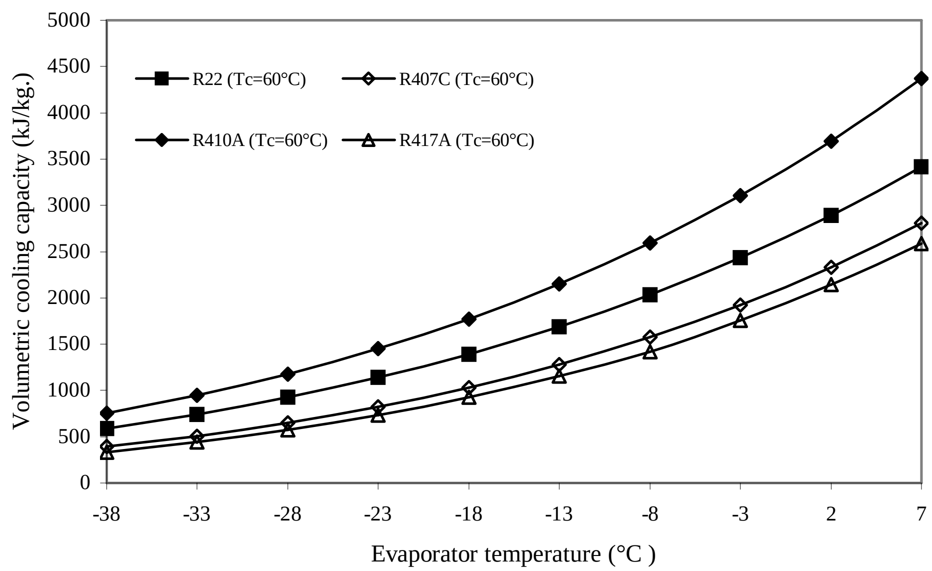


Figure 22. Comparison of volumetric cooling capacity with varying evaporator temperature (Tc=60°C)

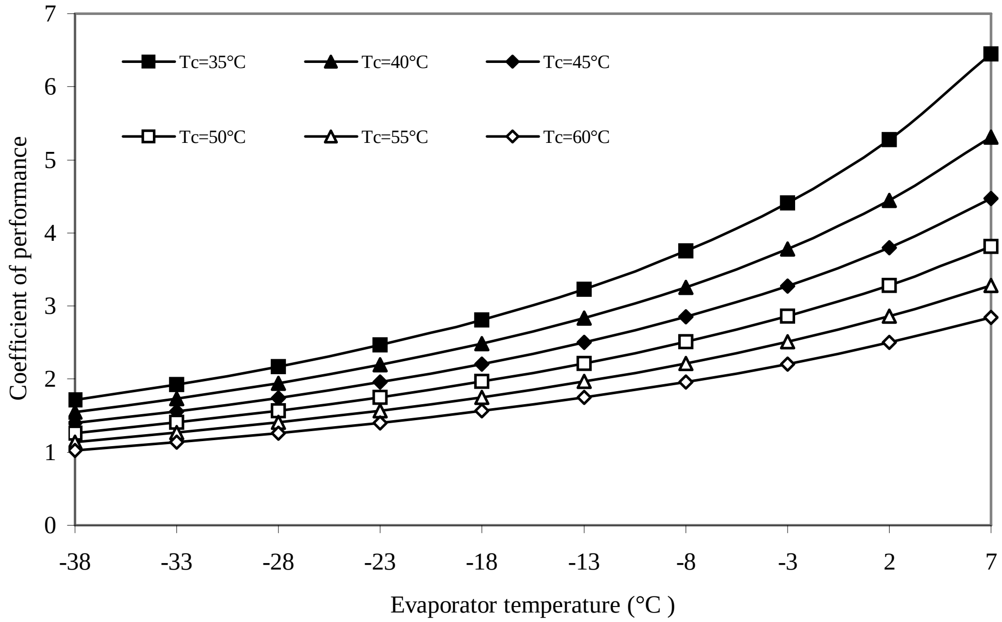


Figure 23. Variation of coefficient of performance with varying evaporator temperature (R22)

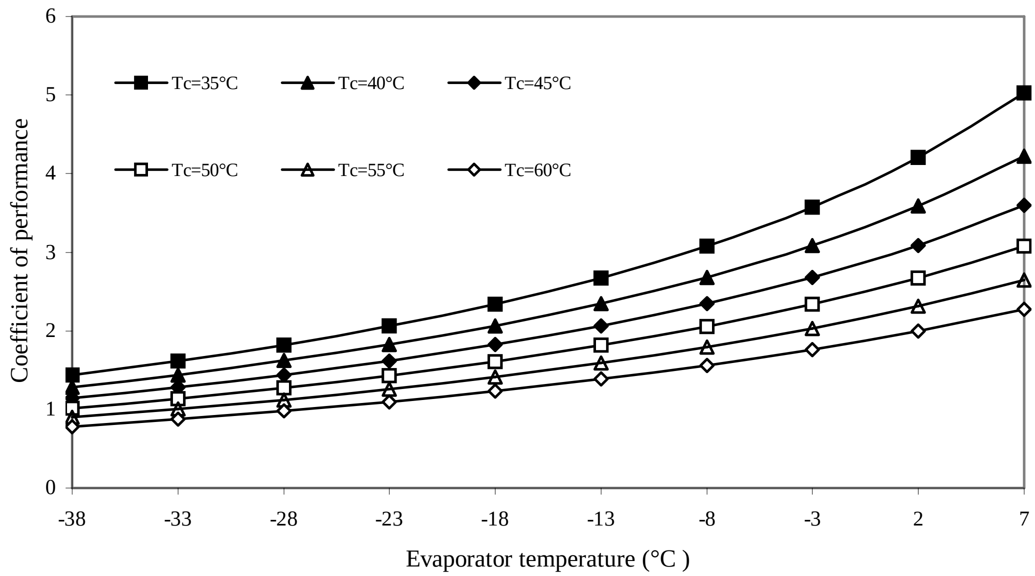


Figure 24. Variation of coefficient of performance with varying evaporator temperature (R407C)

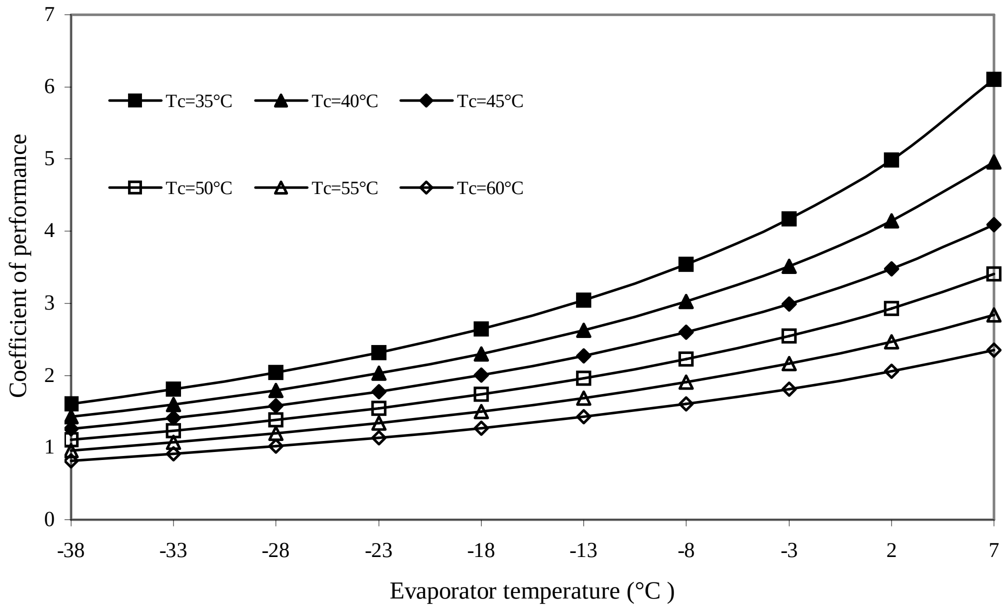


Figure 25. Variation of coefficient of performance with varying evaporator temperature (R410A)

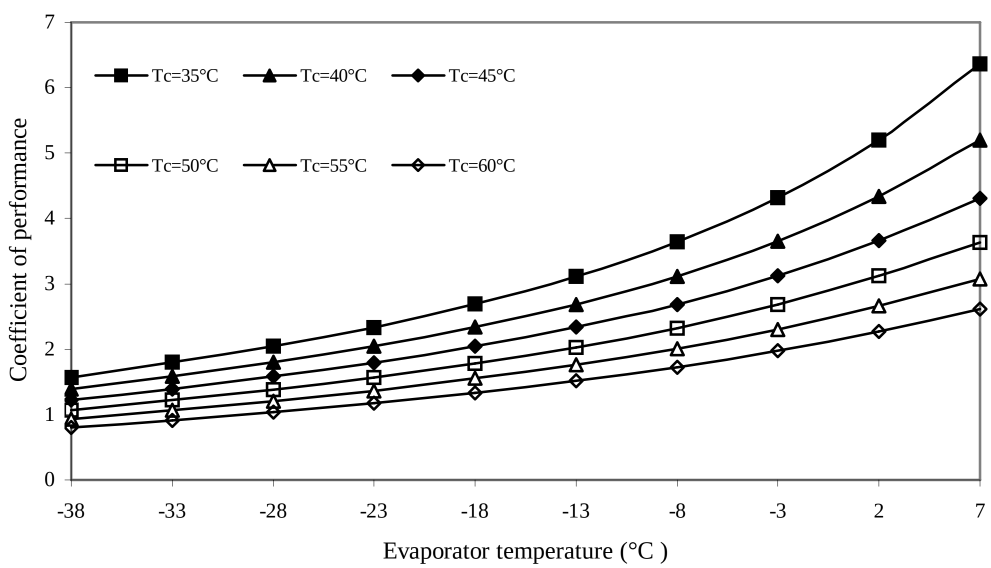


Figure 26. Variation of coefficient of performance with varying evaporator temperature (R417A)

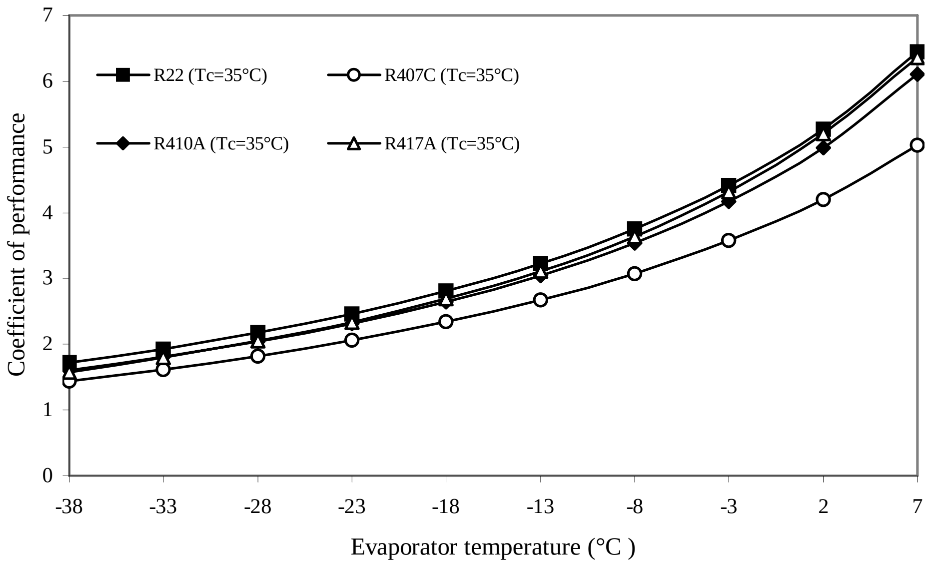


Figure 27. Comparison of coefficient of performance with varying evaporator temperature (Tc=35°C)

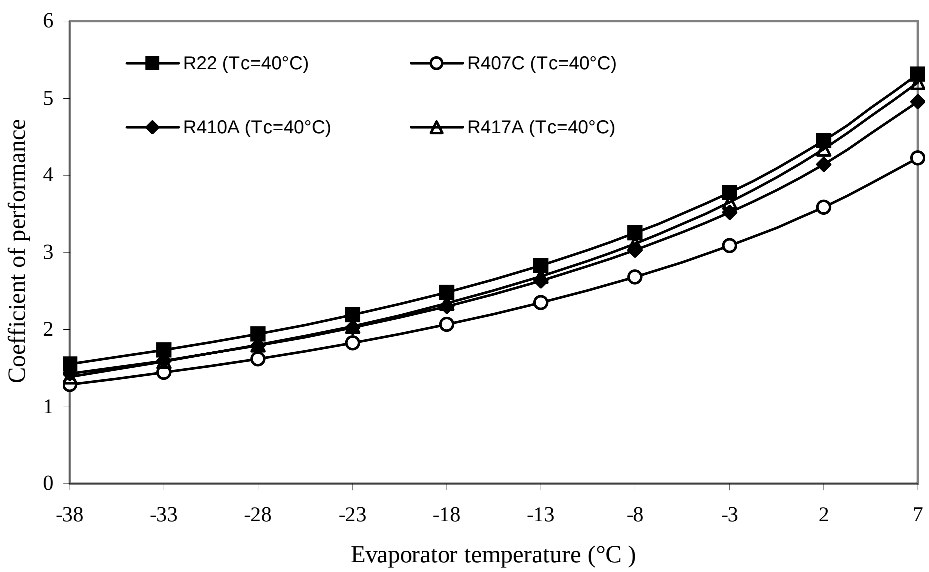


Figure 28. Comparison of coefficient of performance with varying evaporator temperature (Tc=40°C)

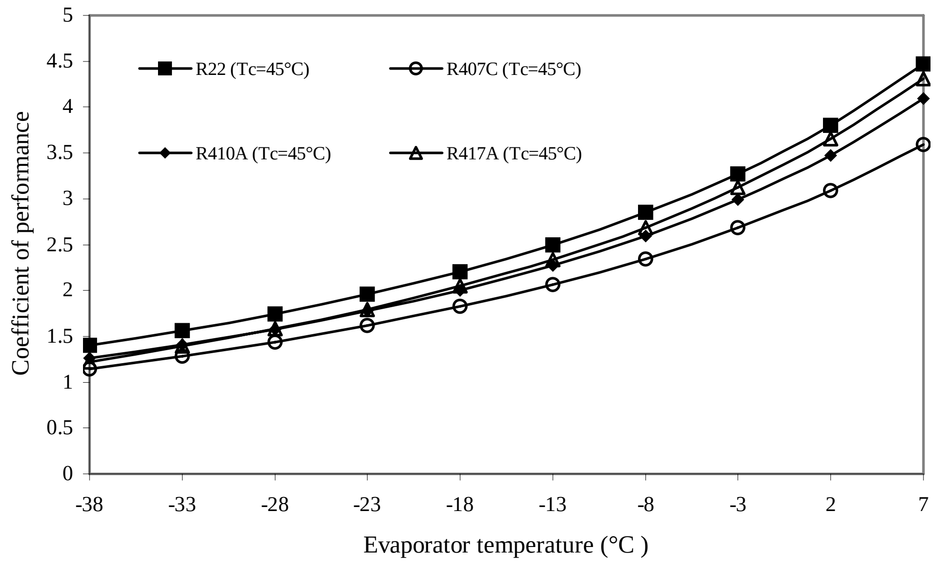


Figure 29. Comparison of coefficient of performance with varying evaporator temperature (Tc=45°C)

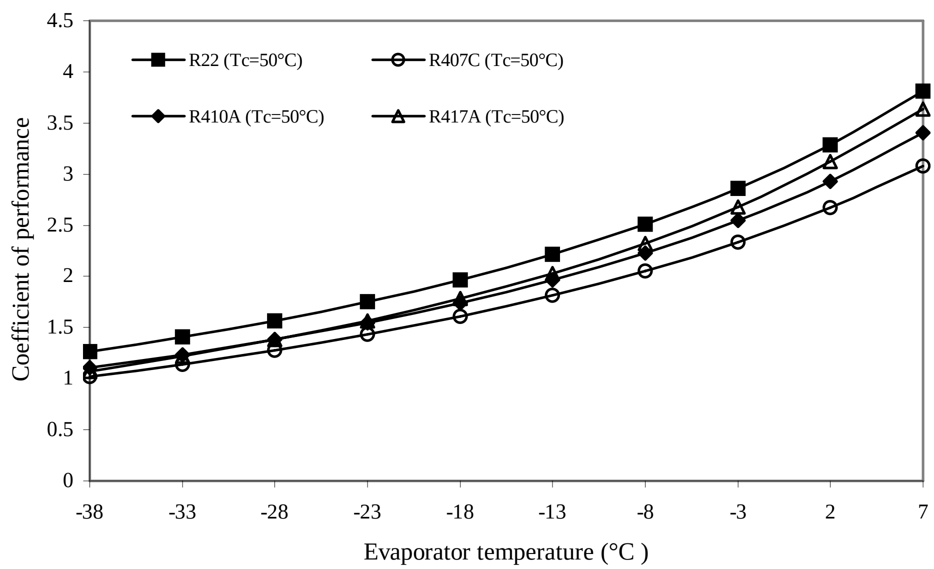


Figure 30. Comparison of coefficient of performance with varying evaporator temperature (Tc=50°C)

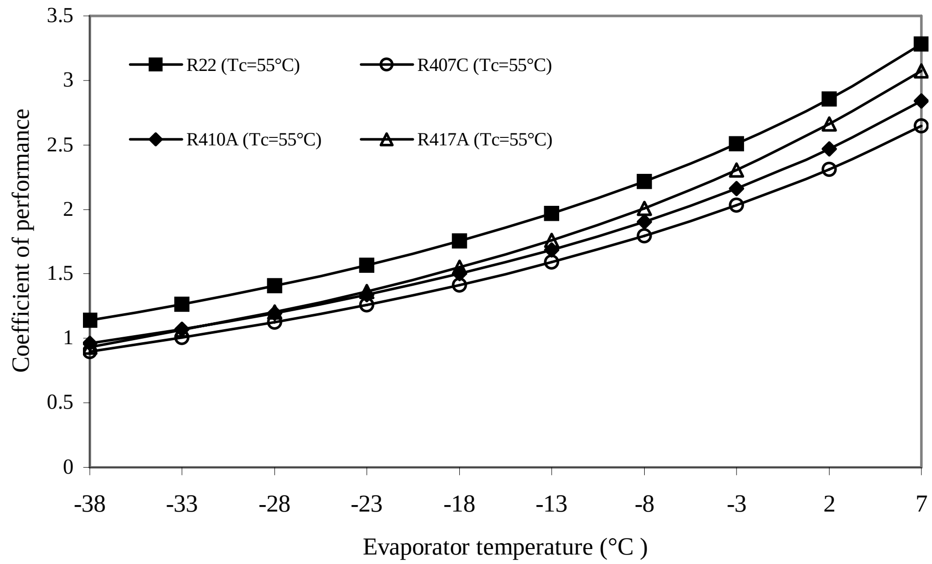


Figure 31.Comparison of coefficient of performance with varying evaporator temperature (Tc=55°C)

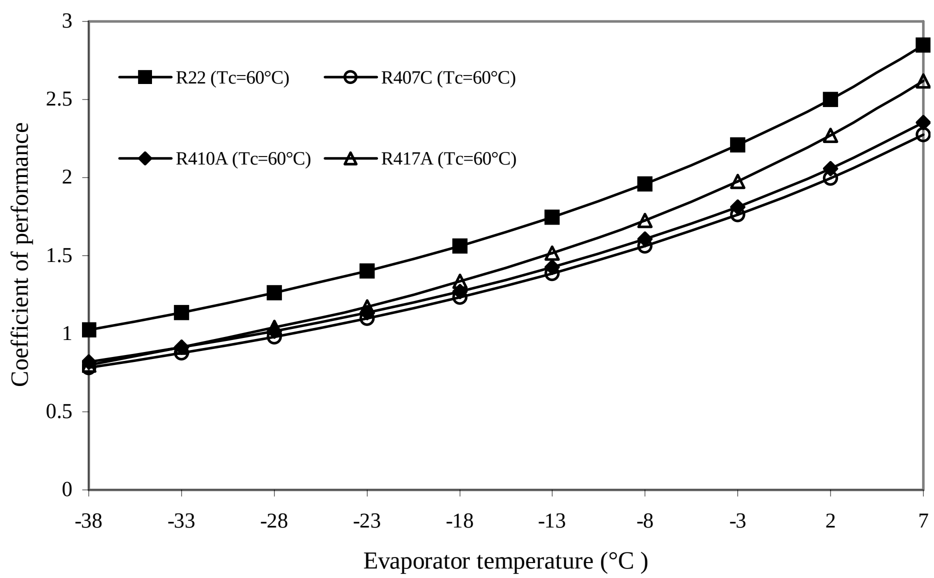


Figure 32. Comparison of coefficient of performance with varying evaporator temperature (Tc=60°C)

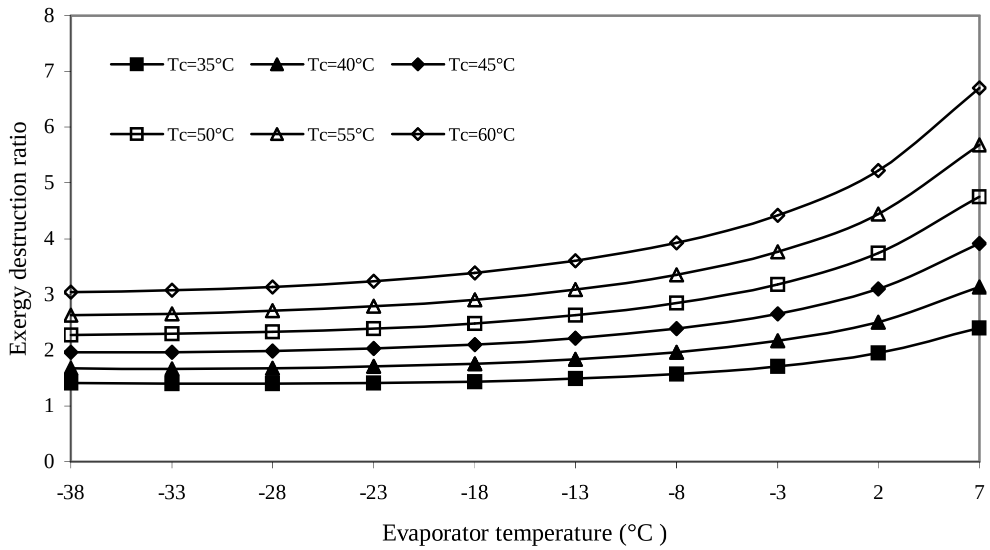


Figure33. Variation of exergy destruction ratio with varying evaporator temperature (R22)

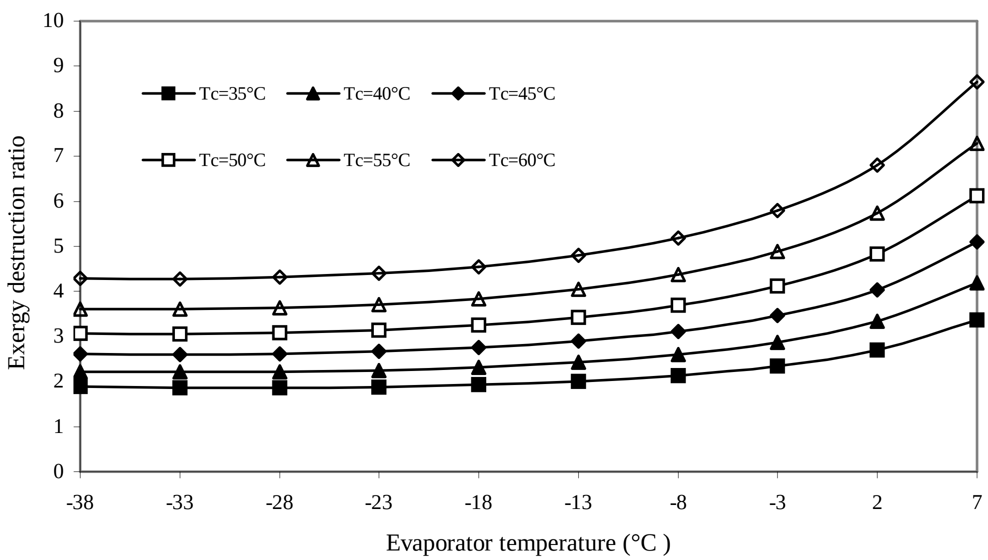


Figure 34. Variation of exergy destruction ratio with varying evaporator temperature (R407C)

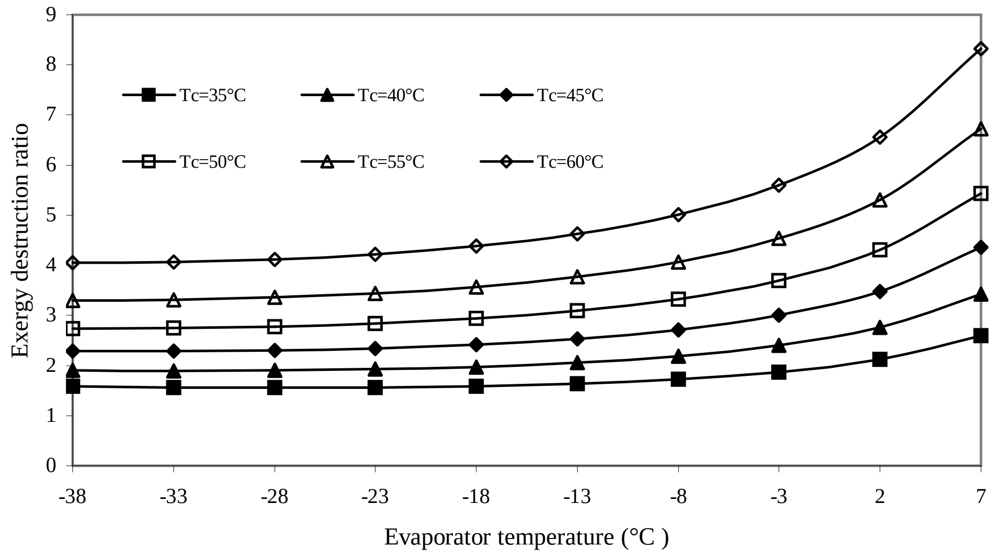


Figure 35. Variation of exergy destruction ratio with varying evaporator temperature (R410A)

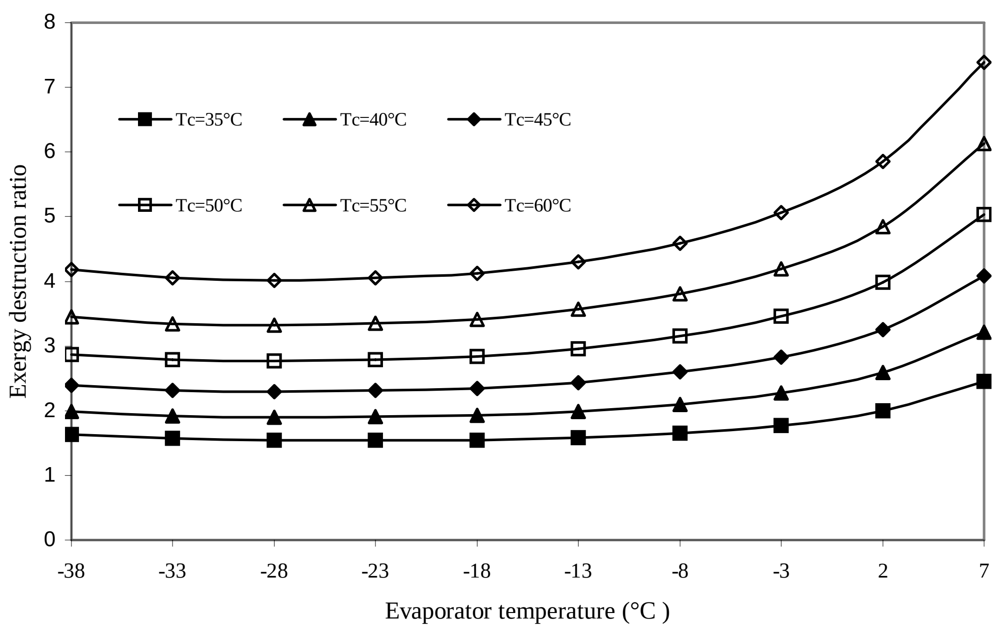


Figure 36. Variation of exergy destruction ratio with varying evaporator temperature (R417A)

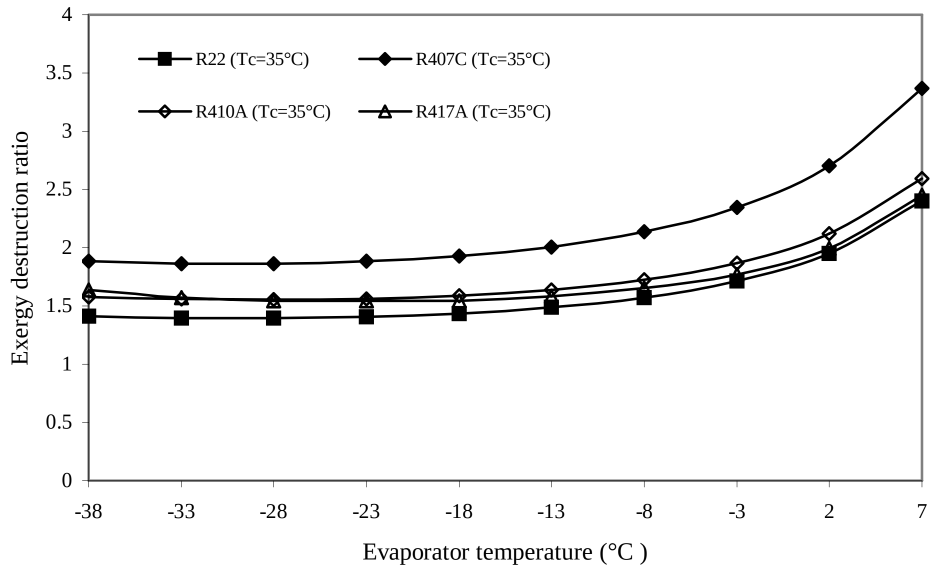


Figure 37. Comparison of exergy destruction ratio with varying evaporator temperature (Tc=35°C)

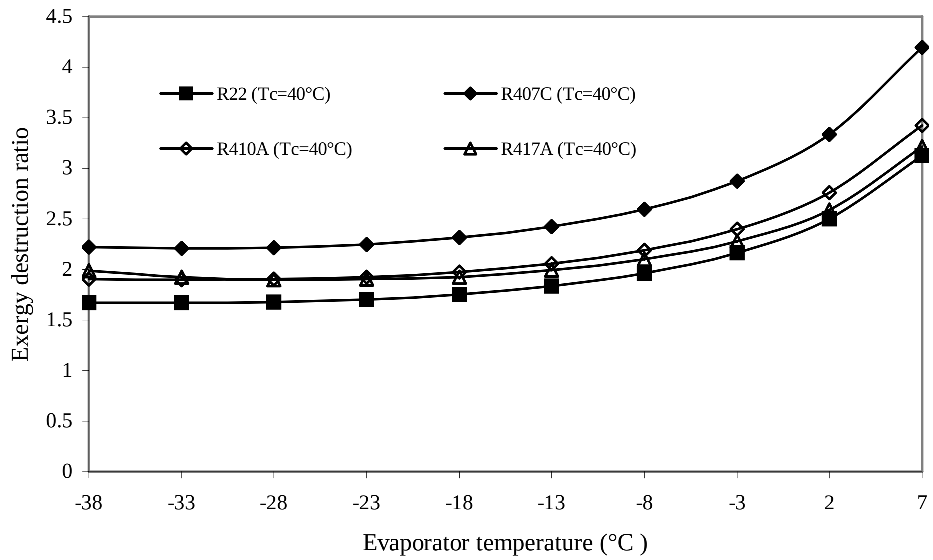


Figure 38. Comparison of exergy destruction ratio with varying evaporator temperature (Tc=40°C)

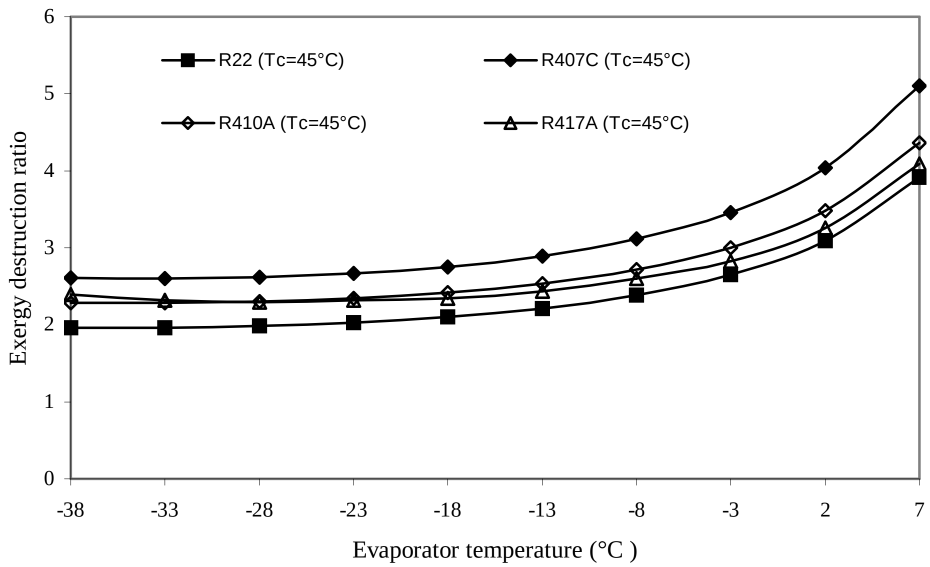


Figure 39. Comparison of exergy destruction ratio with varying evaporator temperature (Tc=45°C)

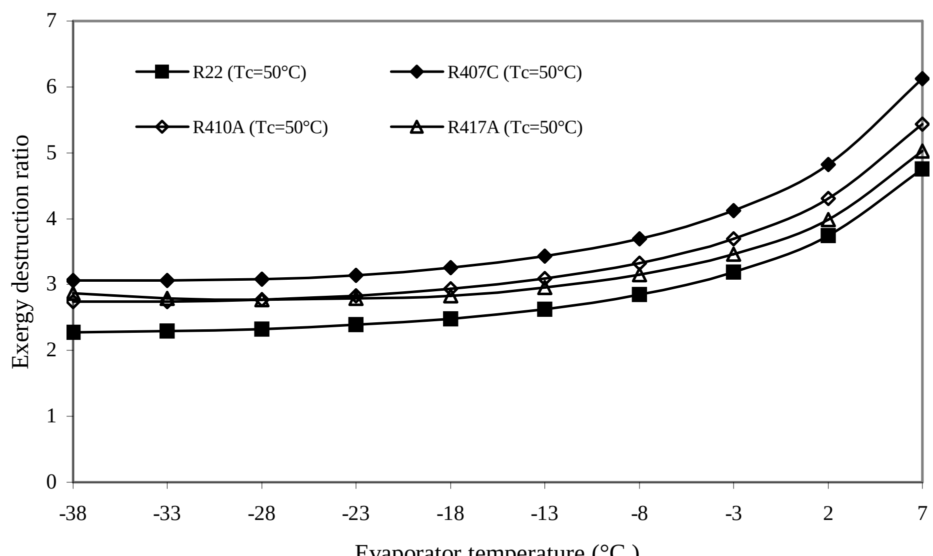


Figure 40. Comparison of exergy destruction ratio with varying evaporator temperature (Tc=50°C)

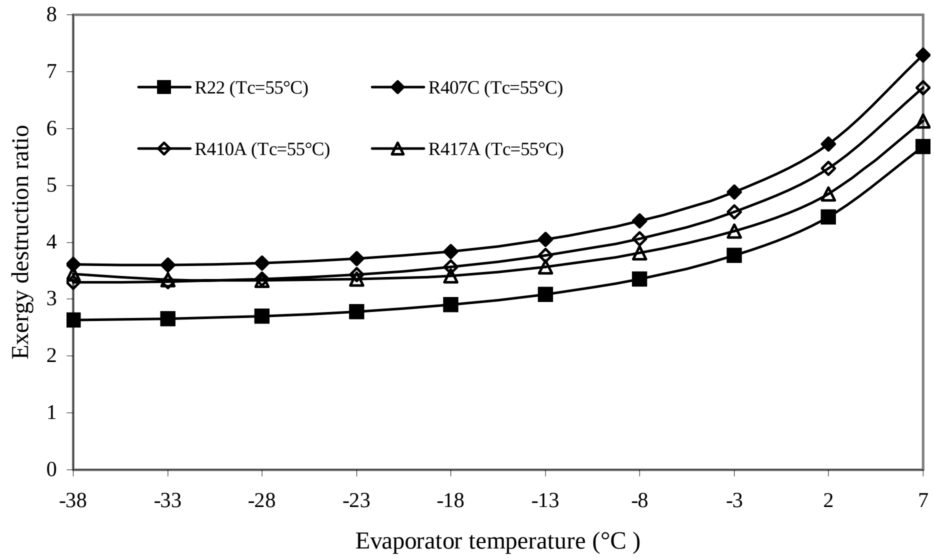


Figure 41. Comparison of exergy destruction ratio with varying evaporator temperature (Tc=55°C)

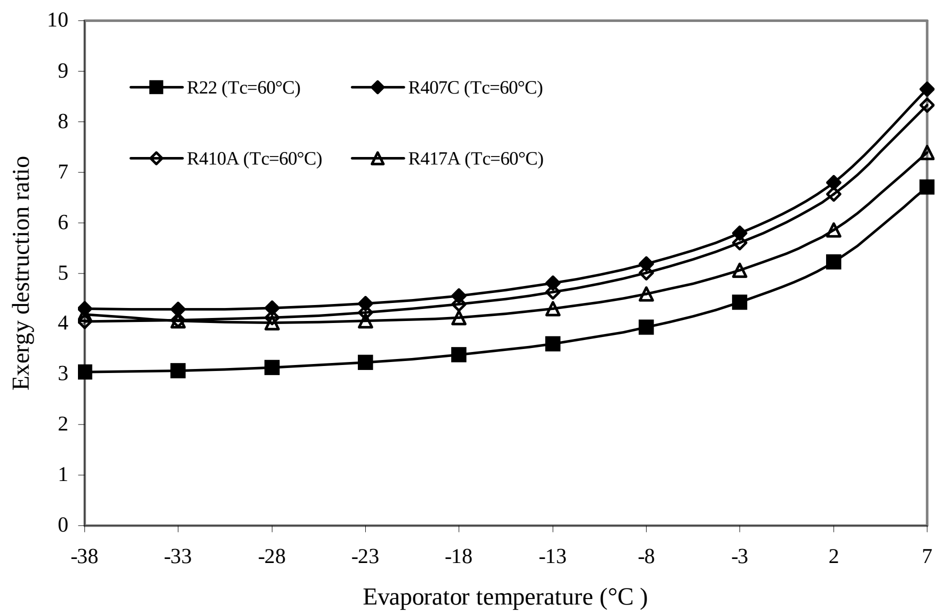


Figure 42. Comparison of exergy destruction ratio with varying evaporator temperature (Tc=60°C)

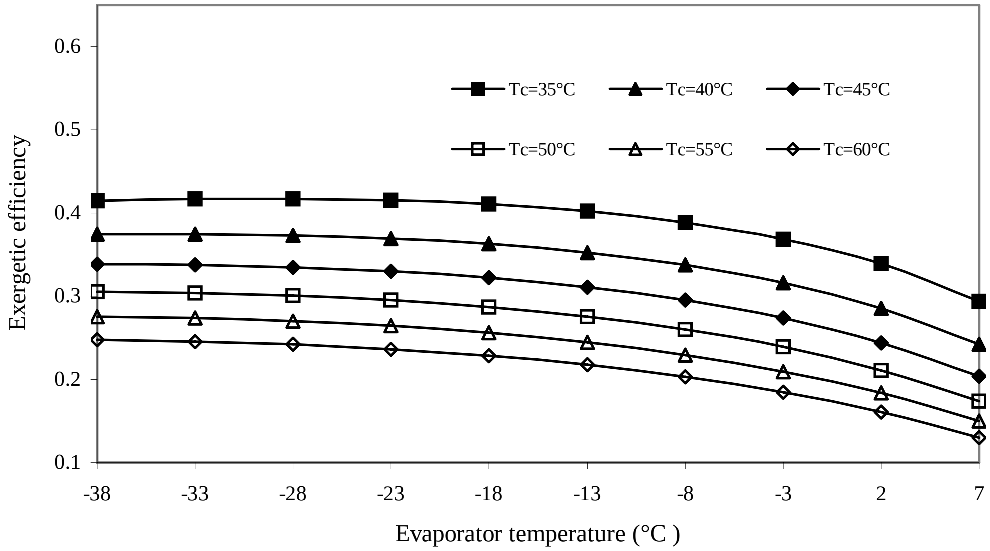


Figure 43. Variation of exergetic efficiency with varying evaporator temperature (R22)

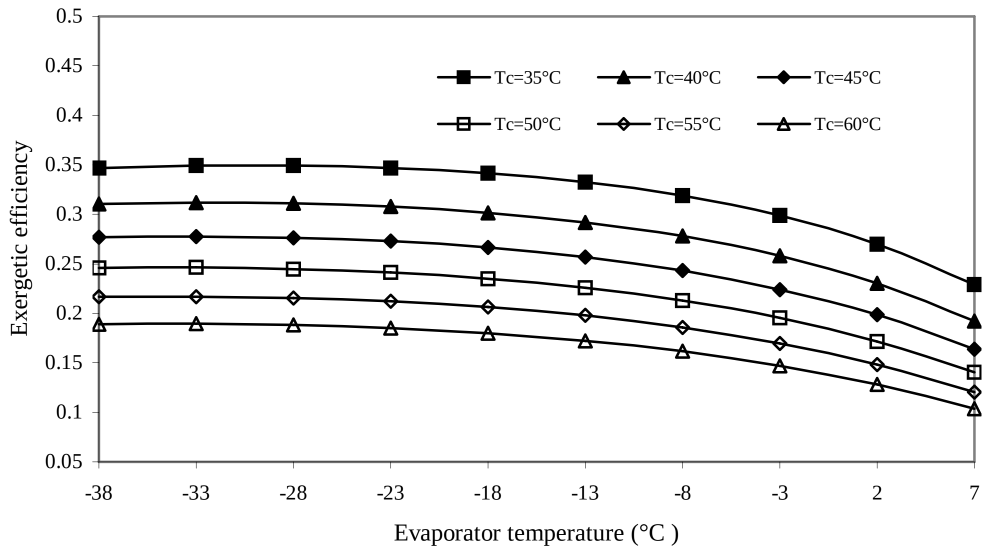


Figure 44. Variation of exergetic efficiency with varying evaporator temperature (R407C)

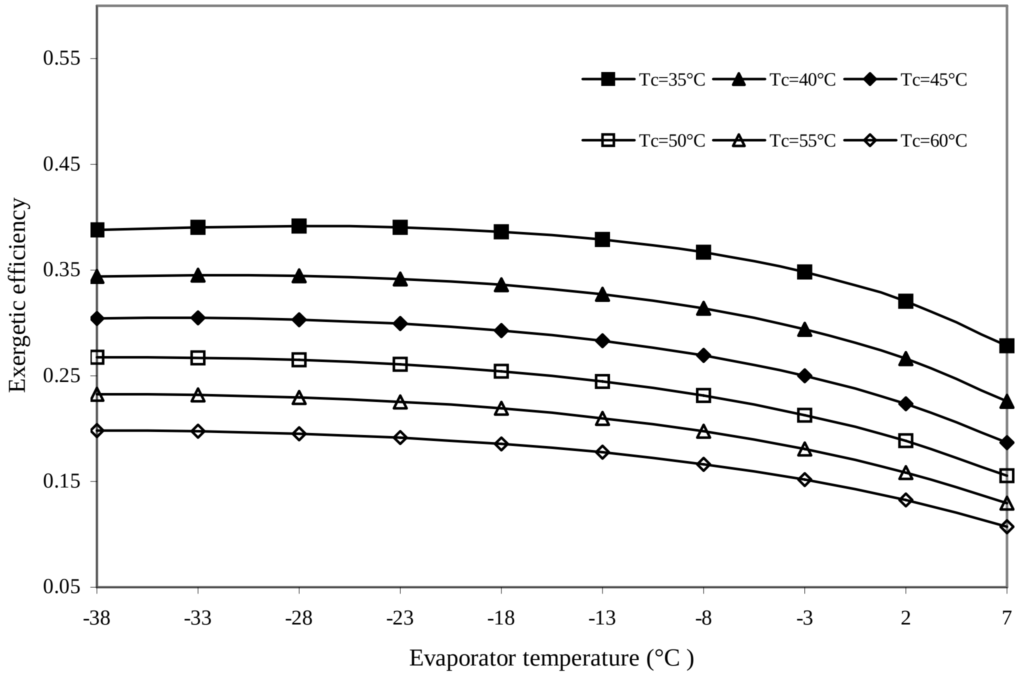


Figure 45. Variation of exergetic efficiency with varying evaporator temperature (R410A)

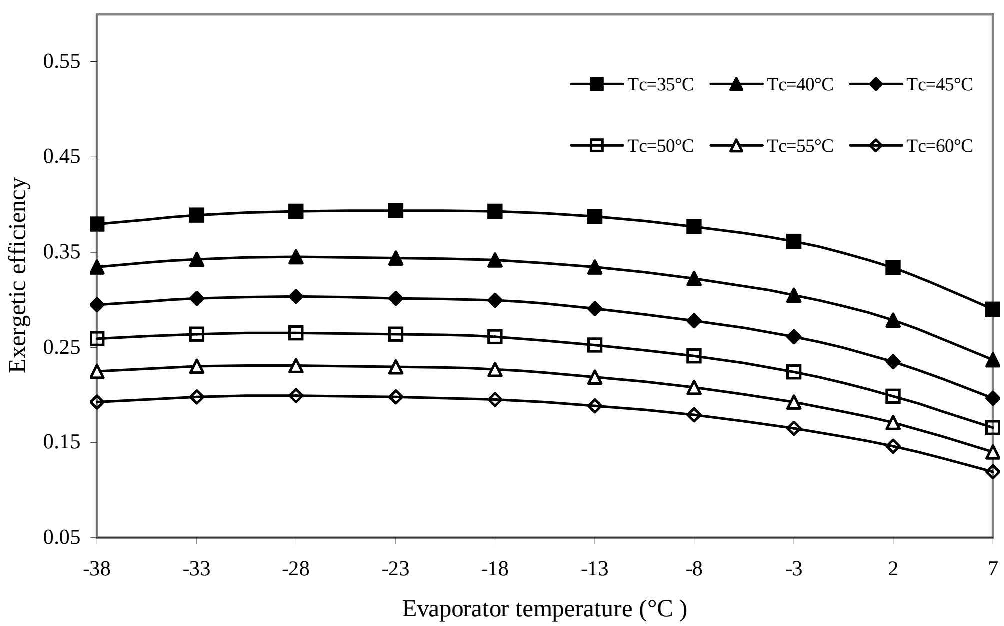


Figure 46. Variation of exergetic efficiency with varying evaporator temperature (R417A)

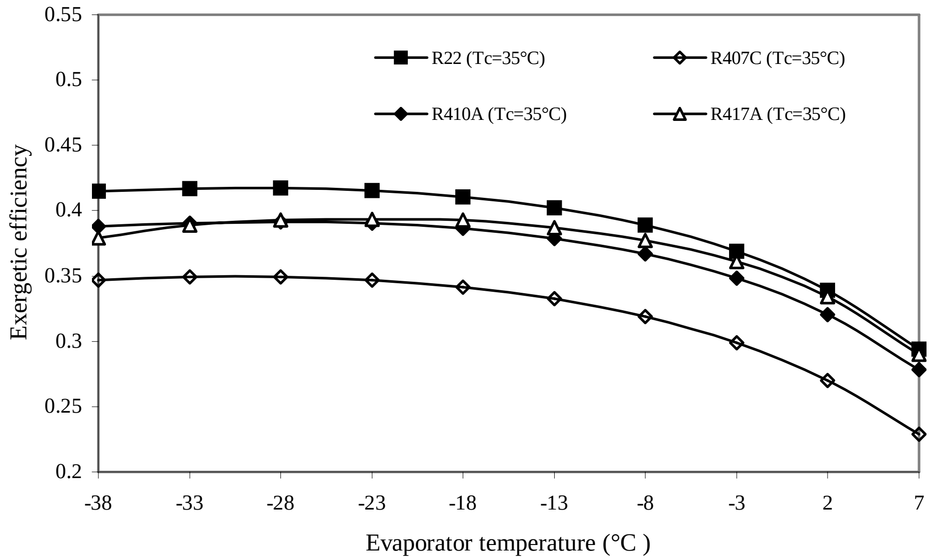


Figure 47. Comparison of exergetic efficiency with varying evaporator temperature (Tc=35°C)

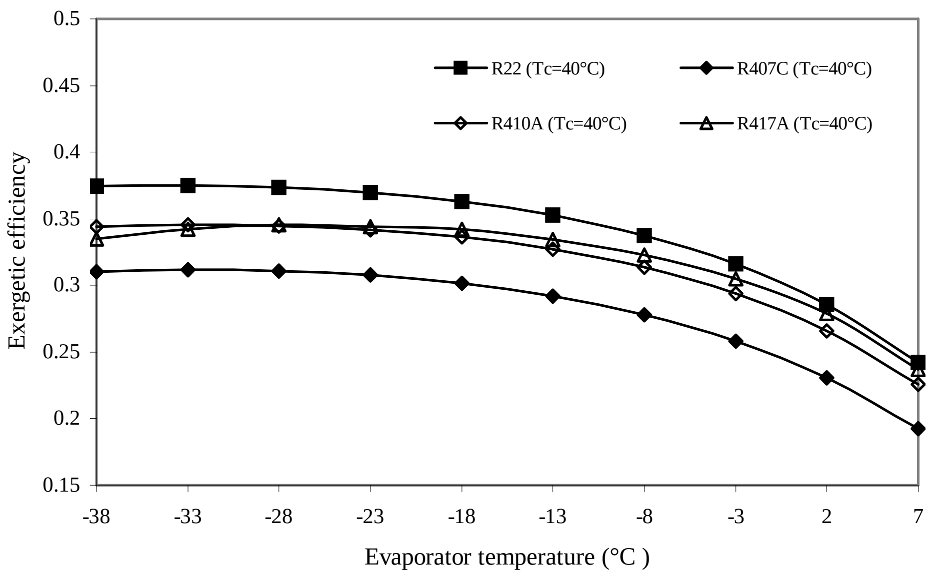


Figure 48. Comparison of exergetic efficiency with varying evaporator temperature (Tc=40°C)

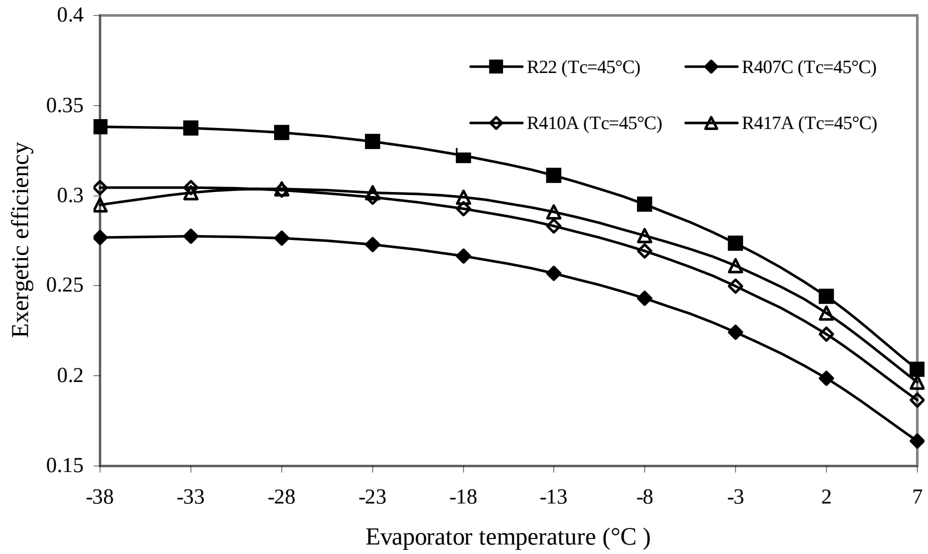


Figure 49. Comparison of exergetic efficiency with varying evaporator temperature (Tc=45°C)

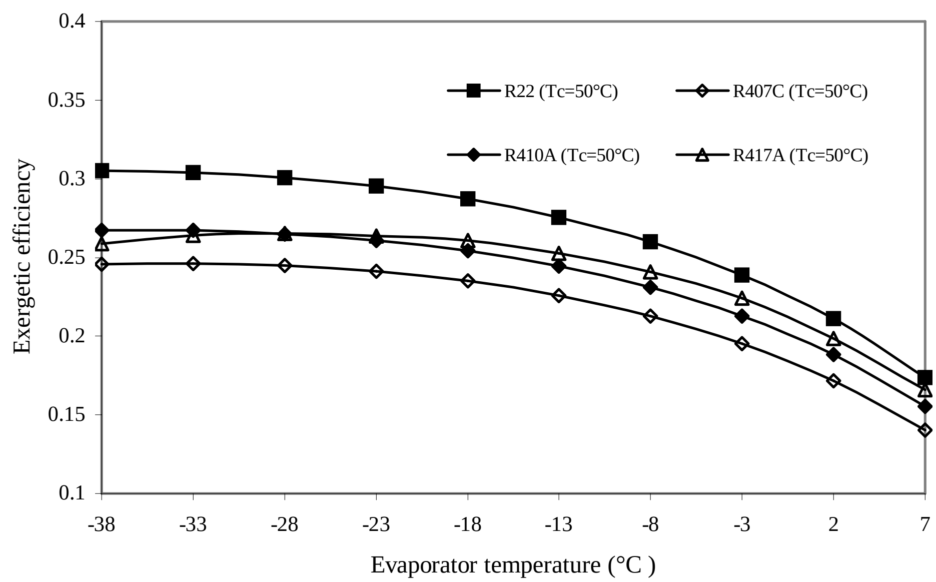


Figure 50. Comparison of exergetic efficiency with varying evaporator temperature (Tc=50°C)

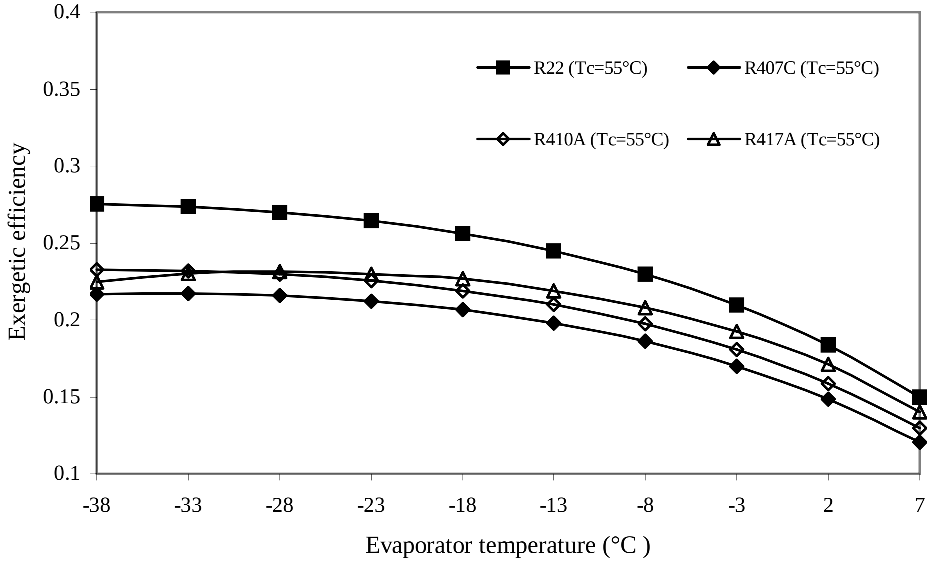
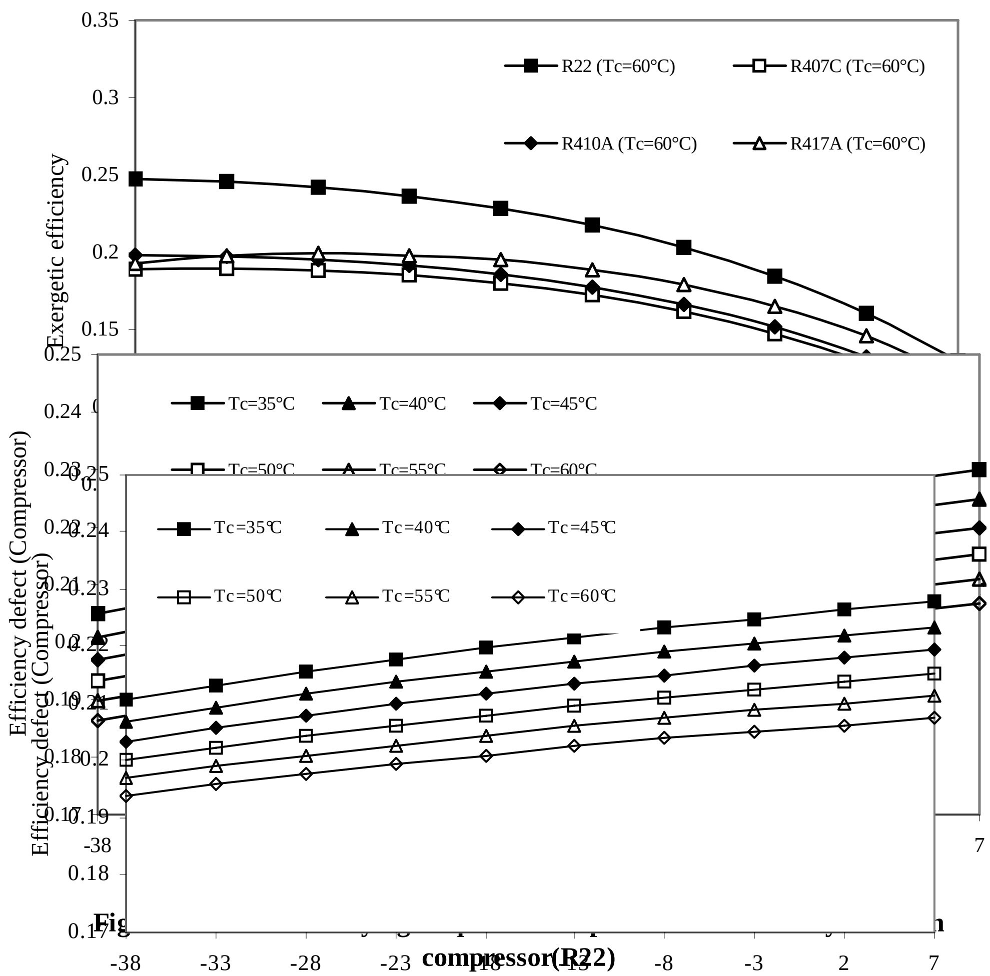


Figure 51. Comparison of exergetic efficiency with varying evaporator temperature (Tc=55°C)



Fig

compressor(R22)

Figure 54. Effect of varying evaporator temperature on efficiency defect in compressor (R407C)

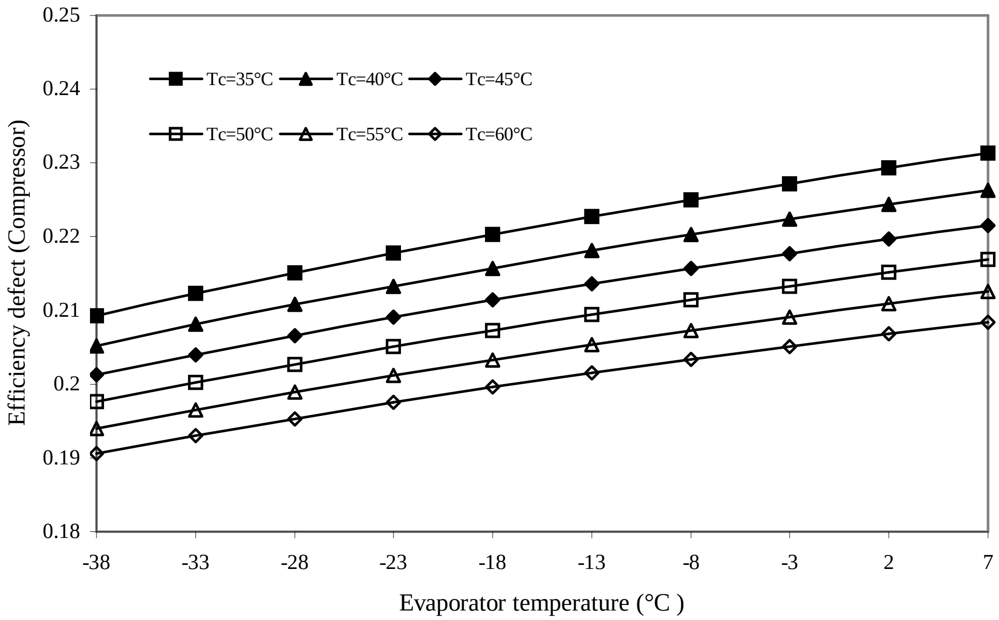


Figure 55. Effect of varying evaporator temperature on efficiency defect in compressor(410A)

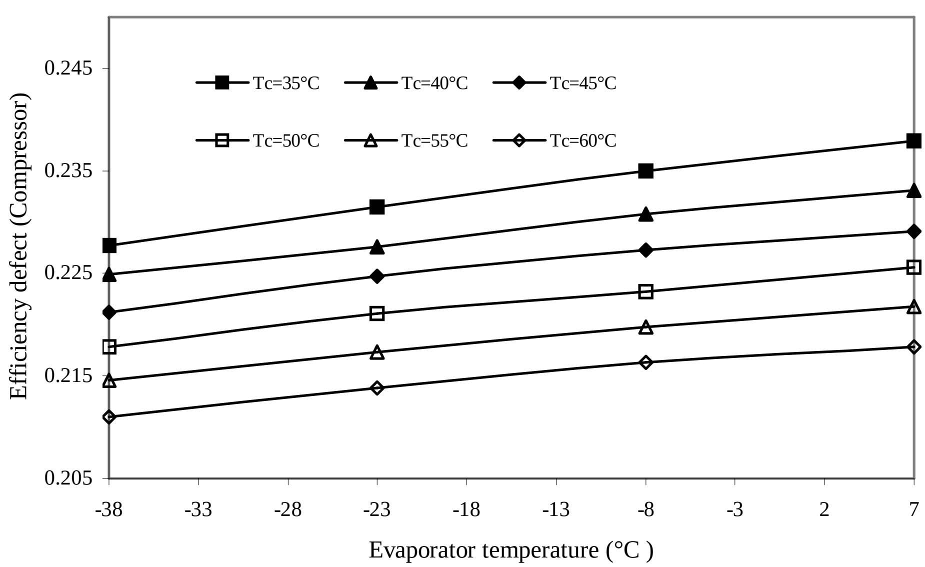


Figure 56. Effect of varying evaporator temperature on efficiency defect in compressor (R417A)

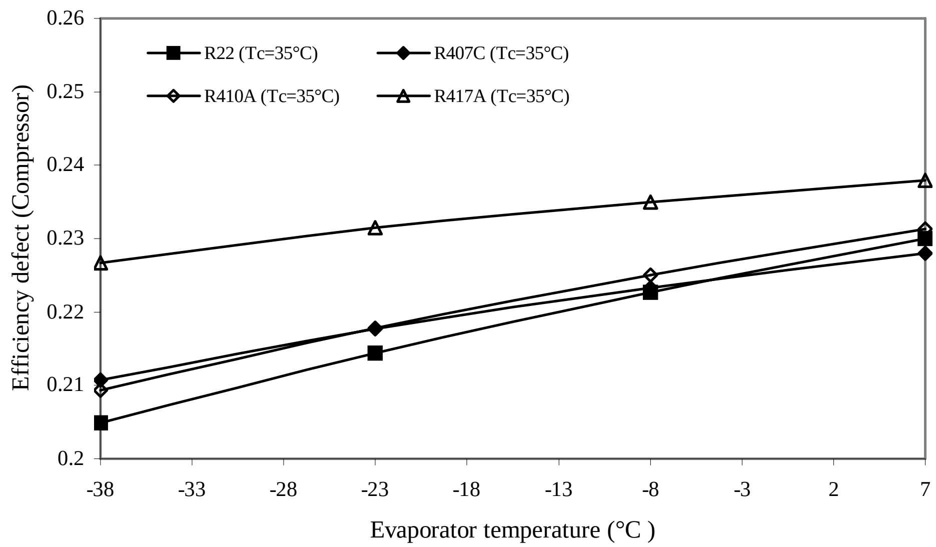


Figure 57. Comparison of efficiency defect in compressor with varying evaporator temperature (Tc=35°C)

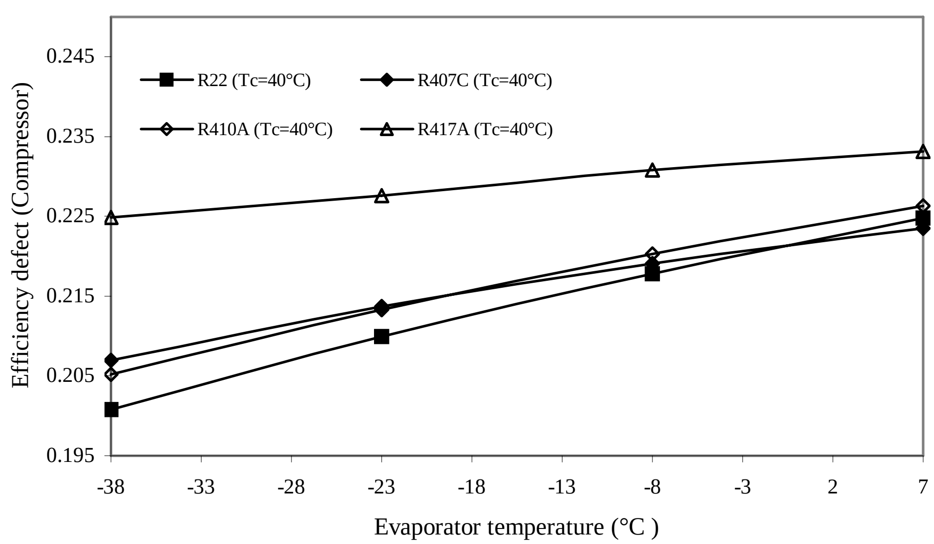


Figure 58. Comparison of efficiency defect in compressor with varying evaporator temperature (Tc=40°C)

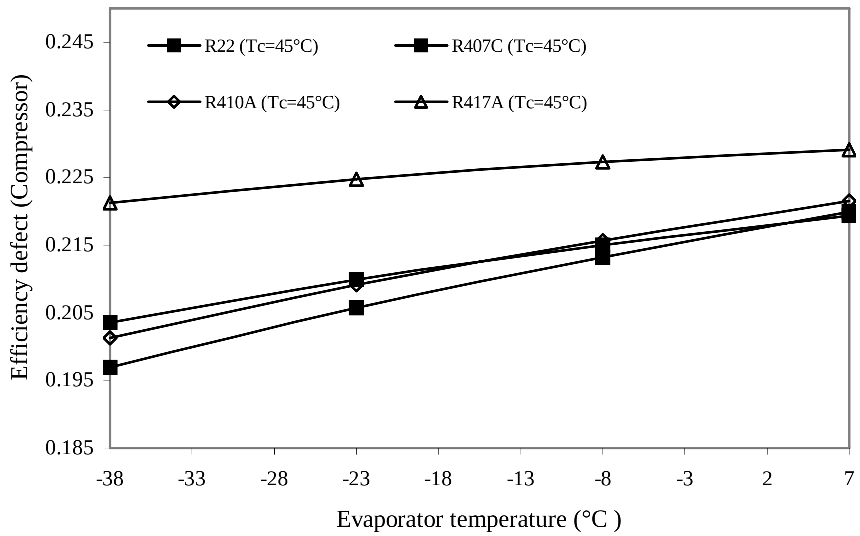


Figure 59. Comparison of efficiency defect in compressor with varying evaporator temperature (Tc=45°C)

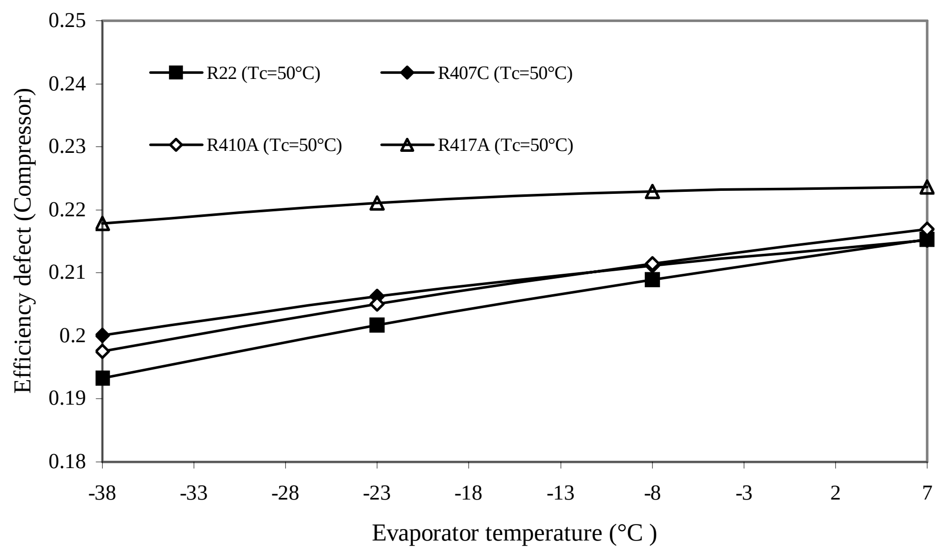


Figure 60. Comparison of efficiency defect in compressor with varying evaporator temperature (Tc=50°C)

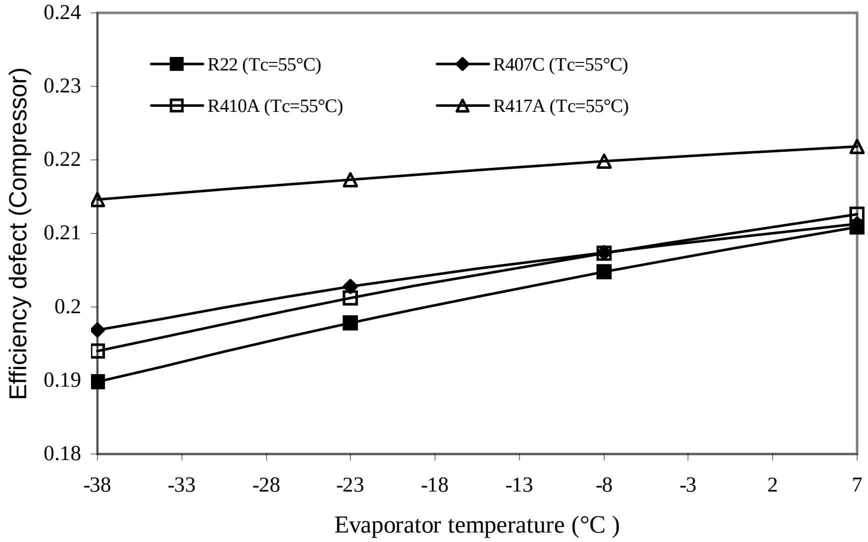


Figure 61. Comparison of efficiency defect in compressor with varying evaporator temperature (Tc=55°C)

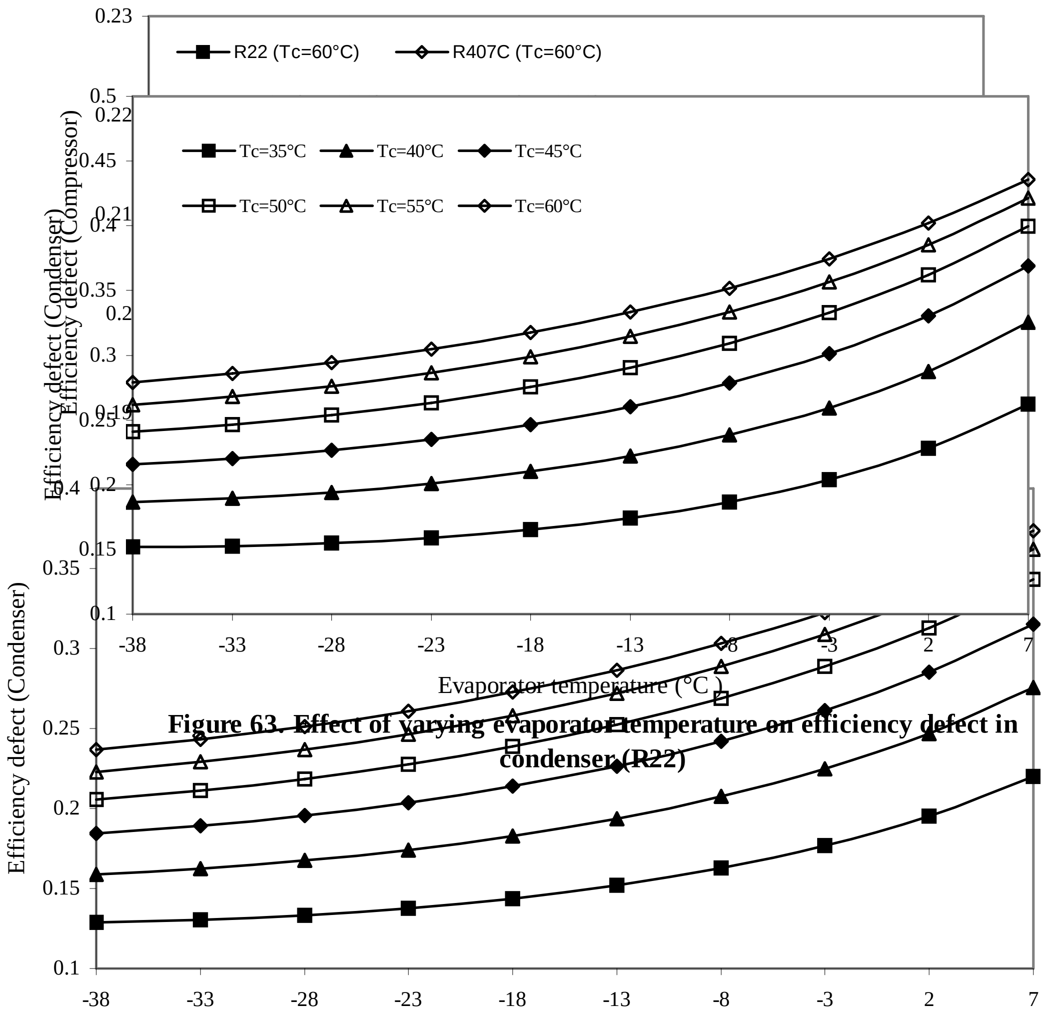


Figure 63. Effect of varying evaporator temperature on efficiency defect in condenser (R22)

Evaporator temperature (°C)

Figure 64. Effect of varying evaporator temperature on efficiency defect in condenser (R407C)

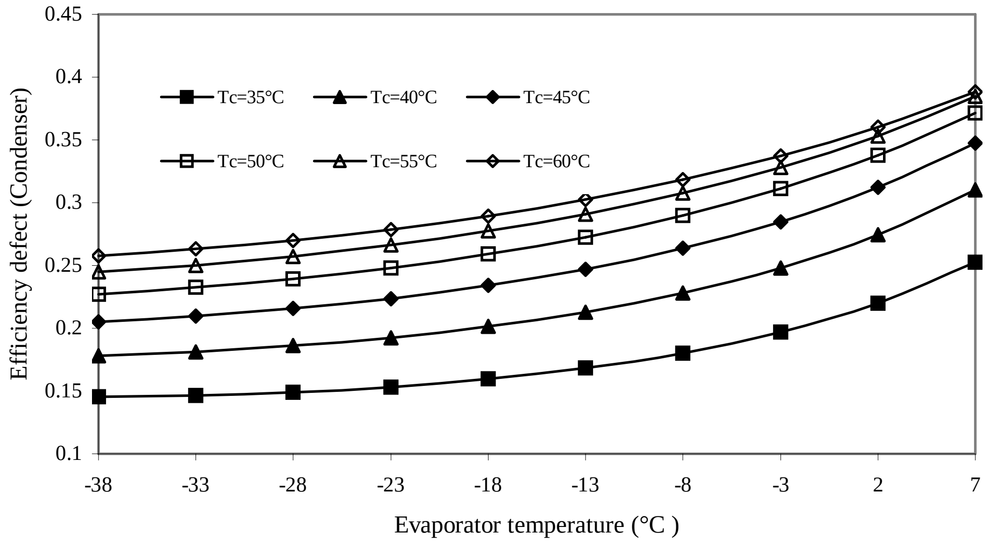


Figure 65. Effect of varying evaporator temperature on efficiency defect in condenser (R410A)

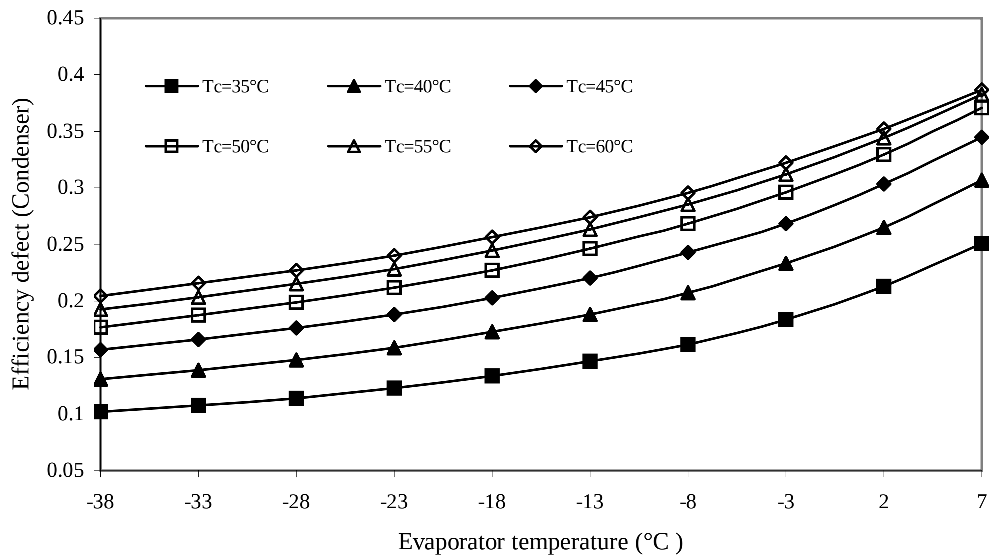


Figure 66. Effect of varying evaporator temperature on efficiency defect in condenser (R417A)

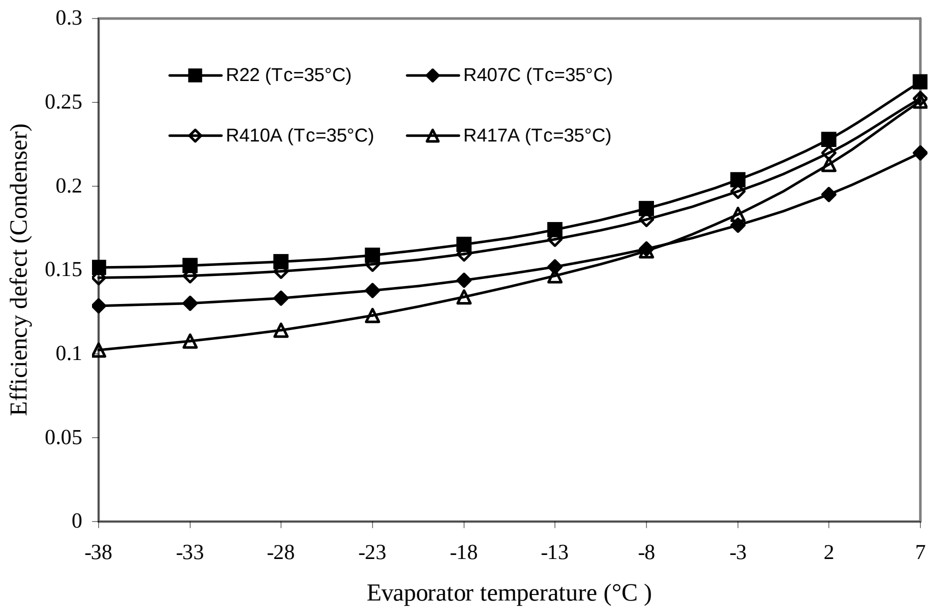


Figure 67. Comparison of efficiency defect in condenser with varying evaporator temperature (Tc=35°C)

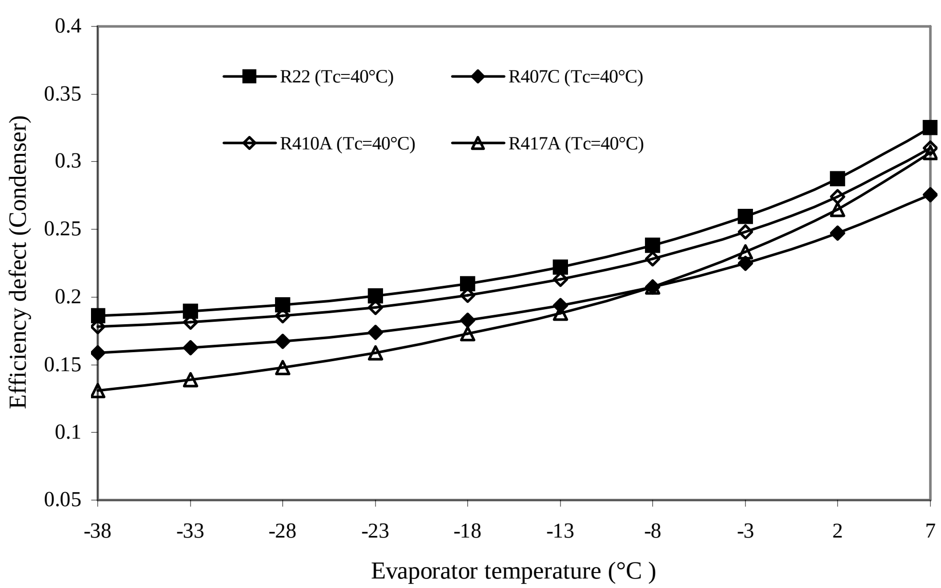


Figure 68. Comparison of efficiency defect in condenser with varying evaporator temperature (Tc=40°C)

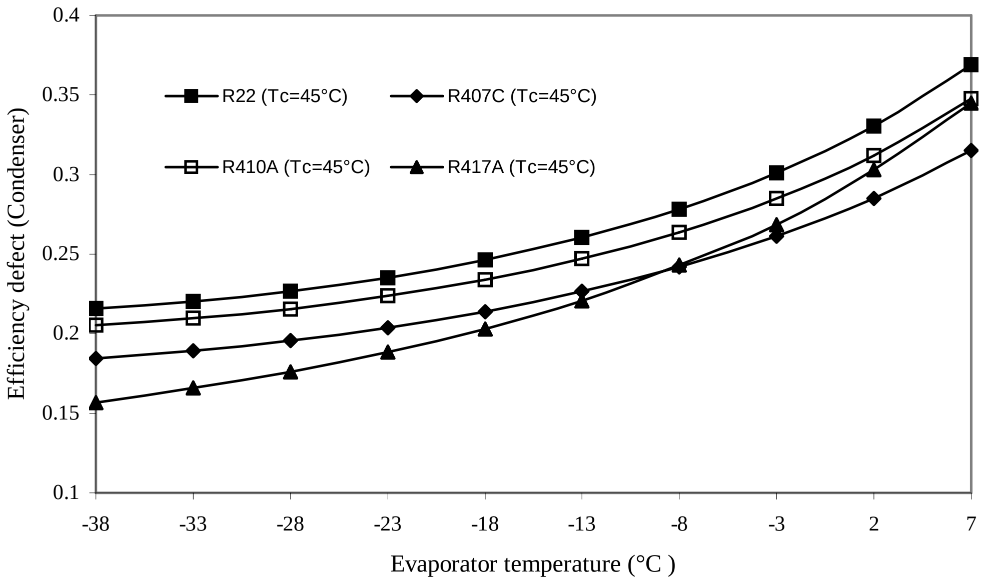


Figure 69. Comparison of efficiency defect in condenser with varying evaporator temperature (Tc=45°C)

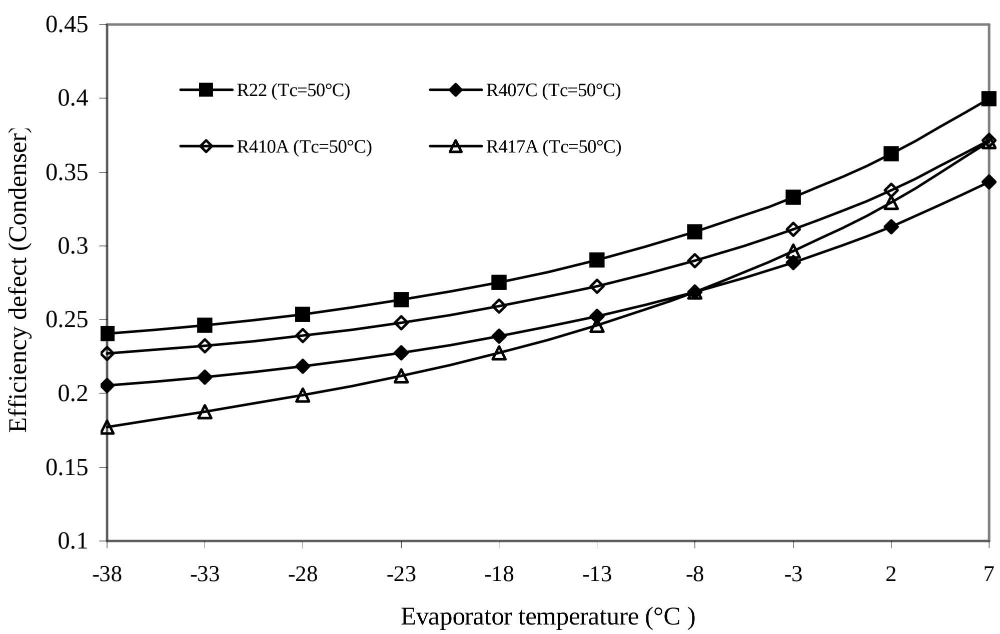


Figure 70. Comparison of efficiency defect in condenser with varying evaporator temperature (Tc=50°C)

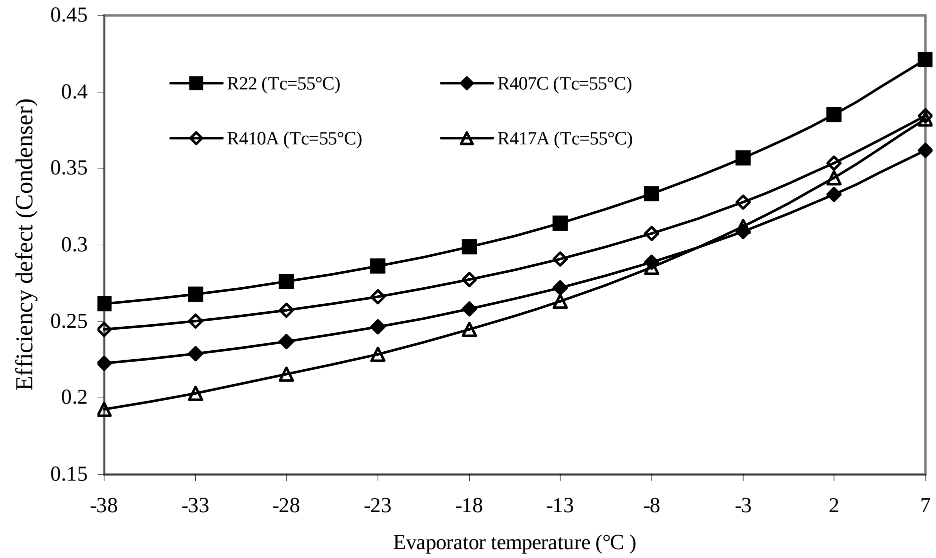


Figure 71. Comparison of efficiency defect in condenser with varying evaporator temperature (Tc=55°C)

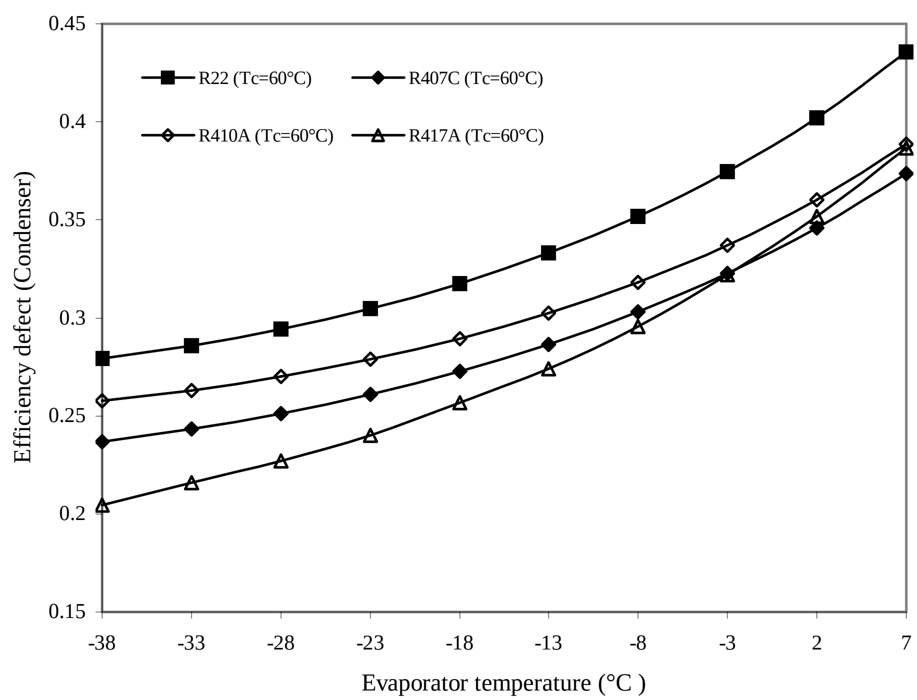


Figure 72. Comparison of efficiency defect in condenser with varying evaporator temperature (Tc=60°C)

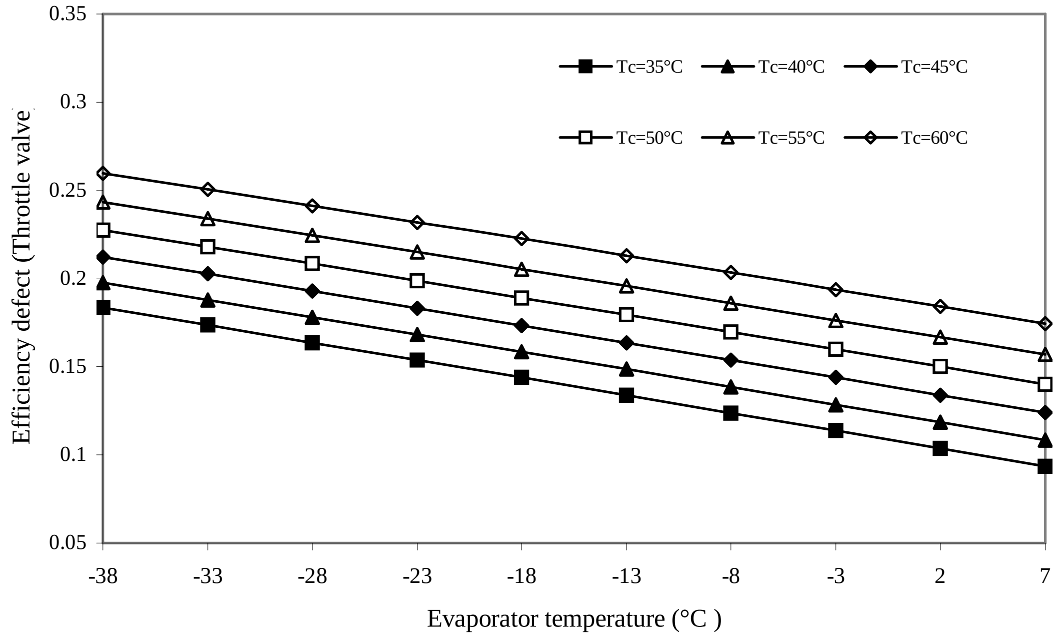


Figure 73. Effect of varying evaporator temperature on efficiency defect in throttle valve (R22)

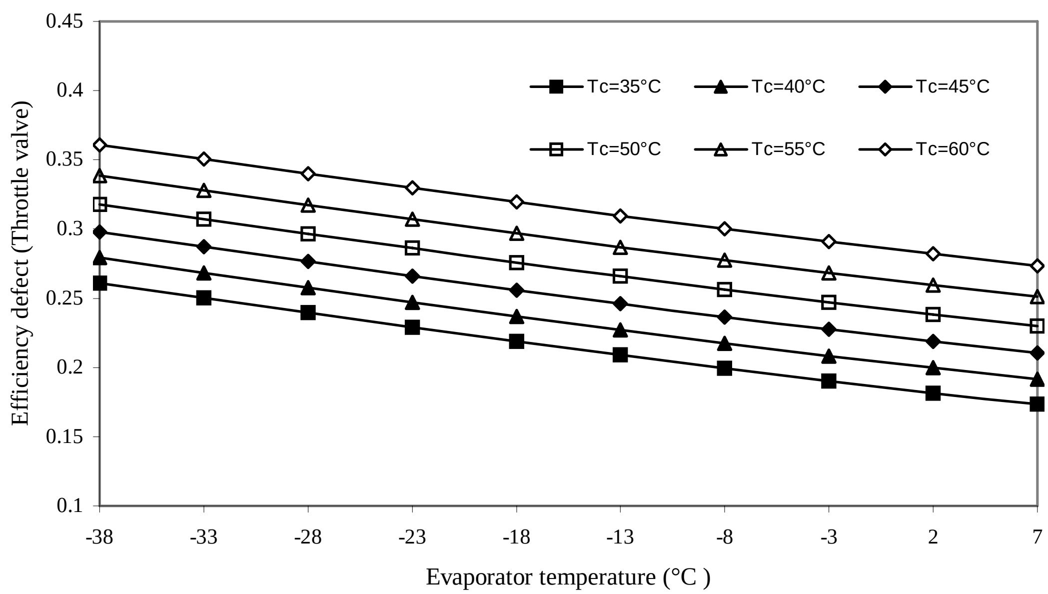


Figure 74. Effect of varying evaporator temperature on efficiency defect in throttle valve (R407C)

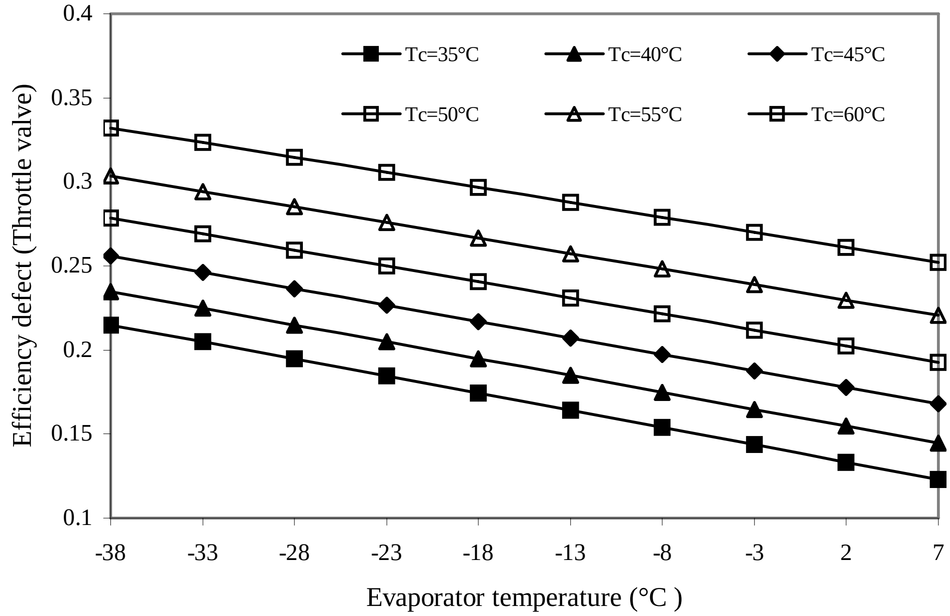


Figure 75. Effect of varying evaporator temperature on efficiency defect in throttle valve (R410A)

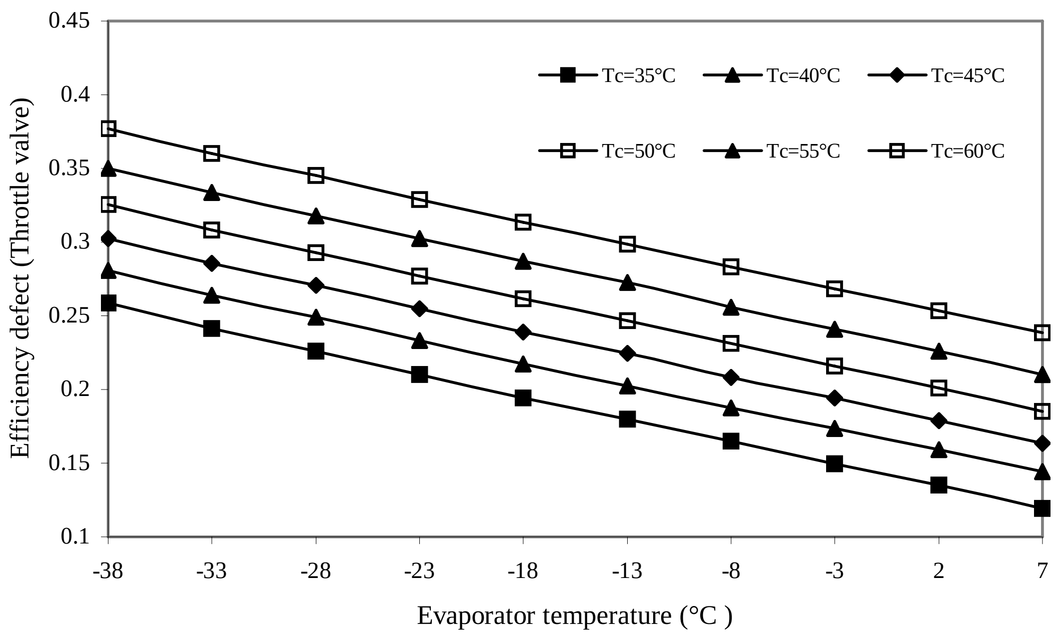


Figure 76 Effect of varying evaporator temperature on efficiency defect in throttle valve (R417A)

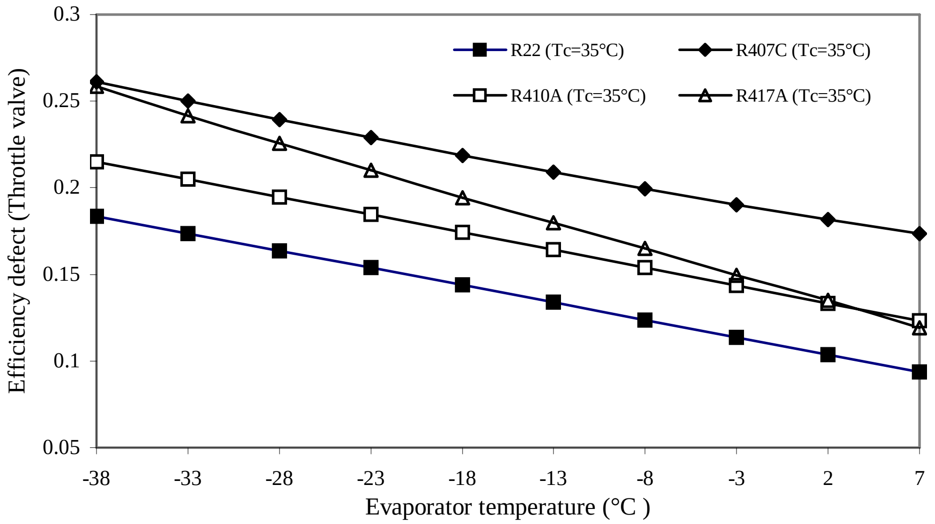


Figure 77. Comparison of efficiency defect in throttle valve with varying evaporator temperature (Tc=35°C)

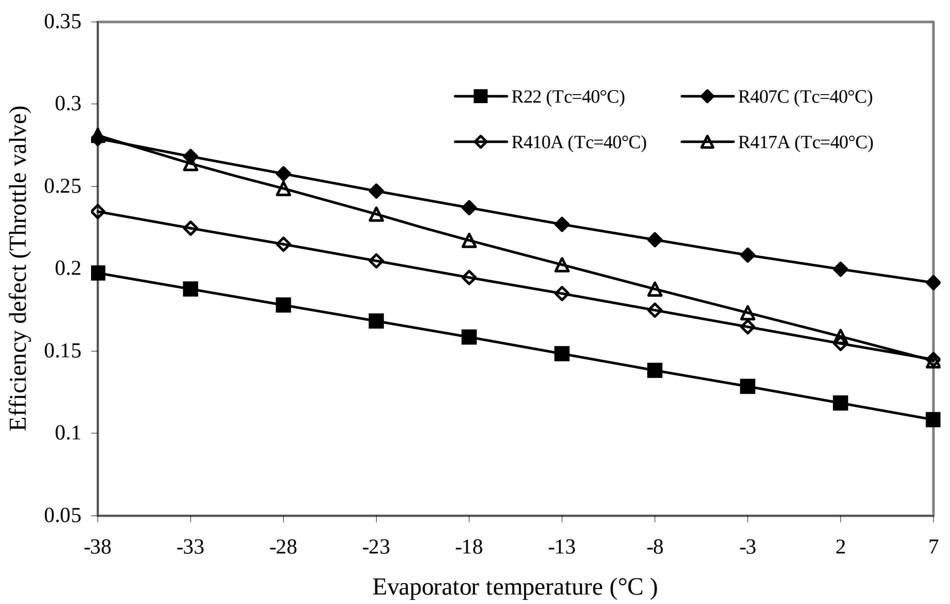


Figure 78. Comparison of efficiency defect in throttle valve with varying evaporator temperature (Tc=40°C)

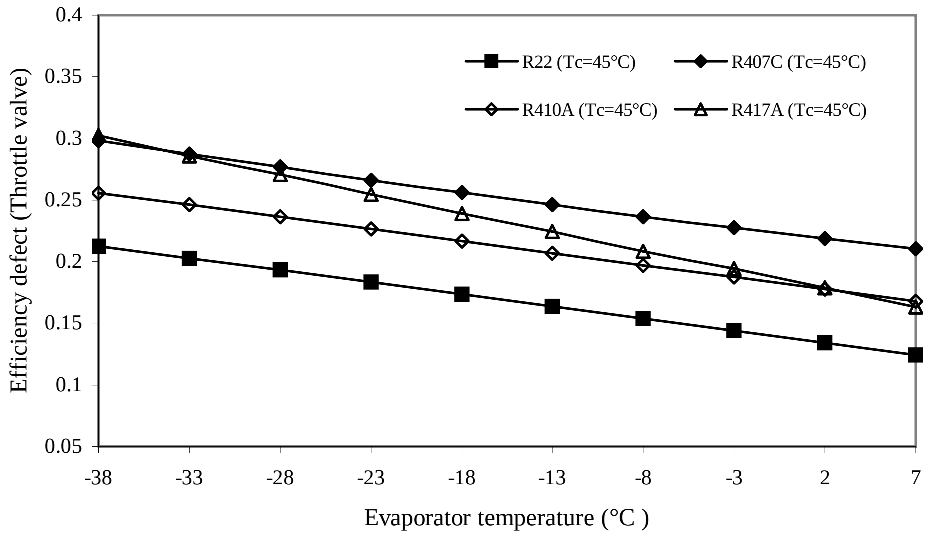


Figure 79. Comparison of efficiency defect in throttle valve with varying evaporator temperature (Tc=45°C)

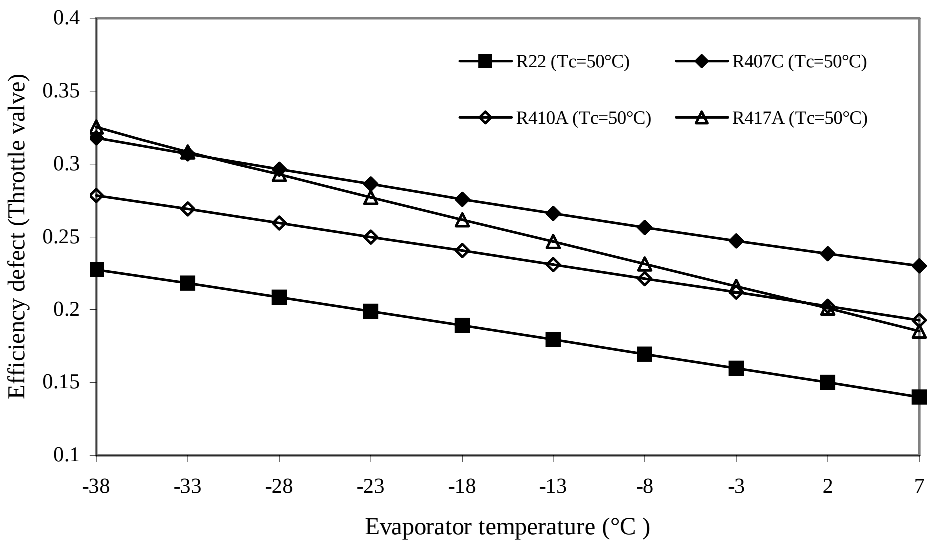


Figure 80. Comparison of efficiency defect in throttle valve with varying evaporator temperature (Tc=50°C)

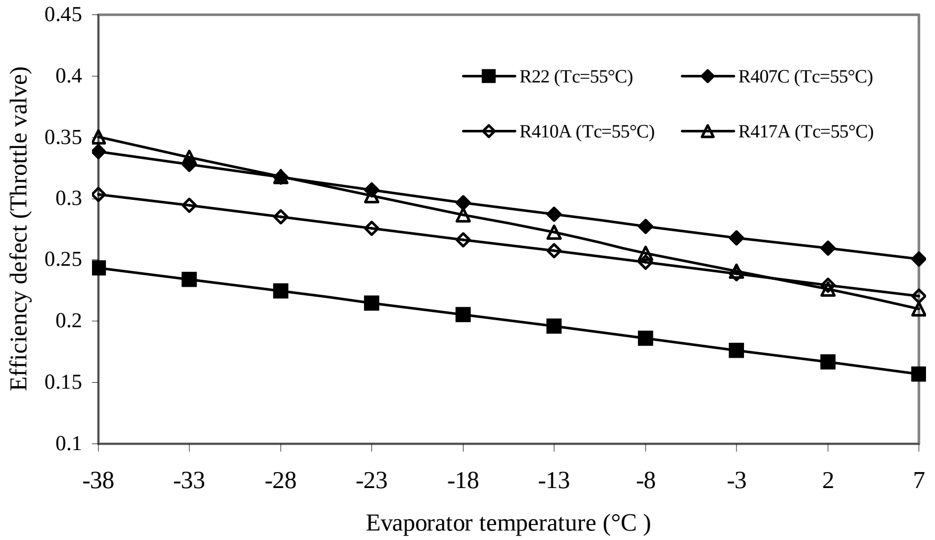


Figure 81. Comparison of efficiency defect in throttle valve with varying evaporator temperature (Tc=55°C)

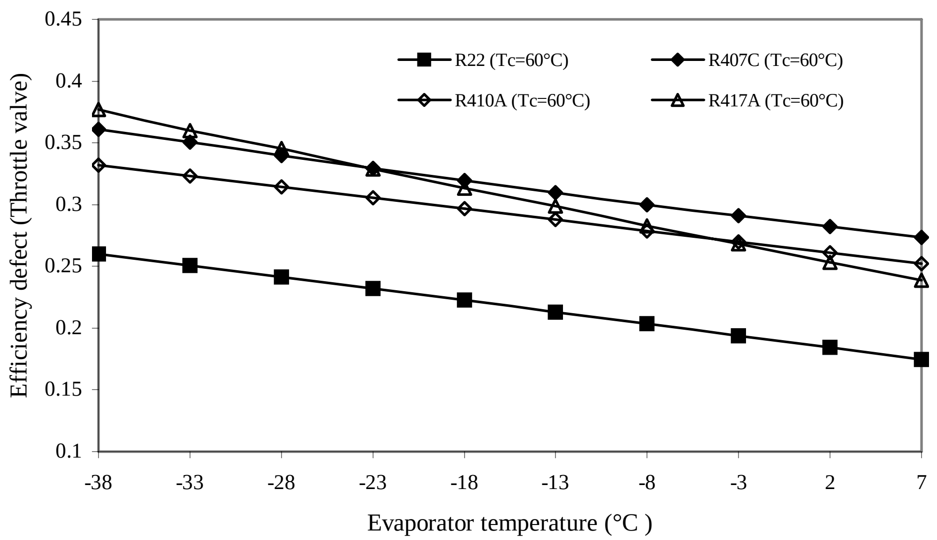


Figure 82. Comparison of efficiency defect in throttle valve with varying evaporator temperature (Tc=60°C)

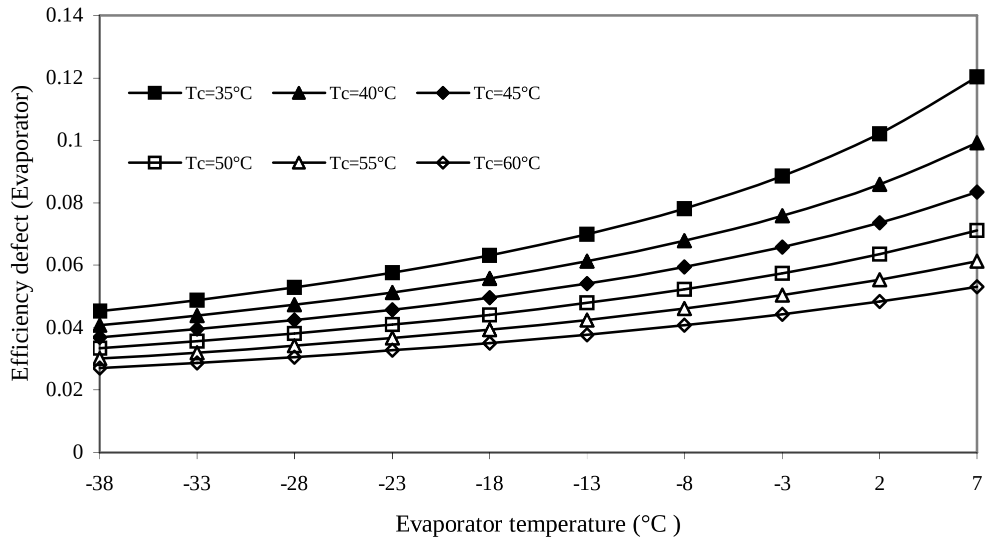


Figure 83. Effect of varying evaporator temperature on efficiency defect in evaporator (R22)

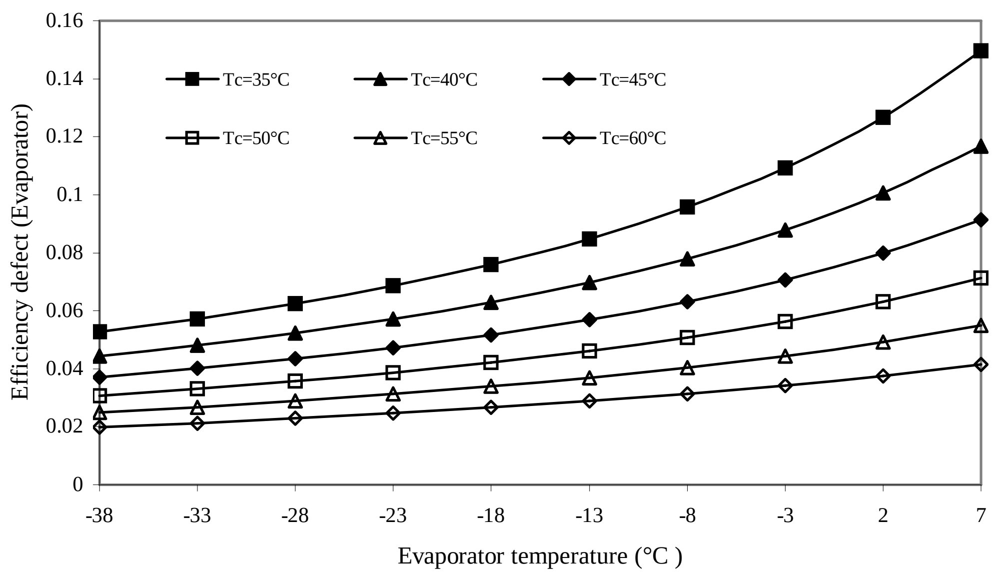


Figure 84. Effect of varying evaporator temperature on efficiency defect in evaporator (R407C)

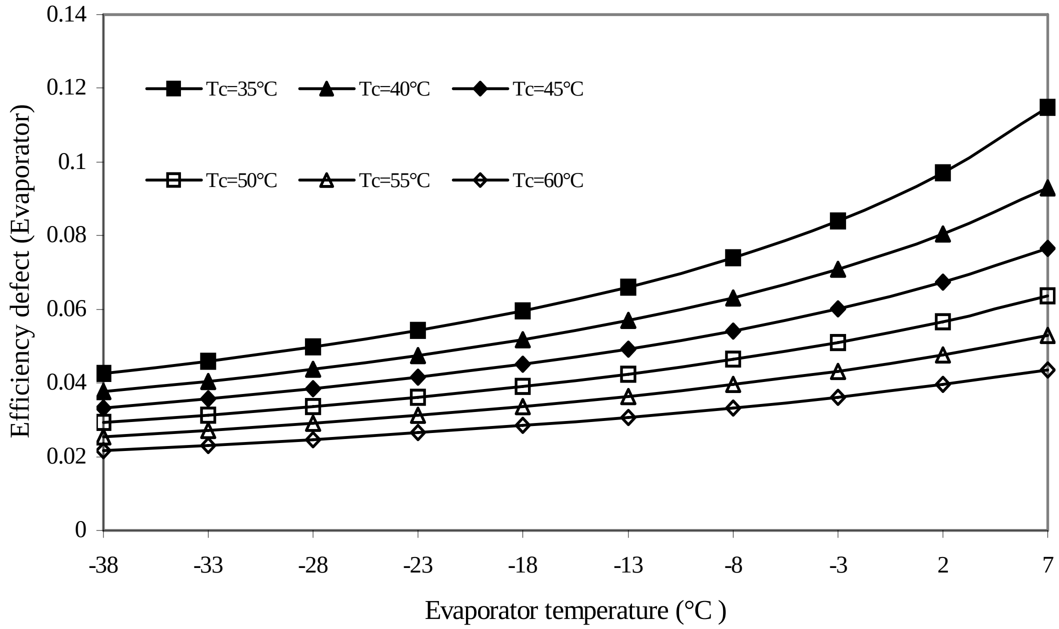


Figure 85. Effect of varying evaporator temperature on efficiency defect in evaporator (R410A)

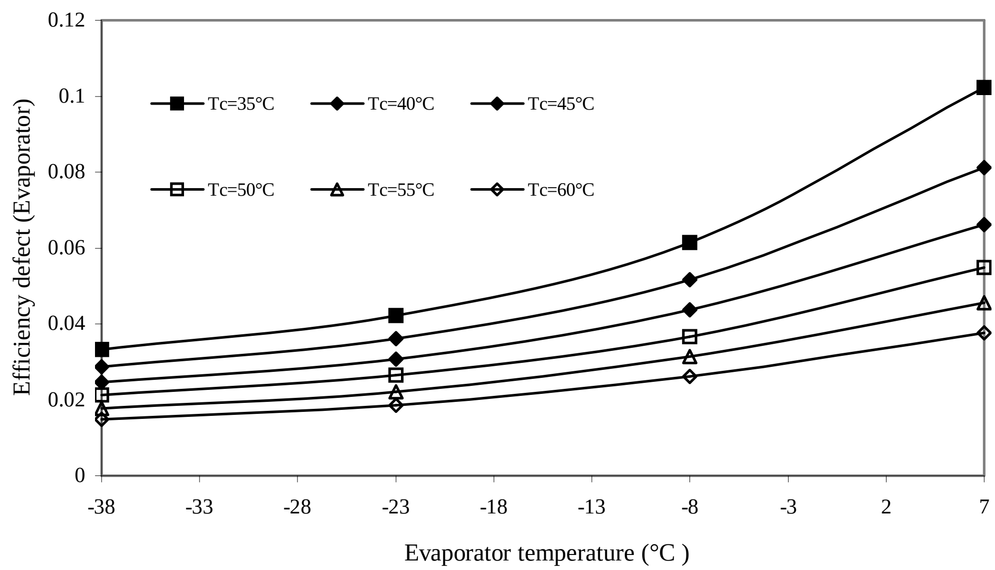


Figure 86. Effect of varying evaporator temperature on efficiency defect in evaporator (R417A)

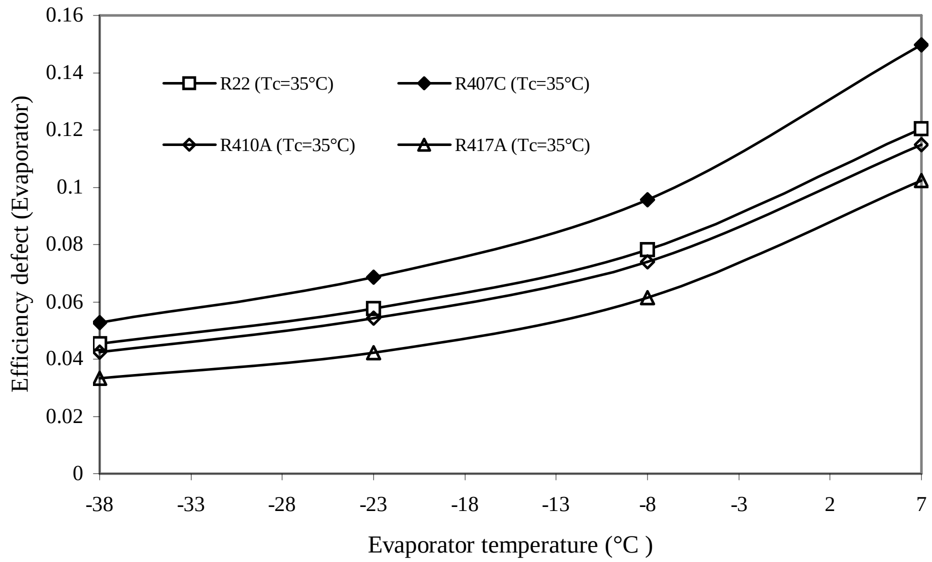


Figure 87. Comparison of efficiency defect in evaporator with varying evaporator temperature (Tc=35°C)

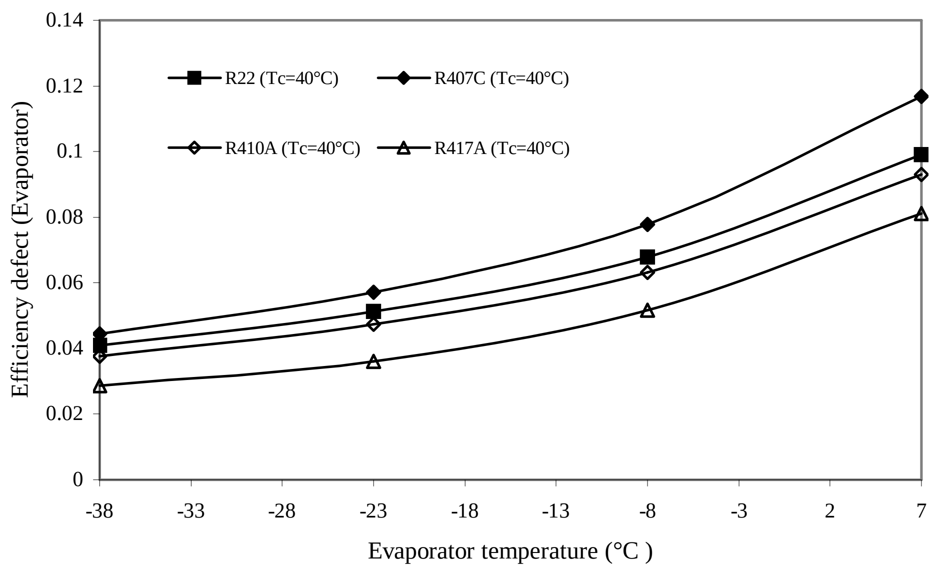


Figure 88. Comparison of efficiency defect in evaporator with varying evaporator temperature (Tc=40°C)

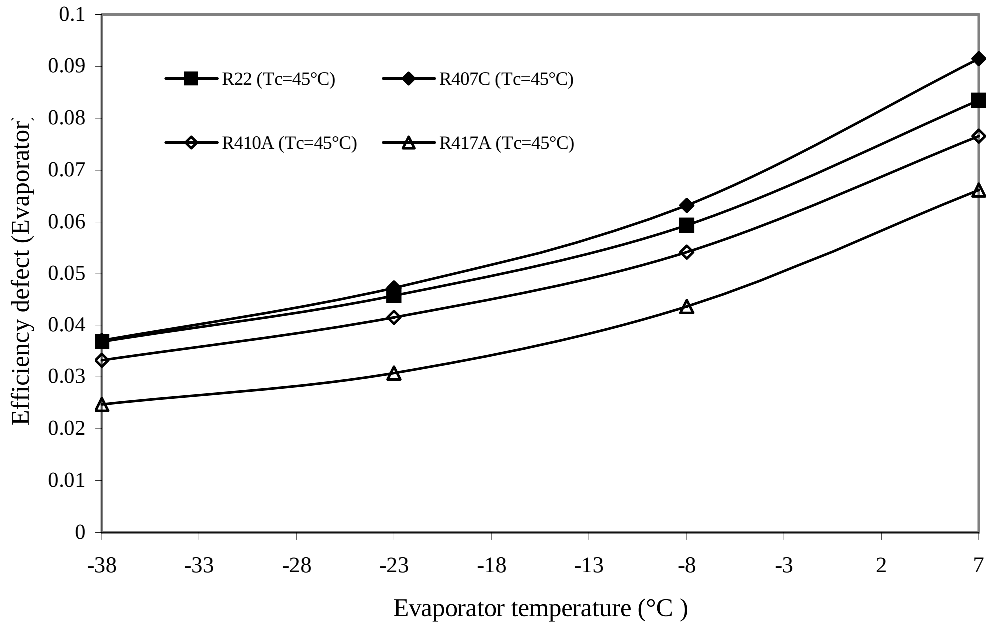


Figure 89. Comparison of efficiency defect in evaporator with varying evaporator temperature (Tc=45°C)

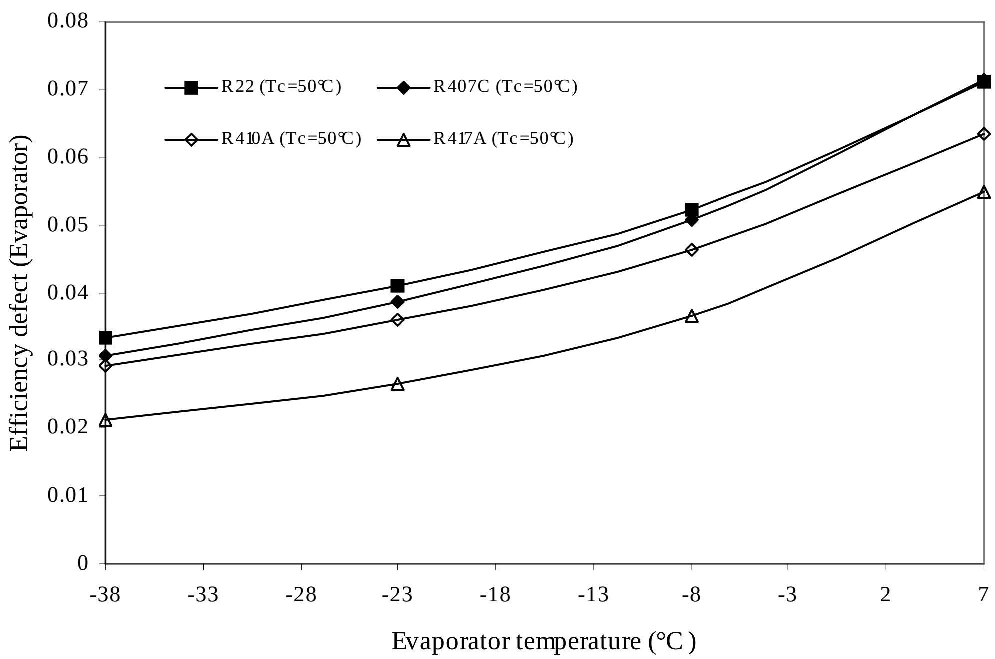


Figure 90. Comparison of efficiency defect in evaporator with varying evaporator temperature (Tc=50°C)

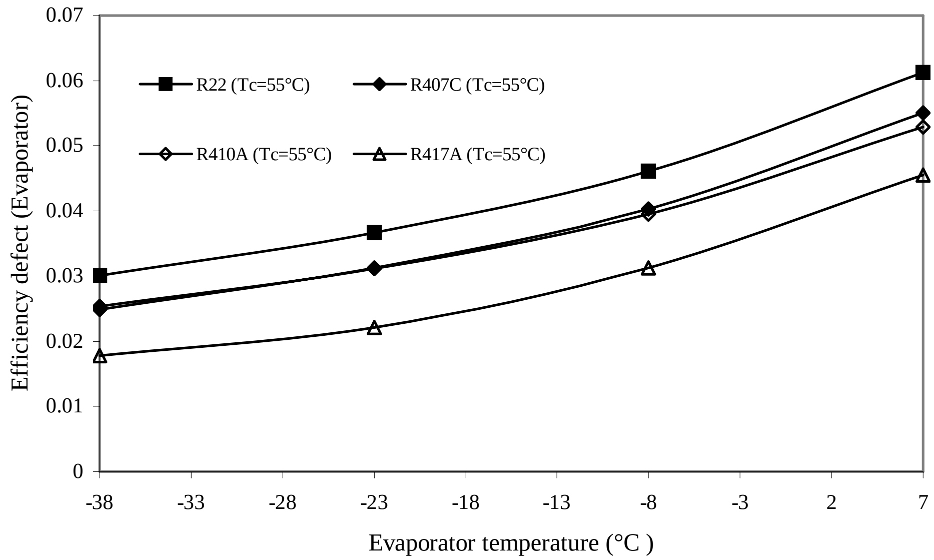


Figure 91. Comparison of efficiency defect in evaporator with varying evaporator temperature (Tc=55°C)

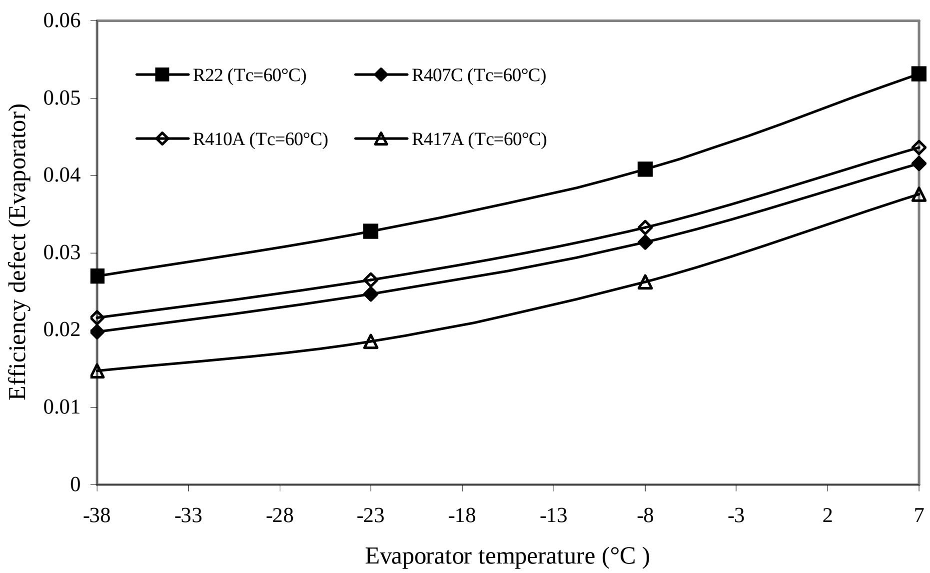


Figure 92. Comparison of efficiency defect in evaporator with varying evaporator temperature (Tc=60°C)

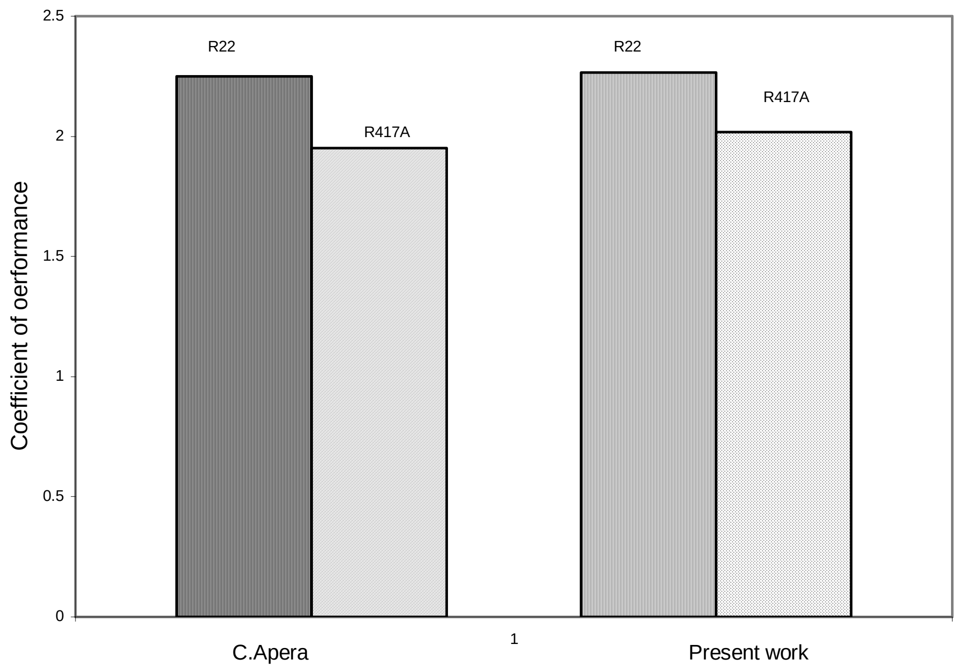


Figure 93. Comparison of experimental results with the present work (COP)

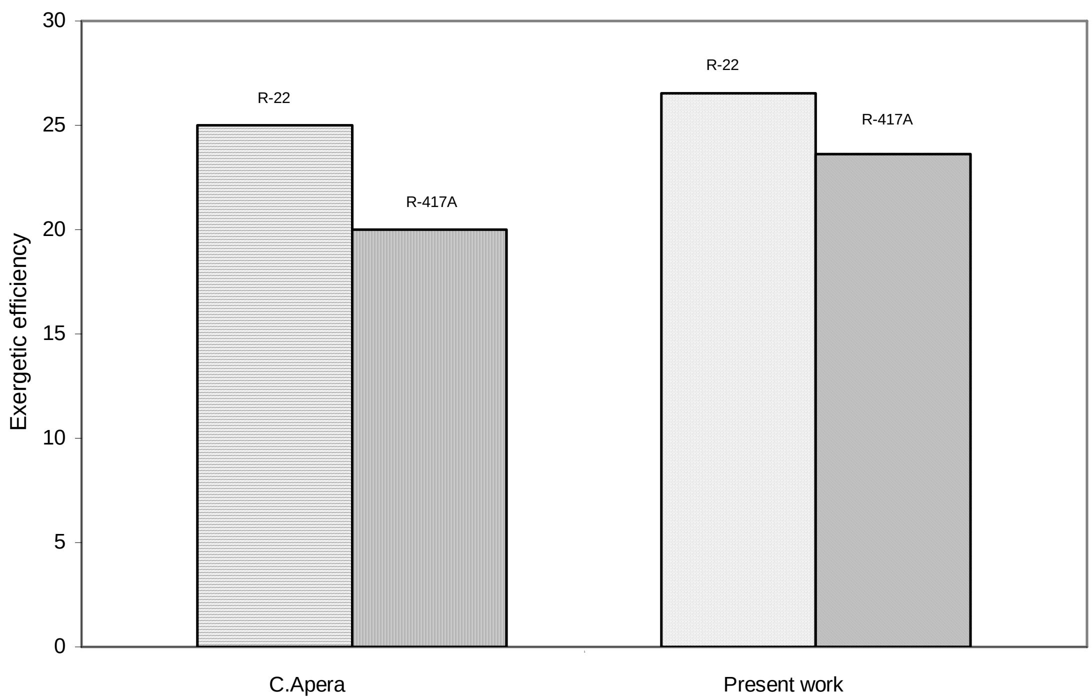


Figure 94. Comparison of experimental results with the present work (Exergetic Efficiency)

Table 2. Variation of Pressure ratio with evaporator varying temperature (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	11.75	13.3	14.99	16.84	18.86	21.04
-33	9.402	10.64	12	13.48	15.09	16.85
-28	7.605	8.608	9.706	10.9	12.21	13.62
-23	6.21	7.03	7.927	8.905	9.97	11.13
-18	5.117	5.793	6.531	7.338	8.215	9.168
-13	4.252	4.813	5.427	6.097	6.826	7.618
-8	3.56	4.03	4.544	5.105	5.716	6.379
-3	3.003	3.4	3.833	4.306	4.821	5.381
2	2.551	2.887	3.255	3.657	4.095	4.57
7	2.18	2.468	2.782	3.126	3.5	3.905

Table 3.Variation of Pressure ratio with evaporator varying temperature (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	16.17	18.29	20.62	23.16	25.92	28.91
-33	12.69	14.36	16.19	18.18	20.35	22.7
-28	10.09	11.42	12.87	14.46	16.18	18.05
-23	8.116	9.185	10.35	11.63	13.01	14.51
-18	6.597	7.466	8.416	9.452	10.58	11.8
-13	5.415	6.128	6.908	7.758	8.683	9.684
-8	4.484	5.074	5.72	6.424	7.189	8.019
-3	3.743	4.236	4.775	5.362	6.001	6.693
2	3.147	3.562	4.015	4.509	5.046	5.628
7	2.664	3.015	3.399	3.817	4.272	4.764

Table 4. Variation of Pressure ratio with evaporator varying temperature (R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	11.11	12.57	14.17	15.92	17.83	19.92
-33	8.955	10.13	11.42	12.83	14.37	16.05
-28	7.289	8.246	9.295	10.44	11.7	13.07
-23	5.989	6.774	7.637	8.581	9.612	10.74
-18	4.962	5.613	6.328	7.11	7.965	8.897
-13	4.145	4.689	5.285	5.939	6.653	7.431
-8	3.487	3.945	4.447	4.997	5.598	6.253
-3	2.955	3.342	3.768	4.234	4.743	5.297
2	2.519	2.85	3.213	3.61	4.044	4.517
7	2.161	2.444	2.756	3.096	3.468	3.874

Table 5. Variation of Pressure ratio with varying evaporator temperature (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	13.26	15.08	17.06	19.22	21.59	24.17
-33	10.28	11.7	13.23	14.91	16.75	18.75
-28	8.228	9.359	10.59	11.93	13.4	15
-23	6.665	7.581	8.575	9.665	10.85	12.15
-18	5.423	6.168	6.977	7.864	8.832	9.886
-13	4.485	5.102	5.771	6.504	7.305	8.177
-8	3.728	4.241	4.797	5.406	6.072	6.797
-3	3.123	3.552	4.018	4.529	5.086	5.694
2	2.634	2.996	3.389	3.819	4.289	4.801
7	2.238	2.546	2.88	3.246	3.645	4.081

Table 6. Variation of Volumetric Cooling Capacity with varying evaporator temperature (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	773.9	738.9	703.2	666.6	629	590.3
-33	968.2	925.1	881.1	836	789.7	742
-28	1200	1147	1093	1038	981.8	923.5
-23	1473	1409	1344	1278	1209	1139
-18	1794	1717	1639	1559	1477	1393
-13	2168	2077	1984	1888	1790	1689
-8	2601	2493	2383	2270	2154	2035
-3	3101	2974	2844	2711	2575	2434
2	3675	3526	3374	3218	3058	2893
7	4330	4156	3979	3798	3611	3419

Table 7. Variation of Volumetric Cooling Capacity with varying evaporator temperature (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	583	547.2	510.4	472.3	432.7	391
-33	748.5	703.5	657.3	609.6	559.9	507.6
-28	949.2	893.5	836.2	777	715.4	650.5
-23	1191	1122	1052	979.2	903.6	824
-18	1479	1395	1310	1221	1129	1033
-13	1819	1719	1616	1509	1398	1282
-8	2221	2101	1977	1850	1717	1577
-3	2691	2548	2401	2249	2091	1925
2	3238	3069	2896	2716	2530	2333
7	3874	3675	3471	3260	3041	2809

Table 8. Variation of Volumetric Cooling Capacity with varying evaporator temperature
(R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1154	1083	1009	930.7	846.2	752
-33	1439	1352	1261	1165	1061	945.1
-28	1778	1672	1561	1443	1317	1176
-23	2178	2049	1915	1773	1621	1450
-18	2647	2493	2332	2161	1978	1773
-13	3194	3010	2818	2615	2396	2152
-8	3828	3610	3383	3142	2882	2593
-3	4562	4305	4036	3752	3446	3104
2	5407	5105	4789	4455	4095	3694
7	6377	6023	5654	5263	4842	4373

Table 9. Variation of Volumetric Cooling Capacity with varying evaporator temperature
(R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	528.3	490.4	452.6	413.7	373.9	332.5
-33	693.1	645.1	597.1	547.7	497.1	444.6
-28	880.6	821.3	762.1	701.2	638.7	573.9
-23	1105	1033	960.4	886.1	809.8	730.7
-18	1382	1294	1206	1115	1023	926.4
-13	1699	1593	1488	1380	1268	1153
-8	2071	1945	1820	1691	1558	1421
-3	2529	2379	2230	2076	1918	1754
2	3062	2884	2707	2525	2339	2145
7	3660	3452	3245	3032	2813	2586

Table 10. Variation of Coefficient of performance with varying evaporator temperature

(R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.717	1.55	1.4	1.264	1.14	1.025
-33	1.928	1.734	1.561	1.406	1.265	1.136
-28	2.174	1.946	1.745	1.567	1.407	1.261
-23	2.464	2.193	1.958	1.752	1.568	1.402
-18	2.811	2.485	2.207	1.965	1.753	1.563
-13	3.231	2.833	2.5	2.214	1.966	1.747

-8	3.752	3.256	2.85	2.508	2.215	1.959
-3	4.411	3.78	3.274	2.858	2.508	2.207
2	5.274	4.444	3.8	3.284	2.858	2.499
7	6.449	5.313	4.468	3.811	3.284	2.848

Table 11. Variation of Coefficient of performance with varying evaporator temperature
(R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.436	1.285	1.147	1.018	0.8974	0.7822
-33	1.615	1.441	1.284	1.139	1.004	0.876
-28	1.82	1.62	1.44	1.276	1.124	0.9811
-23	2.059	1.826	1.619	1.432	1.26	1.099
-18	2.339	2.065	1.825	1.609	1.414	1.233
-13	2.673	2.347	2.064	1.815	1.591	1.385
-8	3.077	2.682	2.346	2.053	1.794	1.56
-3	3.575	3.088	2.682	2.335	2.032	1.761
2	4.204	3.589	3.089	2.671	2.312	1.996
7	5.022	4.223	3.593	3.079	2.647	2.273

Table 12. Variation of Coefficient of performance with varying evaporator temperature

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.606	1.425	1.26	1.108	0.9626	0.82
-33	1.806	1.597	1.409	1.236	1.072	0.9133
-28	2.04	1.796	1.579	1.381	1.197	1.018
-23	2.315	2.028	1.775	1.548	1.338	1.137
-18	2.645	2.301	2.004	1.74	1.5	1.272
-13	3.045	2.628	2.274	1.965	1.686	1.427
-8	3.54	3.025	2.597	2.23	1.904	1.605
-3	4.168	3.517	2.989	2.546	2.161	1.813
2	4.989	4.141	3.475	2.931	2.469	2.059
7	6.107	4.956	4.091	3.407	2.842	2.352

(R410A)

Table 13. Variation of Coefficient of performance with varying evaporator temperature (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.571	1.386	1.221	1.071	0.9309	0.7985
-33	1.799	1.583	1.395	1.221	1.064	0.9148
-28	2.048	1.8	1.582	1.383	1.205	1.039
-23	2.334	2.042	1.79	1.565	1.362	1.173
-18	2.691	2.341	2.049	1.786	1.552	1.336
-13	3.111	2.687	2.338	2.03	1.76	1.517
-8	3.638	3.112	2.682	2.324	2.006	1.726
-3	4.319	3.649	3.126	2.68	2.303	1.974
2	5.198	4.34	3.657	3.12	2.661	2.27
7	6.361	5.2	4.312	3.637	3.076	2.617

Table 14. Variation of Exergy destruction ratio with varying evaporator temperature

(R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.411	1.672	1.958	2.276	2.633	3.04
-33	1.398	1.668	1.963	2.29	2.656	3.072
-28	1.397	1.678	1.986	2.325	2.704	3.133
-23	1.408	1.705	2.03	2.387	2.784	3.232
-18	1.436	1.755	2.102	2.483	2.906	3.381
-13	1.487	1.836	2.214	2.629	3.087	3.6
-8	1.572	1.963	2.386	2.847	3.356	3.925
-3	1.712	2.165	2.653	3.185	3.77	4.421
2	1.951	2.502	3.095	3.739	4.445	5.228
7	2.401	3.129	3.91	4.755	5.679	6.702

Table 15. Variation of Exergy destruction ratio with varying evaporator temperature

(R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.883	2.222	2.611	3.067	3.614	4.294
-33	1.865	2.209	2.602	3.06	3.606	4.28
-28	1.863	2.217	2.619	3.084	3.636	4.312
-23	1.882	2.25	2.666	3.145	3.71	4.397
-18	1.926	2.315	2.752	3.254	3.842	4.552
-13	2.005	2.424	2.893	3.428	4.052	4.8
-8	2.135	2.597	3.113	3.699	4.377	5.187
-3	2.346	2.874	3.461	4.124	4.888	5.794
2	2.702	3.336	4.038	4.827	5.732	6.798
7	3.368	4.194	5.105	6.124	7.287	8.649

Table 16. Variation of Exergy destruction ratio with varying evaporator temperature

(R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.579	1.906	2.285	2.738	3.301	4.049
-33	1.561	1.896	2.283	2.744	3.313	4.064
-28	1.555	1.902	2.301	2.774	3.356	4.118
-23	1.563	1.926	2.343	2.834	3.436	4.219
-18	1.589	1.975	2.416	2.934	3.566	4.382
-13	1.639	2.057	2.533	3.09	3.765	4.632
-8	1.726	2.189	2.715	3.328	4.066	5.011

-3	1.87	2.401	3.002	3.699	4.535	5.597
2	2.12	2.759	3.479	4.311	5.305	6.559
7	2.592	3.426	4.362	5.439	6.719	8.325

Table 17. Variation of Exergy destruction ratio with varying evaporator temperature (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	1.636	1.988	2.391	2.864	3.448	4.186
-33	1.571	1.921	2.315	2.787	3.347	4.056
-28	1.545	1.896	2.294	2.768	3.326	4.015
-23	1.543	1.906	2.316	2.792	3.357	4.058
-18	1.544	1.924	2.342	2.834	3.412	4.125
-13	1.583	1.991	2.436	2.957	3.566	4.298
-8	1.652	2.1	2.598	3.152	3.809	4.591
-3	1.77	2.278	2.827	3.463	4.195	5.061
2	1.994	2.586	3.255	3.989	4.848	5.856
7	2.449	3.218	4.086	5.031	6.132	7.383

Table 18.Variation of Exergetic efficiency with varying evaporator temperature (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.4148	0.3743	0.3381	0.3052	0.2752	0.2475
-33	0.4169	0.3748	0.3375	0.3039	0.2735	0.2456
-28	0.4173	0.3734	0.3349	0.3007	0.27	0.242
-23	0.4153	0.3696	0.3301	0.2953	0.2643	0.2363
-18	0.4106	0.363	0.3224	0.2871	0.256	0.2283
-13	0.4022	0.3526	0.3111	0.2756	0.2447	0.2174
-8	0.3888	0.3375	0.2954	0.2599	0.2295	0.203
-3	0.3688	0.316	0.2737	0.2389	0.2096	0.1845
2	0.3389	0.2855	0.2442	0.211	0.1837	0.1606
7	0.294	0.2422	0.2037	0.1738	0.1497	0.1298

Table 19. Variation of Exergetic efficiency with varying evaporator temperature (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.3469	0.3104	0.2769	0.2459	0.2167	0.1889
-33	0.3491	0.3116	0.2776	0.2463	0.2171	0.1894
-28	0.3493	0.3109	0.2763	0.2449	0.2157	0.1883
-23	0.347	0.3077	0.2728	0.2413	0.2123	0.1853
-18	0.3417	0.3017	0.2665	0.2351	0.2065	0.1801
-13	0.3327	0.2921	0.2569	0.2258	0.198	0.1724

-8	0.319	0.278	0.2431	0.2128	0.186	0.1616
-3	0.2989	0.2581	0.2242	0.1952	0.1698	0.1472
2	0.2701	0.2306	0.1985	0.1716	0.1485	0.1282
7	0.2289	0.1925	0.1638	0.1404	0.1207	0.1036

Table 20. Variation of Exergetic efficiency with varying evaporator temperature (R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.3878	0.3442	0.3044	0.2675	0.2325	0.198
-33	0.3905	0.3453	0.3046	0.2671	0.2318	0.1975
-28	0.3914	0.3446	0.3029	0.265	0.2296	0.1954
-23	0.3902	0.3418	0.2991	0.2608	0.2254	0.1916
-18	0.3863	0.3362	0.2927	0.2542	0.219	0.1858
-13	0.3789	0.3271	0.283	0.2445	0.2099	0.1776
-8	0.3669	0.3136	0.2692	0.2311	0.1974	0.1664
-3	0.3484	0.294	0.2499	0.2128	0.1807	0.1516
2	0.3206	0.266	0.2232	0.1883	0.1586	0.1323
7	0.2784	0.226	0.1865	0.1553	0.1296	0.1072

Table 21. Variation of Exergetic efficiency with varying evaporator temperature (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.3793	0.3347	0.2949	0.2588	0.2248	0.1928
-33	0.389	0.3423	0.3016	0.2641	0.23	0.1978
-28	0.3929	0.3453	0.3036	0.2654	0.2312	0.1994
-23	0.3933	0.3441	0.3016	0.2637	0.2295	0.1977
-18	0.3931	0.342	0.2992	0.2608	0.2267	0.1951
-13	0.3872	0.3344	0.291	0.2527	0.219	0.1888
-8	0.3771	0.3226	0.278	0.2408	0.208	0.1789
-3	0.3611	0.305	0.2613	0.2241	0.1925	0.165
2	0.334	0.2789	0.235	0.1986	0.171	0.1459
7	0.29	0.2371	0.1966	0.1658	0.1402	0.1193

Table 22.Effect of varying evaporator temperature on efficiency defect in compressor (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2049	0.2008	0.1969	0.1933	0.1898	0.1864

-33	0.2082	0.204	0.2	0.1962	0.1926	0.1892
-28	0.2114	0.207	0.2029	0.199	0.1953	0.1918
-23	0.2144	0.2099	0.2057	0.2017	0.1978	0.1942
-18	0.2173	0.2127	0.2083	0.2042	0.2003	0.1965
-13	0.22	0.2153	0.2108	0.2066	0.2026	0.1988
-8	0.2227	0.2178	0.2132	0.2089	0.2048	0.2009
-3	0.2252	0.2202	0.2156	0.2111	0.2069	0.2029
2	0.2276	0.2226	0.2178	0.2132	0.2089	0.2048
7	0.23	0.2248	0.2199	0.2153	0.2109	0.2067

Table 23. Effect of varying evaporator temperature on efficiency defect in compressor (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2107	0.207	0.2035	0.2001	0.1969	0.1938
-33	0.2132	0.2094	0.2058	0.2023	0.199	0.1958
-28	0.2155	0.2117	0.2079	0.2044	0.201	0.1977
-23	0.2177	0.2137	0.2099	0.2063	0.2028	0.1994
-18	0.2197	0.2156	0.2117	0.208	0.2044	0.201
-13	0.2216	0.2174	0.2134	0.2096	0.206	0.2025
-8	0.2233	0.2191	0.215	0.2111	0.2074	0.2039
-3	0.2249	0.2206	0.2165	0.2126	0.2088	0.2051
2	0.2265	0.2221	0.2179	0.2139	0.21	0.2063
7	0.228	0.2235	0.2193	0.2152	0.2113	0.2075

Table 24. Effect of varying evaporator temperature on efficiency defect in compressor (R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2093	0.2052	0.2013	0.1976	0.194	0.1906
-33	0.2123	0.2081	0.204	0.2002	0.1965	0.193
-28	0.2151	0.2108	0.2066	0.2027	0.1989	0.1953
-23	0.2178	0.2133	0.2091	0.2051	0.2012	0.1975
-18	0.2203	0.2157	0.2114	0.2073	0.2033	0.1996
-13	0.2227	0.2181	0.2136	0.2094	0.2054	0.2015
-8	0.225	0.2203	0.2157	0.2114	0.2073	0.2034
-3	0.2272	0.2224	0.2177	0.2133	0.2091	0.2051
2	0.2293	0.2244	0.2197	0.2152	0.2109	0.2068
7	0.2313	0.2263	0.2215	0.2169	0.2126	0.2084

Table 25. Effect of varying evaporator temperature on efficiency defect in compressor (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2267	0.2249	0.2212	0.2178	0.2146	0.211
-33	0.2286	0.226	0.2223	0.2194	0.2158	0.2118

-28	0.2307	0.2267	0.2231	0.2204	0.2165	0.2125
-23	0.2315	0.2276	0.2247	0.2211	0.2173	0.2148
-18	0.2325	0.2287	0.2254	0.2219	0.2178	0.215
-13	0.2336	0.23	0.2263	0.2224	0.219	0.2159
-8	0.235	0.2308	0.2273	0.2229	0.2198	0.2163
-3	0.2358	0.2309	0.2278	0.2236	0.2208	0.2169
2	0.2368	0.231	0.2284	0.2236	0.2212	0.2176
7	0.2379	0.2311	0.2291	0.2236	0.2218	0.2178

Table 26. Effect of varying evaporator temperature on efficiency defect in condenser (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.1517	0.1864	0.2158	0.2407	0.2616	0.2792
-33	0.1525	0.1894	0.2203	0.2462	0.2679	0.2859
-28	0.1548	0.1941	0.2267	0.2537	0.276	0.2943
-23	0.1589	0.2009	0.2352	0.2633	0.2862	0.3048
-18	0.1652	0.2101	0.2463	0.2754	0.2989	0.3176
-13	0.1742	0.2223	0.2604	0.2905	0.3144	0.3332
-8	0.1866	0.2383	0.2783	0.3093	0.3334	0.3519
-3	0.2039	0.2594	0.3012	0.3328	0.3567	0.3746
2	0.2279	0.2874	0.3306	0.3622	0.3854	0.4021
7	0.2622	0.3254	0.369	0.3997	0.4212	0.4357

Table 27. Effect of varying evaporator temperature on efficiency defect in condenser (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.1287	0.159	0.1844	0.2055	0.2229	0.2367
-33	0.1303	0.1625	0.1892	0.2112	0.2291	0.2432
-28	0.1333	0.1675	0.1956	0.2185	0.237	0.2512
-23	0.1377	0.1741	0.2038	0.2277	0.2466	0.261
-18	0.1438	0.1828	0.214	0.2388	0.2582	0.2727
-13	0.152	0.1937	0.2266	0.2524	0.2721	0.2866
-8	0.1627	0.2075	0.2421	0.2688	0.2888	0.3031
-3	0.1767	0.2249	0.2613	0.2887	0.3088	0.3226
2	0.1952	0.247	0.2851	0.313	0.3328	0.3458
7	0.22	0.2757	0.3152	0.3431	0.362	0.3737

Table 28. Effect of varying evaporator temperature on efficiency defect in condenser (R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.1455	0.1782	0.2052	0.2272	0.2447	0.2576
-33	0.1466	0.1813	0.2096	0.2324	0.2502	0.2631
-28	0.1491	0.186	0.2156	0.2392	0.2573	0.2701

-23	0.1533	0.1925	0.2237	0.248	0.2663	0.2788
-18	0.1595	0.2014	0.234	0.259	0.2774	0.2895
-13	0.1682	0.213	0.2471	0.2727	0.291	0.3025
-8	0.1802	0.2281	0.2638	0.2898	0.3077	0.3182
-3	0.1968	0.248	0.2849	0.311	0.3281	0.3372
2	0.2197	0.2744	0.3121	0.3376	0.3533	0.3603
7	0.2523	0.31	0.3476	0.3714	0.3845	0.3885

Table 29. Effect of varying evaporator temperature on efficiency defect in condenser (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.1023	0.1307	0.1569	0.177	0.1926	0.2046
-33	0.1076	0.1391	0.1658	0.1876	0.2031	0.2159
-28	0.114	0.1478	0.1761	0.199	0.2154	0.2272
-23	0.1228	0.1589	0.1883	0.2118	0.2285	0.24
-18	0.134	0.1728	0.2028	0.2273	0.2449	0.2566
-13	0.1465	0.1882	0.2205	0.2463	0.2633	0.2739
-8	0.1616	0.2073	0.243	0.2685	0.2852	0.2956
-3	0.1833	0.2333	0.2686	0.2963	0.3122	0.3219
2	0.2129	0.2648	0.3032	0.3295	0.344	0.3519
7	0.2508	0.3066	0.3448	0.3707	0.3824	0.3867

Table 30. Effect of varying evaporator temperature on efficiency defect in throttle valve (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.1834	0.1976	0.2123	0.2275	0.2433	0.2598
-33	0.1736	0.1879	0.2027	0.218	0.234	0.2506
-28	0.1637	0.1782	0.1931	0.2085	0.2245	0.2413
-23	0.1538	0.1683	0.1833	0.1988	0.215	0.2319
-18	0.1438	0.1584	0.1735	0.1891	0.2054	0.2225
-13	0.1338	0.1485	0.1636	0.1794	0.1958	0.2129
-8	0.1237	0.1385	0.1538	0.1696	0.1861	0.2034
-3	0.1137	0.1285	0.1439	0.1598	0.1764	0.1938
2	0.1036	0.1185	0.1339	0.15	0.1667	0.1842
7	0.09349	0.1085	0.124	0.1401	0.157	0.1746

Table 31. Effect of varying evaporator temperature on efficiency defect in throttle valve (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2611	0.2793	0.2981	0.3178	0.3386	0.3608
-33	0.2502	0.2684	0.2874	0.3071	0.328	0.3504
-28	0.2395	0.2577	0.2767	0.2965	0.3175	0.3399
-23	0.229	0.2472	0.2662	0.2861	0.3071	0.3296

-18	0.2187	0.237	0.256	0.2759	0.2969	0.3195
-13	0.2089	0.2271	0.2461	0.266	0.287	0.3096
-8	0.1993	0.2176	0.2365	0.2564	0.2774	0.3001
-3	0.1902	0.2084	0.2274	0.2472	0.2682	0.2908
2	0.1815	0.1997	0.2186	0.2384	0.2594	0.282
7	0.1734	0.1915	0.2103	0.2301	0.251	0.2736

Table 32. Effect of varying evaporator temperature on efficiency defect in throttle valve (R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2149	0.2348	0.2558	0.2784	0.3035	0.3322
-33	0.2049	0.2249	0.2461	0.269	0.2943	0.3234
-28	0.1947	0.2149	0.2364	0.2595	0.2851	0.3145
-23	0.1845	0.2049	0.2266	0.25	0.2759	0.3056
-18	0.1743	0.1949	0.2168	0.2405	0.2666	0.2966
-13	0.1641	0.1849	0.207	0.2309	0.2573	0.2877
-8	0.1538	0.1749	0.1972	0.2214	0.2481	0.2788
-3	0.1436	0.1648	0.1874	0.2118	0.2388	0.2699
2	0.1333	0.1548	0.1776	0.2023	0.2296	0.261
7	0.1231	0.1448	0.1679	0.1928	0.2205	0.2523

Table 33. Effect of varying evaporator temperature on efficiency defect in throttle valve (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.2585	0.281	0.3023	0.3253	0.3502	0.3768
-33	0.2415	0.2639	0.2857	0.3084	0.3336	0.36
-28	0.2258	0.2489	0.2706	0.2929	0.3179	0.3452
-23	0.2102	0.2333	0.2547	0.277	0.3025	0.329
-18	0.1943	0.2173	0.2391	0.2617	0.2868	0.3135
-13	0.1798	0.2024	0.2243	0.2465	0.2725	0.2987
-8	0.1649	0.1877	0.2082	0.2312	0.2557	0.283
-3	0.1494	0.1734	0.1944	0.2159	0.2408	0.2685
2	0.1351	0.159	0.1789	0.201	0.226	0.2534
7	0.119	0.1441	0.1633	0.185	0.2101	0.2386

Table 34. Effect of varying evaporator temperature on efficiency defect in evaporator (R22)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.04527	0.04085	0.03689	0.03331	0.03004	0.02701
-33	0.04879	0.04386	0.03949	0.03557	0.03201	0.02874
-28	0.05285	0.04729	0.04242	0.03809	0.03419	0.03064
-23	0.05757	0.05124	0.04575	0.04093	0.03663	0.03275

-18	0.06316	0.05584	0.04959	0.04416	0.03938	0.03511
-13	0.06988	0.06127	0.05406	0.04789	0.04252	0.03777
-8	0.07813	0.06782	0.05935	0.05223	0.04612	0.0408
-3	0.08853	0.07586	0.06571	0.05736	0.05033	0.04428
2	0.102	0.08598	0.07353	0.06354	0.0553	0.04835
7	0.1204	0.09915	0.08338	0.07113	0.06129	0.05315

Table 35. Effect of varying evaporator temperature on efficiency defect in evaporator (R407C)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.05265	0.04437	0.03708	0.03063	0.0249	0.01978
-33	0.0572	0.04805	0.04006	0.03302	0.0268	0.02126
-28	0.06247	0.05227	0.04342	0.03569	0.0289	0.02288
-23	0.06865	0.05716	0.04728	0.03872	0.03124	0.02466
-18	0.07599	0.06289	0.05174	0.04217	0.03388	0.02664
-13	0.08484	0.06968	0.05696	0.04615	0.03688	0.02885
-8	0.09568	0.07788	0.06316	0.05082	0.04034	0.03135
-3	0.1092	0.08794	0.07065	0.05636	0.04439	0.03423
2	0.1267	0.1006	0.07985	0.06306	0.0492	0.03758
7	0.1497	0.1168	0.09142	0.07131	0.05501	0.04157

Table 36. Effect of varying evaporator temperature on efficiency defect in evaporator (R410A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.04248	0.03767	0.03329	0.02924	0.02538	0.0216
-33	0.04584	0.04051	0.0357	0.03128	0.02712	0.02307
-28	0.04972	0.04374	0.03841	0.03356	0.02905	0.02469
-23	0.05425	0.04746	0.0415	0.03614	0.0312	0.02648
-18	0.05961	0.05181	0.04506	0.03907	0.03362	0.02847
-13	0.06607	0.05696	0.04921	0.04245	0.03637	0.03071
-8	0.07402	0.06316	0.05413	0.04639	0.03954	0.03326
-3	0.08405	0.0708	0.06005	0.05105	0.04324	0.03619
2	0.09712	0.08043	0.06734	0.05666	0.04761	0.0396
7	0.1148	0.09297	0.07654	0.06357	0.05287	0.04362

Table 37. Effect of varying evaporator temperature on efficiency defect in evaporator (R417A)

Te (°C)	Tc=35°C	Tc=40°C	Tc=45°C	Tc=50°C	Tc=55°C	Tc=60°C
-38	0.0332	0.02871	0.02469	0.02122	0.01776	0.01477
-33	0.03341	0.02874	0.02466	0.02059	0.01741	0.01457
-28	0.03654	0.03124	0.02658	0.02237	0.01909	0.01568
-23	0.0422	0.03607	0.03074	0.02649	0.02214	0.01853
-18	0.04615	0.03926	0.03347	0.02817	0.02387	0.01975

-13	0.05291	0.04509	0.03798	0.03211	0.02616	0.02274
-8	0.06144	0.05166	0.04363	0.03658	0.03134	0.02624
-3	0.07038	0.05733	0.04789	0.04015	0.03383	0.0277
2	0.0812	0.06636	0.05456	0.04541	0.03781	0.03122
7	0.1023	0.08119	0.06618	0.05482	0.04549	0.03757

References

1. Bejan A., Entropy Generation Through Heat and Fluid Flow, Willey,New York, 1982.
2. Bejan, A., Tsatsaonis, G., Moran, M., Thermal design and optimisation, John Wiley and Sons Inc. (1996), pp. 143-156.Bejan A. Advanced Engineering Thermodynamics, Wiley, New York,1988.
3. Aphornratana, S., Eames, I.W. Thermodynamic analysis of absorption refrigeration cycles using the second law of thermodynamics method, *International journal of refrigeration* (1995), vol. 18, No. 4, pp. 244-252.
4. Aprea C., Renno C. Experimental comparison of R22 with R417A performance in a vapour compression refrigeration plant subjected to a cold store *Energy Conversion and Management 45 (2004) pp.1807–1819*
5. C. Aprea, A. Greco An exergetic analysis of R22 substitution Applied Thermal Engineering 22 (2002) 1455–1469 1467
6. Dincer, I, and Cengel, Y.A. (2001) Energy, entropy and exergy concepts and their roles in thermal engineering, Entropy, Vol 3, pp 116-149.

7. Devotta, S, Waghamare, A.V. Sawant, N. N. and Domkundwar, B.M. (2001) Alternatives to HCFC-22 for air-conditioners, Appl. Thermal Eng., Vol. 21 pp 703-715.

8. Engler T, Mobner F, Oellrich LR. Experimental results and theoretical investigations with alternative refrigerants.In: Proc 19th Int Cong of Refrig, vol. IVb, The Hague, The Netherlands, 20–25 August 1995.

9. Erol Arcaklioglu a, Abdullah C¸ Ali Eris_en Thermodynamic analysis of refrigerant mixtures for possible replacements for CFCs by an algorithm compiling property data *Applied thermal engineering pp 430 to438(2005)*

10. Gallagher J, McLinden M et. al. (1993) *Refprop Version 4*, *Chemical Science and Technology Laboratory, NIST, Gaitherburg , MD 20899*

11. Houghton J. Global warming: the underlying science and the possible response. In: Proc 19th Int Cong of Refrig,vol. IVb, The Hague, The Netherlands, 20–25 August 1995.

12. K.J. Wark, Advanced Thermodynamics for Engineers, McGraw-Hill,New York, 1995.

13. Kotas T.J. *The Exergy Method Of Thermal Plant Analysis (1985) pp. 72 to73*.

14. Klein S.A. and Alvarado F.L. (2002) Engineering Equation Solver academic version 6.548 N.

15. Lee, S.F., Sherif, S.A. Second law analysis of various double effect Lithium Bromide / Water absorption chillers, ASHRAE transactions (2001) AT-01-9-5, pp. 664-673

16. M.J. Moran, Availability Analysis: A Guide to Efficient Energy Use,Prentice-Hall, Englewood Cliffs, NJ, 1982.

17. M. Kanoglu, Exergy analysis of the multistage cascade refrigeration cycle used for natural gas liquefaction, Internat. J. Energy Res. (2002),

18. M.A.Khalid, Comparision of performance analysis of R22 and its alternates *11th HVACR cofrence Krachi. April 2006*

19. Said S.A. and Ismail B. Exergetic assessment of the coolants HCFC123, HFC134a, CFC11 and CFC12. *Energy* (1994), Vol. 19, No.11, pp 1181 to 1186,

20. Y. Çerçi, Y.A. Çengel, B. Wood, The minimum work requirement for distillation processes, in: Twelfth International Symposium on Transport Phenomena (ISTP-12), Istanbul Turkey, July 16–20, 2000.

21.Zhang Chuan *,Ma Shanwei,Chen Jiangpin,Chen Zhijiu (2005) Experimental analysis of R22 and R407c flow through electronic expansion valve Energy Conservation and Management ARTICLE IN PRESS

21. www. refrigeration engineers.com

Annexure-1

Energy and Exergy Analysis Programme in Engineering Equation Solver

(Klein S.A. and Alvardo F.L. (2002) academic version 6.548N.)

Parameter (Fixed)

Mass flow of refrigerant = 1kg./ second
Room temperature = 5°C higher than evaporator temperature
Environment temperature = 25°C
Isentropic efficiency (Compressor) = 75%

Parameter (Variable)

Evaporator temperature (Te) = -38 °C to 7°C

Condenser temperature (Tc) = 35°C to 60°C

Calculations

Evaporator pressure (Pe)

Pe=PRESSURE(R$,T=Te,x=1)

where R$ =Refrigerant (R22, R407C, R410A and R417A*)

x=dryness fraction

(* Thermodynamic property of R-417A is calculated from REFPROP. version 4.0)

Condenser pressure

Pc=PRESSURE(R$,T=Tc,x=0)

Pressure ratio (R)

R=Pc/Pe

Specific volume (vg)at inlet to compressor

vg=VOLUME(R$,x=1,P=PE)

Voluetric cooling capacity (CC_VOL)

CC_vol=Qe/(mr*vg)

Enthalpy (h)

Compressor inlet

h1=ENTHALPY(R$,X=1,P=Pe)

Compressor outlet

h2s=ENTHALPY(R$,P=Pc,s=s2s)

Condenser outlet

h3=ENTHALPY(R$,P=Pc,x=0)

h4=h3

h2 = (h2s – h1)/isen._eff. + h1

Entropy

s1=ENTROPY(R$,X=1,P=Pe)
s1=s2s
s2=ENTROPY(R$,h=h2,P=Pc)
s3=ENTROPY(R$,x=0,P=Pc)
s4=ENTROPY(R$,x=X4,P=Pe)

Compressor work (wc)
wc=mr*(h2-h1)

Refrigerating effect

Qe=mr*(h1-h4)

Coefficient of performance (COP)

COP =(Qe/wc)

Irreversibility

Compressor (icomp.)

Icomp. =(wc+mr*((h1-t0*s1)-(h2-t0*s2)))

Condenser (i cond.)

icond=(mr*(h2-T0*s2)-mr*(h3-T0*s3))

Throttle valve
it=(mr*((h3-T0*s3)-(h4-T0*s4)))

Evaporator
ie=(mr*(h4-T0*s4)-mr*(h1-T0*s1)+Qe*(1-T0/(Tr+273.15)))

Total Irreversibility (ED_Total)

Ed_Total=(ic+icond+it+ie)

Exergy of the product (EP)

EP=-Qe*(1-T0/(Tr+273.15))

Exergy destruction ratio (EDR)

EDR=Ed_Total/(EP)

Efficiency defect (eff._decect)

Compressor
eff._defect_comp=icomp./(wc)

Condenser
eff._defect _cond=icond/(wc)

Throttle valve
Eff._defec_tthrott=it/(wc)

Evaporator
eff._defecte_vapo=ie/(wc)

Exergetic efficiency

exergetic efficiency =1-(eff._defect_comp. +eff._defect_cond ++eff._defec_tthrott
eff._defect_evapo.)