Performance Evaluation of Multi Evaporator Vapour Compression Refrigeration System with Liquid-Vapour Heat Exchanger and Flash Chamber Using Alternative Pure Refrigerants

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CANDIDATE’S DECLARATION

I hereby declare that the work which being presented in the major thesis entitled “**Performance Evaluation of Multi Evaporator Vapour Compression Refrigeration System with Liquid-Vapour Heat Exchanger and Flash Chamber Using Alternative Pure Refrigerants**” in the partial fulfilment for the award of the degree of Master of Technology in “THERMAL ENGINEERING” submitted to Delhi Technological University (Formerly Delhi College of Engineering), is an authentic record of my own work carried out under the supervision of Dr. Akhilesh Arora, Department of Mechanical Engineering, Delhi Technological University (Formerly Delhi College of Engineering). I have not submitted the matter of this dissertation for the award of any other Degree or Diploma or any other purpose what so ever. I confirm that I have read and understood ‘Plagiarism policy of DTU’. I have not committed plagiarism when completing the attached piece of work, similarity found after checking is 15% which is below the permitted limit of 20%.

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ABSTRACT

Parametric investigation of energy and exergy analysis of multi-evaporators at different temperatures with individual expansion valve and individual compressor using flash chamber and liquid vapour heat exchanger is carried out for R134A, R142B, R152A, R600 and R1234YF as alternative refrigerants. In engineering equation solver, a computational model is developed for these systems, simple multi-evaporator system and improved one system. The present investigation has been done for evaporator-I in the range -12^{0}C to -20^{0}C, evaporator-II in the range 1^{0}C to 4^{0}C and condenser in the range 35^{0}C to 55^{0}C. Performance parameters like exergetic efficiency, the coefficient of performance and exergy destruction ratio are calculated over these ranges and compared for these refrigerants.

The performance comparison of the simple multi-evaporator system and improved system for dairy plant application, COP improves by 16.99%, 15.97%, 15.88%, 16.24% and 18.41% for refrigerants R134A, R142B, R152A, R600 and R1234YF respectively in multi-evaporator system with flash chamber and LVHE. Exergy efficiency improves by 16.98%, 15.97%, 15.87%, 16.22% and 18.36% for refrigerants R134A, R142B, R152A, R600 and R1234YF respectively in multi-evaporator system with flash chamber and LVHE. Due to additional components in basic system, flash chamber and LVHE, exergy destruction in multi-evaporator system increases. EDR % increases by 20.37%, 16.84%, 14.74%, 18.66% and 24.92% for refrigerants R134A, R142B, R152A, R600 and R1234YF respectively in multi-evaporator system with flash chamber and LVHE. The corresponding values of input energy consumed for expansion valve, evaporator and compressor are varied between 7% to 18%, 11% to 22% and 18 % to 24 % respectively.

From the point of enery-exergy analysis, R142B is best among all five selected refrigerants as total exergy destruction of all components is always less for R142B than that of all others and R142B refrigerant has higher COP and Exergetic efficiency in this modified system. Also, R142B has least EDR in this analysis. Though R142B have highest COP and exergetic efficiency among all refrigerants, it is not recommended due to its GWP 2400, which is highest among all. Second best refrigerant R600 has only GWP 3. Hence it is recommended over R142B in dairy plant application.

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NOMENCLATURE

COP	Coefficient of performance (non dimensional)
h	Specific Enthalpy (kJ/kg)
s	Specific Entropy (kJ/kgK)
m	Mass flow rate (kg/s)
P	Pressure (kPa)
T	Temperature (^{0}C)
Q	Heat Exchange per unit mass (kW)
W	Specific Work (kJ/kg)
η	Isentropic Efficiency (non dimensional)
RC	Refrigeration capacity (TR)
ED	Exergy Destruction (kJ/kg)
EDR	Exergy Destruction Ratio
EP	Exergy of Product (kJ/kg)
η_{ex}	Exergetic Efficiency (non dimensional)

Subscript/Superscript

C	Condenser
E1	Evaporator-I
E2	Evaporator-II
C1	Compressor-I
C2	Compressor-II
cond	Condenser
t1	Expansion Valve-I
t2	Expansion Valve-II
flash	Flash Chamber
LVHE	Liquid Vapour Heat Exchanger

CHAPTER 1

INTRODUCTION

The method of producing cold by mechanical process is quite recent. Process of removing heat from a substance under controlled conditions is known as refrigeration. The peace of development was slow in beginning when steam engines were the only prime movers known to run the compressors. Refrigeration means the process of reducing and maintaining the temperature of the body below the general temperature of the surroundings, which also defined as a continued extraction of a heat from a body whose temperature, is already below of the surroundings.

The reversed carnot cycle with vapour as a refrigerant can be used as a practical cycle with minor modifications, cycle with modification is known as vapour compression cycle. In VCRS, the suitable working substance known as a refrigerant is used. Refrigerant condenses and evaporates at pressure and temperature close to the atmospheric condition. The refrigerant used in vcrs, is circulated through the system alternatively first it passes through condensing unit, and then the evaporating unit. Refrigerant does not leave the system. In the condensing process, refrigerant gives out its latent heat to the surrounding. In the evaporating process, it absorbs the latent heat from the region to be condensed. The refrigerants which are used for vcrs are ammonia, sulphur dioxide and carbon dioxide.

But, sometimes for low refrigeration systems, the vapour refrigerants required to deliver at a very high pressure. In such situations either, compress refrigerant in two or more compressors in series or we should compress it by employing single stage compressor with a very high-pressure ratio among condenser and evaporator. The compression which is carried out in two or more compressor is known as “Multistage Compression”

In event of single evaporator system, the entire load is contain by the single evaporator at one temperature. But, in different applications or refrigeration installations, different temperatures are required to be maintained at different points, such as restaurants, food, hotels, mart and industrial plants where food products are accept in large quantities and they want to maintain at distinct temperatures for safety. For instance, vegetables, cut meats, chilly products, stock goods, fruits, bottles goods, dairy products have all distinct conditions of humidity and temperature for storing. In such applications, each place is cooled by its own evaporator so that we can keep more sufficient check of the conditions. Such refrigeration system, which hold two or more evaporators are for refrigeration is understood as “Multiple Evaporator System”. Different Types of multiple compressor and evaporator systems are important from the point of evaluating Multiple Evaporator System, they are,

1. Multiple evaporators at the same temperature with individual expansion valve and compressor.
2. Multiple evaporators at distinct temperatures with, single expansion valves, back pressure valves and single compressor.
3. Multiple evaporators at distinct temperatures with (more than one) multiple expansion valves, back pressure valves and single compressor.
4. Multiple evaporators at distinct temperatures with single expansion valves and individual compressors.

5. Multiple evaporators at distinct temperatures with multiple expansion valves and individual compressors.
6. Multiple evaporators at distinct temperatures with single expansion valves and compound compressions.
7. Multiple evaporators at distinct temperatures with single expansion valves, flash intercoolers and compound compressions.
8. Multiple evaporators at distinct temperatures with, single expansion valves, flash intercoolers and compound compressions.

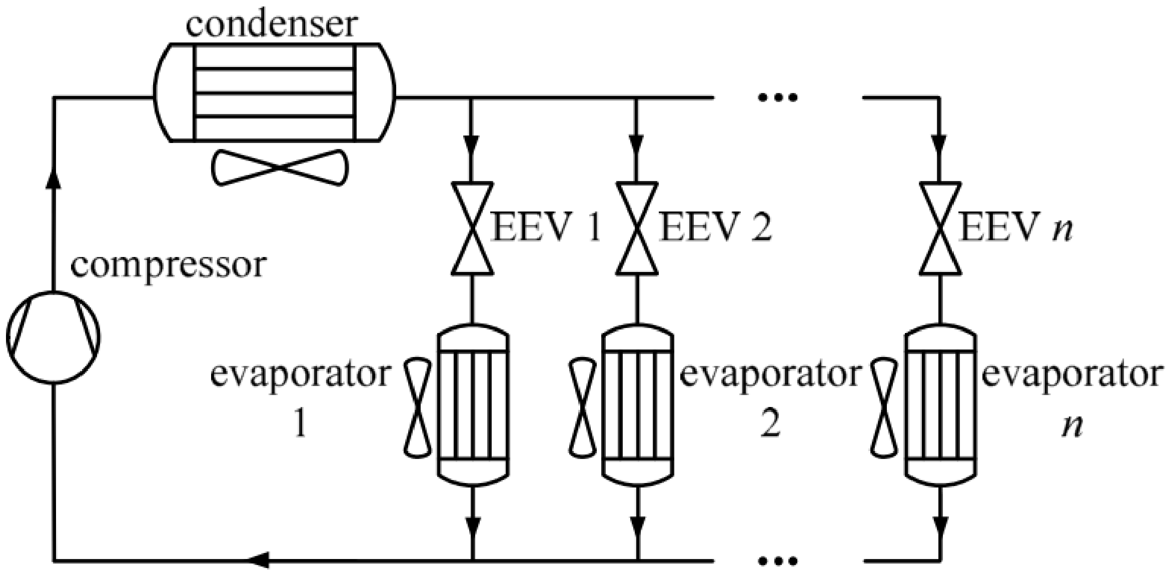

Figure 1 : Multiple evaporators at different temperatures with individual expansion valves and single compressor

In this system, each load requires a different temperature. Therefore, whole system operated at various suction pressures with individual compressors for each evaporator or at a suction pressure equal to the lowest evaporator pressure leading to single compressor system, leading to a multi-compressor system.

If we consider dairy plant refrigeration, there are two main products which needed to preserve, milk and ice-cream. According to US standards for milk plant, the temperature of milk for preservation should not be more than 40 F (4.44^{0}C) and temperature of ice-cream for preservation should not more than 10 F (-12^{0}C), otherwise colour, taste, quality and flavour will decrease.

Refrigeration is a basic requirement for the processing and storage of milk and milk products as a majority of dairy products are perishable in nature. The need of refrigeration is indicated below.

1. Chilling of milk at producers' level by employing bulk milk coolers and at milk chilling centres is the first requirement in the dairy industry. Immediate cooling of milk to about
2. 2-3 ºC is very important to reduce the multiplications of micro-organisms and to get the low bacterial count in the milk and milk products.
3. Processing of milk using either batch pasteurizer or HTST plant requires chilled water or any other cooling medium for cooling of milk.
4. Manufacture of many products requires refrigeration. e.g. butter, ice-cream etc.
5. Storage of milk and milk products requires maintaining a low temperature in the cold storages depending on the type of product to be stored. e.g. milk is stored at around 3-4 ºC while ice-cream is stored at -30 ºC temperature.
6. Transportation of many products requires refrigerated vehicles to maintain the quality of products.
7. Low-temperature storage is required at a distribution of products as well as at the consumers' level.

A refrigeration system is an essential and integrant part of Dairy Industry. And hence, temperature conditions may be need at 20^0C for chilling milk and at $–30^0$C for making ice cream in a dairy plant. In such action, we can go for a multi-evaporator system with the high-temperature evaporator operant at 10^0C and low-temperature evaporator in operation at-20^0C. To affirm the quality of products while transporting from one position to another, milk product carrying van also need multiple evaporation refrigeration systems.

The earth's ozone layer in the higher atmosphere takes up the injurious ultraviolet rays from the sun. In 1985, the world was socked after finding out a gaping cave above Antarctic in the ozone layer which was preserve earth from ultraviolet rays. Depletion of this ozone layer is linked to CFCs. CFCs have been varying the degree of ozone depletion potential. They also act as greenhouse gases. Therefore, they have world-wide warming potential as well.

According to an international contract, the generally used refrigerants R12, R12, R113, R114 and R502, that are examine to have high ODP, fully halogenated CFCS, have been phased out from the year 2000 AD. HCFCs have much lower ODP and have some GWP. HCFCs have to phase out by the year 2030. But until 2030, HCFCs can be utility. R22 is an HCFC and its ODP is only 5 % of that ODP is only 5 % of that of R12. R22 will be phased out by 2030. Even with the measures taken so far, a 2.7 million square kilometre ozone layer hole was detected, as late as 2008.

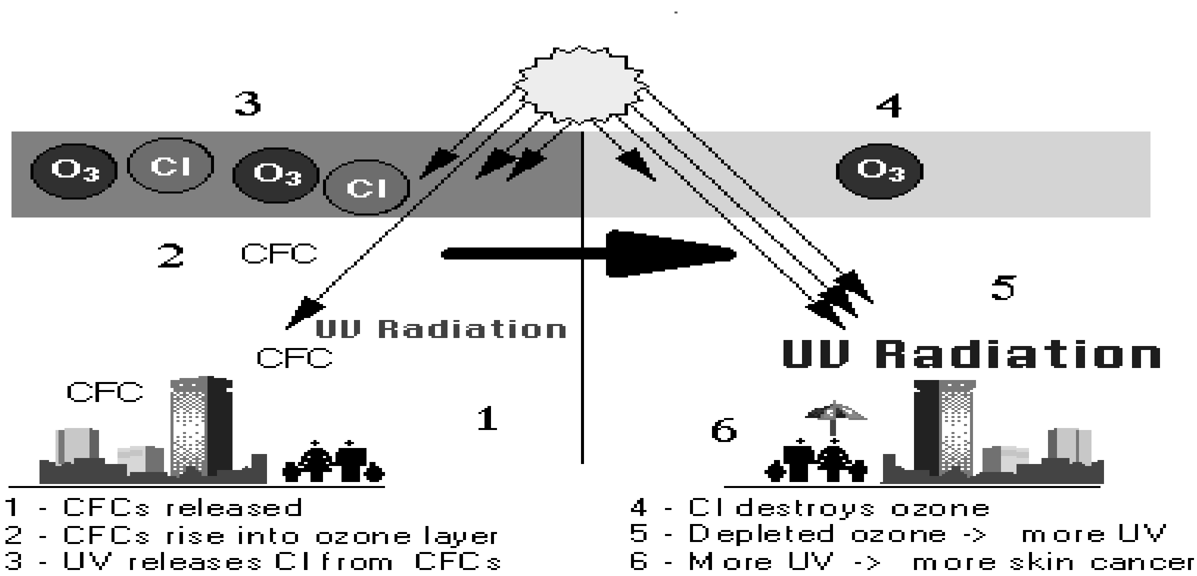

Figure 2 : Ozone Depletion Process

In 1974, two researchers contain a radio chemist postulated that CFCs have a extended life in lower atmosphere since they are so constant. Though CFCs being heavier than N2 and O2, these moderately migrate into the higher atmosphere by molecular diffusion.. It was hypothesised that by act of sunshine, the chlorine atoms which came from molecule would be burst off and the liberated chlorine will react with ozone in the ambiance. Hence, O3 will be depleted to O2. The principal question with CFCs is that the chain reaction. A individual atom of Cl released from CFC is reacted with almost 1,00,000 molecules of O3. Therefore, the even short concentration of CFC also gets essential.

Nowadays, we should examine for refrigerants which will not reason global warming question. CFC duplicate fall into four categories basically: those supported on HFCs, N2 and HCFCs, inert gases and HCs. Hydro fluorocarbons and Hydrocarbons afford an alternate to completely halogenated CFC refrigerants.

Also, HCFCs have a level of ODP in augmentation to GWP. Therefore, these also have to be phased out in the end. Till then, they can be usage as transitional refrigerants. R142b has GWP 0.52 and ODP 0.043 which can be a good alternative to now utility refrigerant in the multi-evaporator refrigerant system. R134a has zero ODP and R152a has zero GWP, so they can be examine as alterative which will shorten the environmental jeopardy.

SCOPE OF PRESESNT THESIS

In present composition, utility of alternate refrigerants in multi-evaporator vapour compression refrigeration system with the flash chamber and liquid vapour heat exchanger is comprised out. For dairy plant application in general use, the multi-evaporator system with evaporator-I temperature -12^{0}C with capacity 2 TR and evaporator-II temperature 4^{0}C with the capacity 10 TR is assumed.

CHAPTER 2

LITERATURE REVIEW

In this chapter, it is intended to give a brief literature review of work being carried out on multi-evaporator refrigeration system during last decade.

2.1 LITERATURE

Mishra [1] has carried out detailed energy and exergy analysis of multi-evaporator refrigeration system using liquid vapour heat exchanger. Performance analysis is carried out by using refrigerants R507A, R152A, R125, R404A, R134A, R707, R290, R407C, R600, R410A, R600A, R1234YF and R1234ZE. Numerical computation has been done for both systems, with and without liquid vapour heat exchanger. It was concluded that the first law and second law efficiency is improved by 20% by using liquid vapour heat exchanger. Among all these thirteen refrigerants, R134A is recommended for practical and commercial applications.

Arora and Kaushik [2] carried out energy and exergy analysis on the vapour compression refrigeration system with liquid vapour heat exchanger. A computational model has been setup to analysis its performance in the specific temperature range of evaporator and condenser. This investigation proves that R502 is better refrigerant than R404A and R507A. Exergy transfer is better in liquid vapour heat exchanger than that of the condenser.

Reddy et al [3] did numerically and graphical investigation on vapour compression refrigeration system using R507A, R134A, R502, R143A, and R410A.COP and exergetic efficiency largely affected by evaporator and condenser temperature. Among all these refrigerants R134A has better performance while that of R407C has least.

Ahamed et al. [4] carried out exergy analysis of domestic refrigeration among all the components considered in the system; compressors have highest system defects (69%).

Kumar et al. [5] did detail comparison of performance between R290/R600A mixture and R134A on the domestic refrigerator. R290/R600A mixture is used as a drop in replacement. In this study, it is found that COP and exergetic efficiency of R290/R600A mixture are higher than that of R134A. Also found that highest irreversibility in the compressor.

Yumrutas et al. [6] have performed exergy analysis of vapour compression refrigeration system of the effect of condensing and evaporating temperature in terms of exergy losses, pressure losses, second law efficiency and COP. With the increase in the evaporator and condenser temperature, total exergy losses of the system decrease but first law efficiency and exergy efficiency increases. Change in the temperature of condenser has a very negligible effect on exergy losses of expansion valve as well as the compressor.

Joybari et al. [7] carried out experimental analysis on the domestic refrigerator which was manufactured to use R134A. It is found that exergetic defects found in compressor were much higher compare to other components of the system. For same performance, we can use R600a instead of R1434a which reduce into economical advantages and it also reduce the risk of flammability of hydrocarbon refrigerants.

Padilla et al. [8] have mainly focused on exergy analysis of vapour compression refrigeration system with R413a and R12 in a domestic application. Performance is analysed in terms of exergy efficiency, power consumption and irreversibility. It is found that R413a can be used as a replacement for R12 in domestic vapour compression refrigeration system.

Tyagi et al.[9] performed energy and exergy analysis of window air conditioner test rig of 2 tonne of refrigeration capacity with R22 as working fluid. When the system is 100% charged, irreversibility will be highest of system components while when the system is 25% charged, it will be lowest. And, irreversibility of the compressor is greater among all components.

Nikolaidis and Probert [10] carried out an analytical study on two-stage vapour compression refrigeration system using R22 refrigerant. Change in condenser and evaporator temperatures of the system shows the considerable effect on plant irreversibility. They suggested that there is need of optimisation of condenser and evaporator conditions.

Bolaji et al. [11] compared performance analysis of R134A, R32 and R152A refrigerants in vapour compressor refrigerator. R152A and R134A show nearly same performance and R32 shows the lowest performance among all refrigerants. R152A was found to best performance refrigerant and it is recommended among these three refrigerants.

Kumar et al. [12] performed exergy and energy analysis of vapour compression refrigeration system. The exergy-enthalpy diagram is used for analysis. The coefficient of performance is calculated by first law analysis and various losses occurred in different components is calculate by second law analysis of vapour compression refrigeration system using R12 and R11 as refrigerants.

Ahamed et al. [13] carried out energy and exergy analysis of vapour compression refrigeration system using hydrocarbons. Compression shows highest energy destruction compared to all remaining components. By using nano lubricants and nano fluid in compressor, this exergy destruction can be minimised.

Stanciu et al. [14] have performed graphical and numerical investigation on one stage vapour compression refrigeration system using R404A, R22, R507A, R134A and R717. Performance is carried out in terms of exergy efficiency, compressor work; refrigeration work and COP. Effect of compression ratio, superheating and subcooling are also studied on the same system using all these refrigerants.

Spartz and Motta [15] carried out an experimental investigation of medium temperature vapour compression refrigeration system. The main focus of this research paper was to the replacement of R12 by R140A. In terms of thermodynamical analysis, comparison of pressure drop and heat transfer characteristics, R410A gives best results among R290A, R404A and R12.

Cabello et al. [16] did detail study about the effect of operating parameters on work input, cooling capacity and first law efficiency of single stage vapour compression refrigeration system. Due to change in the condensing temperature, evaporating temperature and suction pressure, exergetic parameters undergoes great influence.

Han et al. [17] concluded through experimental analysis that under different working conditions, there could be the replacement of R407C with a mixture of R32/R125/R161 in vapour compression refrigeration system. This drop in replacement shows less pressure ratio, slightly high discharge temperature and higher COP.

Xuan and Chen [18] conducted an experimental study about the replacement of R502 by a mixture of HFC-161 in vapour compression refrigeration system. As a drop in replacement, mixture HFC-161 shows higher performance at higher evaporative temperature than R404A.

Mohanraj et al. [19] concluded through experimental investigation that under different environmental temperatures, COP of a domestic refrigeration system using a mixture of R290 and R600A in the proportion of 45.2:54.8 by weight showing up to 3.6% higher than the same system uses R134A. Also, Discharge temperature of the compressor with the mixture is lower than the same compressor with R134A.

Halimic et al. [20] did numerical and graphical performance analysis of R290, R134A and R401a as a drop in replacement for R12 in vapour compression refrigeration system. R134A can be replaced in the present system as a drop in replacement due to its similar performance compare to R12. But R290 is practically accepted as drop-in replacement in reference to green house impact.

Getu and Bansal [21] carried out optimisation of the design and operating parameters like evaporation temperature, the temperature difference in cascade heat exchanger, superheating temperature, subcooling temperature and condensing temperature in R744-R717 cascade refrigeration system. To obtain optimum thermodynamic parameters of the system, regression analysis is done.

Cabello et al. [22] performed the analysis on the effect of evaporating pressure, the degree of superheating and condensing pressure on single-stage vapour compression refrigeration system using R134A, R407c and R22 refrigerants. Change in the suction conditions of the compressor; greatly affect the mass flow rate which in result affects the refrigeration capacity. For higher compression ratio R407C give higher COP than R22.

Arora et al. [23] carried out a parametric evaluation of actual vapour compression refrigeration system in terns of exergetic efficiency, exergy destruction ratio and coefficient of performance using R407C, R410a and R22. COP and exergetic efficiency of R22 are higher than R410A and R407C. A computational model was developed for this investigation.

2.2 CONCLUSION AND GAPS

Vapour compression refrigeration system is used to achieve and maintain required low temperature. Systems which are operating on R22 or R22 containing refrigerants are converting to use alternative refrigerants to minimise environmental issues. If we use alternative refrigerants as drop-in replacement in the existing system then it must be kept in mind that compressor will subject to additional wear due to greater load, it will lead to shorter service life.

Based on literature review, it can be concluded that researchers have gone through detailed investigation on the coefficient of performance by first law analysis and exergetic efficiency by second law analysis of simple vapour compression refrigeration system with single evaporator mainly. Irreversibility analysis is not carried out by researchers for the following systems:

- Simple VCR with flash chamber, flash intercooler, water intercooler, water subcooling and liquid vapour heat exchanger
- Multiple evaporators system with compound compression and multistage expansion in vapour compression refrigeration system.
- Multiple evaporator systems with individual compressor using mixed refrigerants and comparison with pure refrigerants in vapour compression refrigeration system.
- Multiple evaporator systems with liquid vapour heat exchanger and a flash chamber using alternative pure refrigerants in vapour compression refrigeration system.

Refrigerant	Name	Molecular Mass	Boiling Point (^{0}F)	Freezing Point (^{0}F)	Critical Point		
					Temperature (^{0}F)	Pressure (psia)	Specific Volume (Cu.Ft,/lb)
R134a	Tetrafluoroethane	102.03	-15	-142	214	590	0.0290
R142b	1-chloro-1, 1-difluoroethane	100.50	14	-204	279	598	0.0368
R152a	Difluoroethane	66.05	-13	-178	237	690	0.04352
R600	n-Butane	58.12	31.2	-217	306	551	0.0702
R1234yf	2,3,3,3-Tetrafluoropropyl-ene	114	-22	-0.04	203	490	0.03368

Table 1 : Alternative Refrigerant Properties

Alternative refrigerants mentioned in the Table 1, can be used in multi-evaporator refrigeration system with flash chamber and liquid vapour heat exchanger for dairy plant application.

Alternative Refrigerant	GWP	ODP
R134A	1300	0
R142B	2400	0.043
R152A	124	0
R600	3	0
R1234YF	4	0

Table 2 : Alternative Refrigerants and their GWP ODP

2.3 PROBLEM FORMULATION

In the present study, performance evaluation of multiple evaporator vapour compression refrigeration system with liquid vapour heat exchanger and a flash chamber is carried out using alternative pure refrigerants.

It is proposed to examine the effect of following parameters on the performance of multiple evaporator vapour compression refrigeration systems and evaluation of better alternative refrigerant in present work for the application of dairy plant.

- Effect of using LVHE and flash chamber in system on COP, exergetic efficiency and EDR
- Effect of varying condenser temperature on exergetic efficiency
- Effect of varying condenser temperature on exergy destruction ratio
- Effect of varying evaporator temperature on exergetic efficiency
- Effect of varying evaporator temperature on exergy destruction ratio

CHAPTER 3

THERMODYNAMIC ANALYSIS

In this chapter, it is intended to give a thermodynamic analysis of present work, which has been carried out on the multi-evaporator refrigeration system.

3.1 SYSTEM DESCRIPTION

Fig.3 represents a Multi-evaporator system with multiple expansion valves and individual compressors; It consists of two evaporators at different temperatures with individual expansion valve and individual compressor. $Q_{e,I}$ and $Q_{e,II}$ are loads on evaporators in tonnes of refrigeration. $W_{c,I}$ and $W_{c,II}$ are works required for compression in respective compressor.

The vaporised refrigerant returns to the compressor. This steam is cooled in a condenser, turning into liquid under high pressure. The sight glass is often included in the liquid line, a technician can use it to see if there are enough refrigerant in the system, the bubbles will point out the lack of refrigerant.

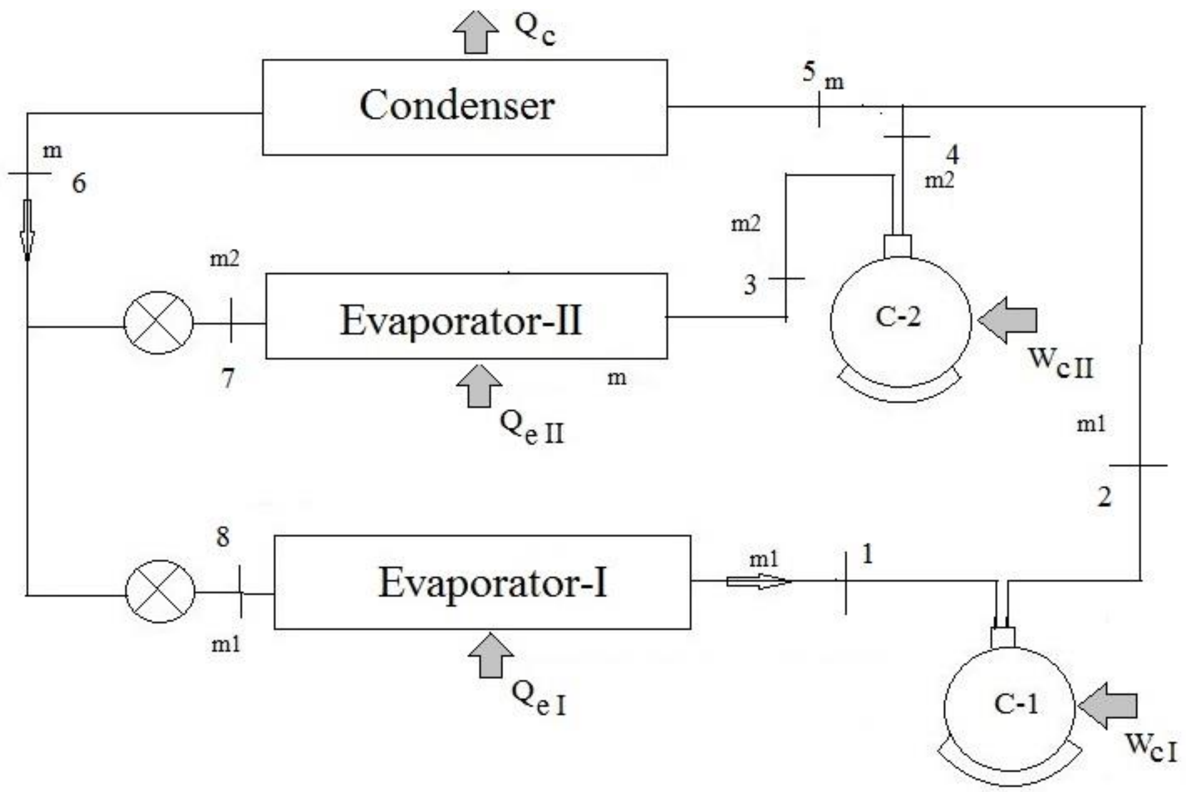

Figure 3 : System Diagram of Multi-evaporator system with multiple compressors and individual expansion valves

In this system, the entire refrigerant from condenser flows through the expansion valve between point 6 and 7 where its pressure reduces from condenser pressure to pressure of Evaporator-II. All the vapours formed after leaving this expansion valve plus enough liquid take care of a load of Evaporator-II. The remaining refrigerant then flows through expansion valve between point 8 and 9 where its pressure reduces from pressure of Evaporator-II to pressure of Evaporator-I. Again, all the vapour formed after leaving this expansion valve plus enough liquid takes care of the load of Evaporator-II.

When the high-pressure liquid refrigerant from condenser passes through the expansion valve, some of it evaporates. This partial evaporation of liquid refrigeration is known as flash. It may be noted that the vapour formed during expansion is of no use to the evaporator in producing refrigeration effect as compared to liquid refrigerant which carries the heat in the form of latent heat. This formed vapour, which is incapable of producing any refrigeration effect, can be bypassed around the evaporator and supplied directly to the suction of compressor. This is done by introducing flash chamber as shown in Fig.4.

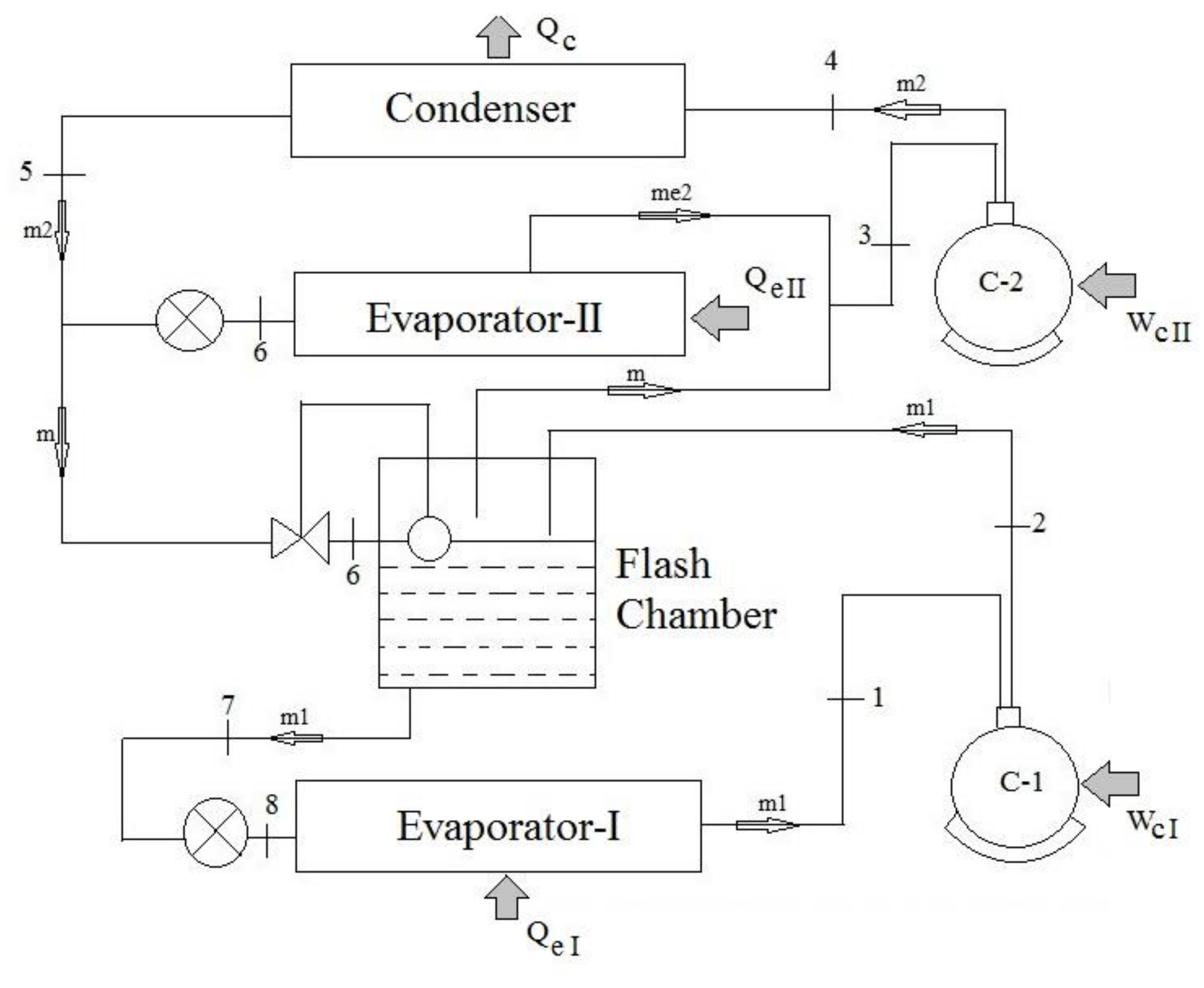

Figure 4 : System Diagram of Multi-evaporator system with Flash Chamber, multiple compressors and individual expansion valves

Also, liquid refrigerant leaving the condenser is at a higher temperature than the vapour refrigerant leaving the Evaporator-I. The liquid refrigerant leaving the condenser can be subcooled by passing it through a heat exchanger which is supplied with saturated vapour from the evaporator as shown in the Fig.5. In the heat exchanger, the liquid heat exchanger gives heat to the vapour refrigerant.

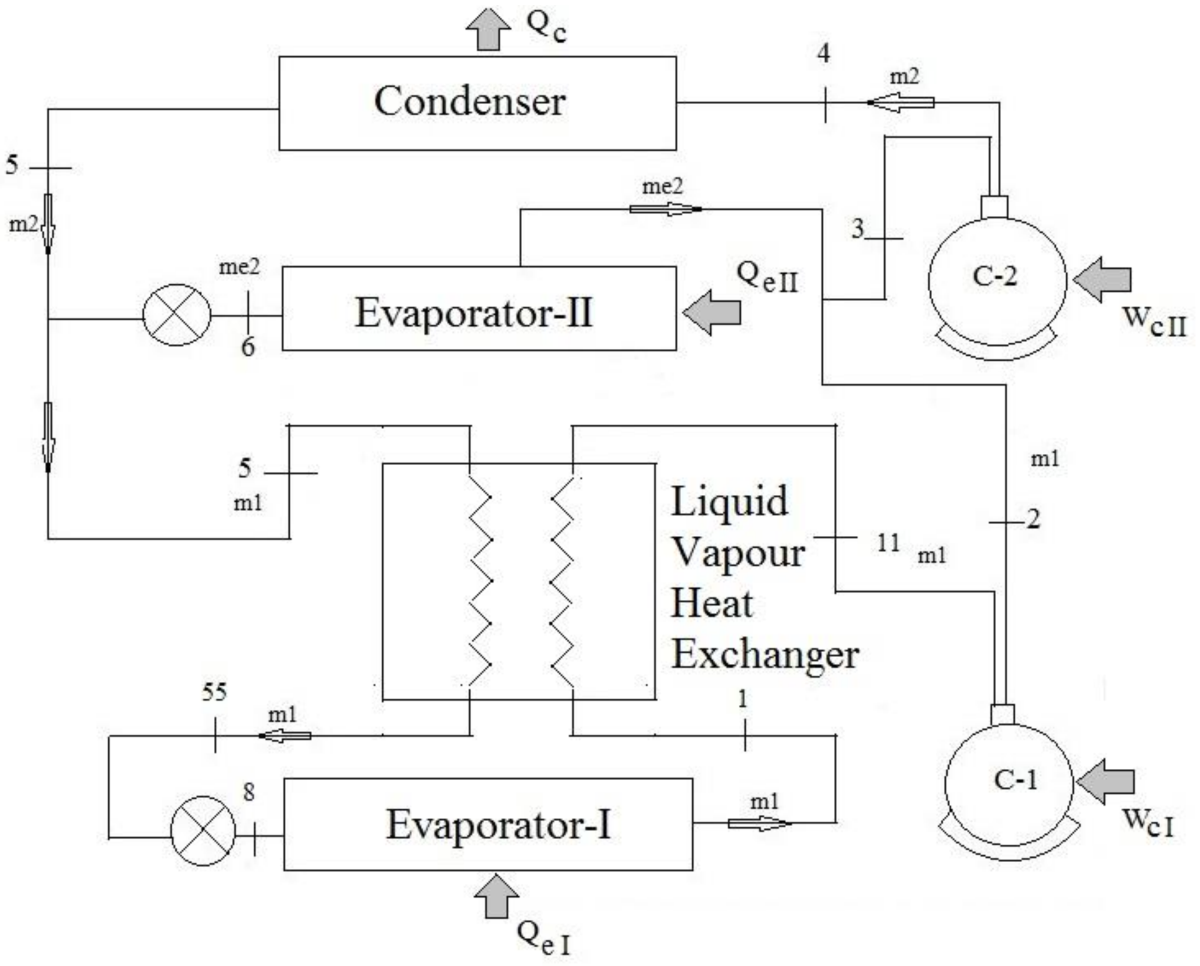

Figure 5 : System Diagram of Multi-evaporator system with LVHE, multiple compressors and individual expansion valves

Also, liquid refrigerant leaving the flash chamber is at a higher temperature than the vapour refrigerant leaving the Evaporator-I. And, hence flash chamber and LVHE both can apply in same multi-evaporator system to obtain better results. The liquid refrigerant leaving the flash chamber can be subcooled by passing it through a heat exchanger which is supplied with saturated vapour from the evaporator as shown in the Fig.6.

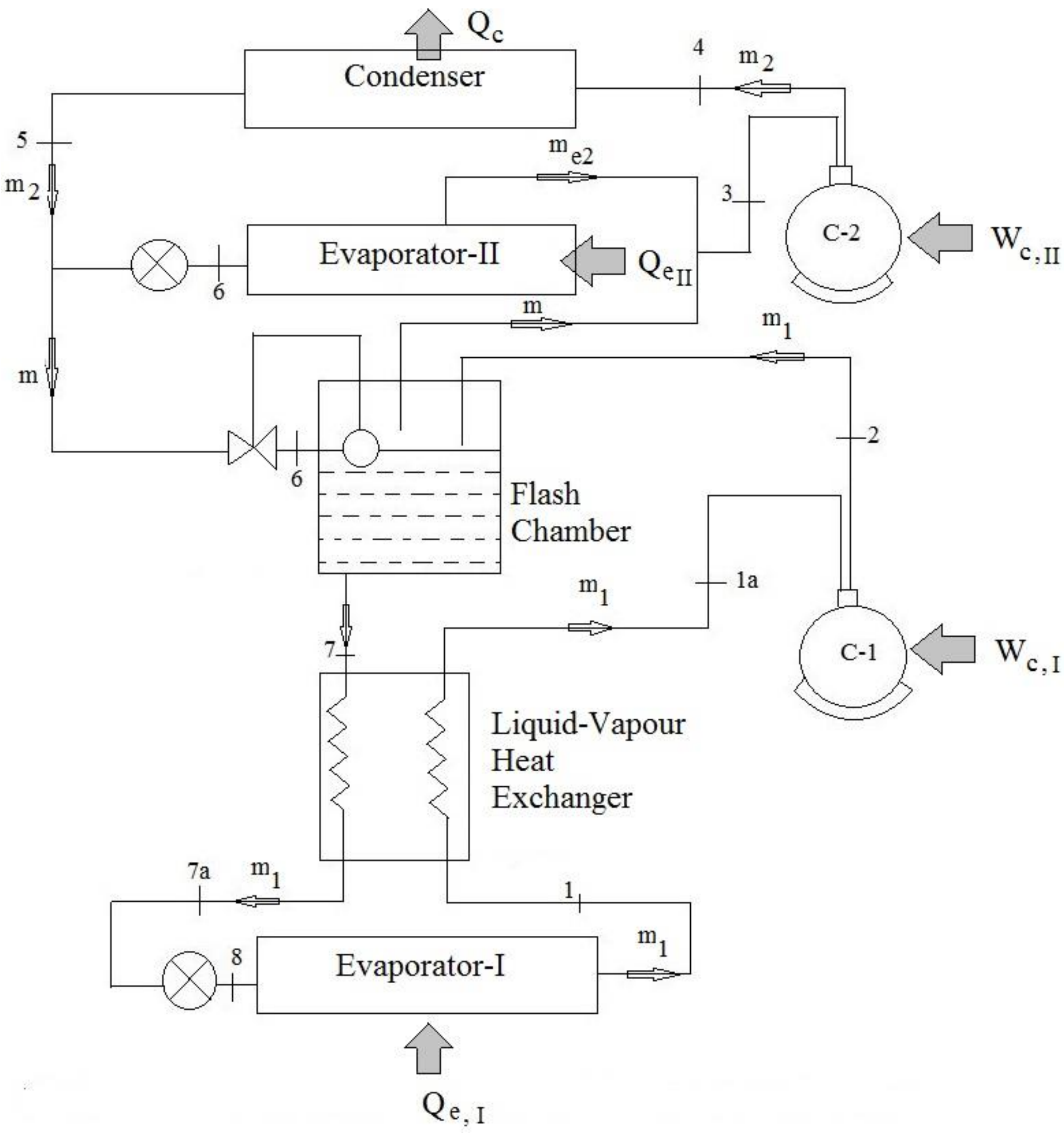

Figure 6 : Multi-Evaporator Vapour Compression Refrigeration System with Liquid-Vapour Heat Exchanger, Flash Chamber multiple compressors and individual expansion valves

3.2 ENERGY ANALYSIS

In the present work, a parametric study with various evaporating and condensing temperatures has been conducted to determine the performance evaluation of multi-evaporator refrigeration system.

The following assumptions are made to simplify the analysis, including energy analysis.

1. All components are assumed to be a steady flow and steady-state process.
2. The changes in the kinetic energy and the potential energy of the components are negligible.
3. The pressure drops and heat loss in the piping connecting the components are negligible.
4. All throttling devices are isenthalpic.
5. Pressure drops in condenser and evaporator are neglected.

Based on assumptions, the equations for energy and mass balance are written for each component. Each component in a multi-evaporator refrigeration system, shown in Fig.6 considered as control volume.

Mass Balance

$$\sum_{in} \mathrm{m_r} = \sum_{out} \mathrm{m_r}$$

Energy Balance

$$\mathrm{Q\text{-}W} + \sum_{in} m_r h - \sum_{out} m_r h = 0$$

Energy changes in each component of multi-evaporator refrigeration system are as follows:

Evaporator: Evaporator is acted as a heat exchanger which absorbs heat from cold space and this effect is called as refrigeration effect.

In Evaporator-I:

$Q_{e,I} = m_1 (h_1 - h_4)$

In Evaporator-II:

$Q_{e,II} = m_{e2} (h_3 - h_6)$

Compressor: Compressor is a work absorbing device. Isentropic work input to the compressor is expressed as,

In compressor-1:

$W_1 = m_{1*} (h_{2s} - h_{1a})$

We have compressor-1 efficiency as,

$$\eta_1 = \frac{h_{2s} - h_{1a}}{h_2 - h_{1a}}$$

Actual compressor-1 work is specified by

$W_1 = m_{1*} (h_2 - h_{1a})$

In compressor-2:

$W_2 = m_{2*} (h_{4s} – h_3)$

We have compressor-2 efficiency as,

$$\eta_2 = \frac{h_{4s} - h_3}{h_4 - h_3}$$

Actual compressor-2 work is specified by

$W_2 = m_{2*} (h_4 – h_3)$

Condenser: Condenser acts as a heat exchanger in which heat is rejected to environment is given by

$Q_c = m_2 * (h_4 - h_5)$

Expansion Valve: Expansion valve is a device in which expansion of refrigerant occurs and enthalpy remains constant.

In expansion valve-1:

$h_5 = h_6$

In expansion valve-2:

$h_7 = h_8$

Flash Chamber: Flash chamber is used to separate liquid and vapour refrigerant before it is supplied to evaporator and its energy balance is given by,

$m*h_6 + m_1*h_2 = m*h_3 + m_{1*}h_7$

Liquid-Vapour Heat Exchanger: Liquid-Vapour Heat Exchanger is used to subcool refrigerant before it passes through evaporator and its energy balance is given by,

$h_7 – h_{7a} = h_{1a} – h_1$

Coefficient of Performance: COP of multi-evaporator refrigeration system is defined as the ratio of refrigeration effect produced by all evaporators to the total work input to all compressors in the system. It can be express by,

$COP = \frac{RC}{W}$

3.3 EXERGY ANALYSIS

Exergy Destruction in Evaporator

In Evaporator-I:

$$ED_{e1} = m_1 * (h_8 - (T_0 + 273) * s_8) + Q_1[1 - \frac{(T_0+273)}{(T_{r1}+273)}] - m_1 * (h_1 - (T_0 + 273) * S_1)$$

In Evaporator-II:

$$ED_{e2} = m_{e2} * (h_6 - (T_0 + 273) * s_6) + Q_2\left[1 - \frac{(T_0+273)}{(T_{r2}+273)}\right] - m_{e2} * (h_3 - (T_0 + 273) * S_3)$$

Exergy Destruction in Compressor

In compressor-1

$$ED_{c1} = m_1 * [(T_0 + 273) * (S_2 - S_!)]$$

In compressor-2:

$$ED_{c2} = m_2 * [(T_0 + 273) * (S_4 - S_3)]$$

Exergy Destruction in Condenser

$$ED_{cond} = m_2 * [h_4 - (T_0 + 273) * S_4] - m_2 * [h_5 - (T_0 + 273) * S_5]$$

Exergy Destruction in Expansion Valve

In expansion valve-1:

$$ED_{t1} = m_1 * [(T_0 + 273) * (S_8 + S_{7a})]$$

In expansion valve-2:

$$ED_{t2} = m_2 * [(T_0 + 273) * (S_6 + S_5)]$$

Exergy Destruction in Flash Chamber

$$ED_{flash} = m * [h_6 - (T_0 + 273) * S_6] + m_1 * [h_2 - (T_0 + 273) * S_2] - m_1 * [h_7 - (T_0 + 273) * S_7] - m * [h_3 - (T_0 + 273) * S_3]$$

Exergy Destruction in Liquid-Vapour Heat Exchanger

$$ED_{LVHE} = m_1 * [h_7 - (T_0 + 273) * S_7] + m_1 * [h_1 - (T_0 + 273) * S_1] - m_1 * [h_{7a} - (T_0 + 273) * S_{7a}] - m_1 * \left[h_{fa} - (T_0 + 273) * S_{fa}\right]$$

Total Exergy Destruction

ED = ED_{e1}+ ED_{e2}+ ED_{c1}+ ED_{c2}+ ED_{cond}+ ED_{t1}+ ED_{t2}+ ED_{flash}+ ED_{LVHE}

Exergy Of Product

EP = $Q_1\left[1-\frac{(T_0+273)}{(T_{r1}+273)}\right]$ + $Q_2[1-\frac{(T_0+273)}{(T_{r2}+273)}]$

Exergetic Efficiency

$\eta_{ex}=\frac{EP}{W}$

Exergy Destruction Ratio

EDR= $\frac{ED}{EP}$

3.4 Input Parameters

The input parameters taken for computation of results are given below:

Condenser Temperature	T_c = 35^0C to 55^0 C
Evaporator-I Temperature	T_{e1} = -12^0C to -20^0C
Evaporator-II Temperature	T_{e2} = 1^0C to 4^0C
Dead State Temperature	T_o= 25^0C
Refrigeration Capacity of Evaporator-1	Q_1 = 2 TR
Refrigeration Capacity of Evaporator-2	Q_2 = 10 TR
Isentropic Efficiency of Compressor-1	η_1 = 0.9
Isentropic Efficiency of Compressor-2	η_2 = 0.85
Effectiveness of LVHE	e = 0.85
Refrigerants Used	R152A,R134A, R142B, R1234YF, R600

By carrying out the thermodynamic analysis of the Multi-Evaporator Vapour Compression Refrigeration System for the conditions stated above, various state points have been obtained. The computer program for the analysis is developed in EES has been given in Appendix A along with its flow diagram for computation procedure.

CHAPTER 4

RESULTS AND DISCUSSION

A computational model is developed using Engineering Equation Solver (Klein and Alvarado, 2005) for evaluating exergy and energy analysis of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE. The input data for evaluation are same as mentioned in chapter 3 except the parameter, whose effect is discussed in particular plot, has been varied.

4.1 Coefficient of Performance

Fig.7 and Fig.8 shows a comparison of coefficient of performance against evaporator-I and evaporator-II temperatures respectively. As we goes on increasing evaporator-I or Evaporator-II temperatures, compressor work reduces due to reduction in pressure ratio. Also, there is increase in specific refrigeration effect which causes cooling capacity to increase. These two factors gives combine effect to increase the overall COP.

Among all the selected five different alternative refrigerants, R142B has the maximum COP corresponding to condenser temperature considered. R600 has second best COP among these five refrigerants. R1234YF has least COP compared to all selected refrigerants.

From Table 2, the improvement in COP achieved by introducing flash chamber and LVHE in simple multi-evaporator vapour compression refrigeration system can be studied. R1234YF presents the maximum COP improvement among all the refrigerants, almost 18.41%. R152A has least COP improvement among selected refrigerants. COP improvements are 16.99%, 15.97%, 15.88%, 16.24% and 18.41% for refrigerants R134A, R142B, R152A, R600 and R1234YF respectively. From Table 5, when evaporator at low temperature has smaller capacity than evaporator at high temperature, system has maximum COP.

4.2 Exergetic Efficiency

Fig. 9 to Fig. 13 shows variation of Exergetic Efficiency with Evaporator-I Temperature and Fig.14 shows comparison of all these variations. Also, Fig. 15 to Fig. 19 shows variation of Exergetic Efficiency with Evaporator-II Temperature, Fig.20 shows comparison of all these variations and Fig. 21 to Fig. 25 shows variation of Exergetic Efficiency with Condenser Temperature, Fig.26 shows comparison of all these variations.

With increase in evaporator temperature, the term $| 1-(T_0 / T_r) |$ reduces as T_0 approaches T_r. Due to this, exergy of cooling effect increases which has negative effect on exergetic efficiency. Also, compressor work reduces as we goes on increasing evaporator pressure which has positive effect on exergetic efficiency. Combined effect of cooling effect and compressor work is to increase exergetic efficiency. It goes on increase till optimum evaporator temperature is achieved.

Among all the selected five different alternative refrigerants, R142B has the maximum exergetic efficiency in all variation of Evaporator-I, evaporator-II and condenser temperature. R600 has second best exergetic efficiency among these five refrigerants. R1234YF has least exergetic efficiency compared to all selected refrigerants.

From Table 4, the improvement in exergetic efficiency achieved by introducing flash chamber and LVHE in simple multi-evaporator vapour compression refrigeration system can be studied. R1234YF presents the maximum exergetic efficiency improvement among all the refrigerants, almost 18.36%. R152A has least exergetic efficiency improvement among selected refrigerants. Exergy efficiency improvements are 16.98%, 15.97%, 15.87%, 16.22% and 18.36% for refrigerants R134A, R142B, R152A, R600 and R1234YF respectively. From Table 6, when evaporator at low temperature has greater capacity than evaporator at high temperature, system has maximum exergetic efficiency.

4.3 Exergy Destruction Ratio

Fig. 27 to Fig. 31 shows variation of EDR with Evaporator-I Temperature and Fig.32 shows comparison of all these variations. Also, Fig. 33 to Fig. 37 shows variation of EDR with Evaporator-II Temperature, Fig.38 shows comparison of all these variations and Fig. 39 to Fig. 43 shows variation of EDR with Condenser Temperature, Fig.44 shows comparison of all these variations.

Trends of curve EDR and exergetic efficiency are almost reverse due to exergetic efficiency is inversely proportional to EDR. Minimum value of EDR gives optimum evaporator temperature. Among all the selected five different alternative refrigerants, R1234YF has the maximum EDR in all variation of Evaporator-I, evaporator-II and condenser temperature. R134A has second large EDR among these five refrigerants. R142B has least EDR compared to all selected refrigerants.

From Table 3, the increase in EDR by introducing flash chamber and LVHE in simple multi-evaporator vapour compression refrigeration system can be studied. R1234YF presents the maximum EDR increase among all the refrigerants, almost 24.92%. R600 has least EDR increase among selected refrigerants. EDR % increases are 20.37%, 16.84%, 14.74%, 18.66% and 24.92% for refrigerants R134A, R142B, R152A, R600 and R1234YF respectively. From Table 7, when evaporator at low temperature has smaller capacity than evaporator at high temperature, system has maximum EDR.

4. Exergy Destruction in Each Component

Fig. 45 to Fig. 62 shows exergy destruction of each component with variations of evaporator-I and evaporator-II temperatures alternatively. It gives an idea about how much input energy destroy in each components and also helps out to know which is worst component of the system. From all the plots, we can conclude that most efficient component of given system is LVHE with minimum exergy destruction. In descending order of better component (i.e. with low exergy destruction) are LVHE, expansion valves, evaporators, compressors and condenser.

Due to irreversibility, input energy consumed in condenser varies between 22% to 41% . The corresponding values of input energy consumed for expansion valve, evaporator and compressor are vary between 7% to 18%, 11% to 22% and 18 % to 24 % respectively. From point of substitute refrigerant, R142B is best among all five selected refrigerants as total exergy destruction of all components is always less for R142B than that of all others.

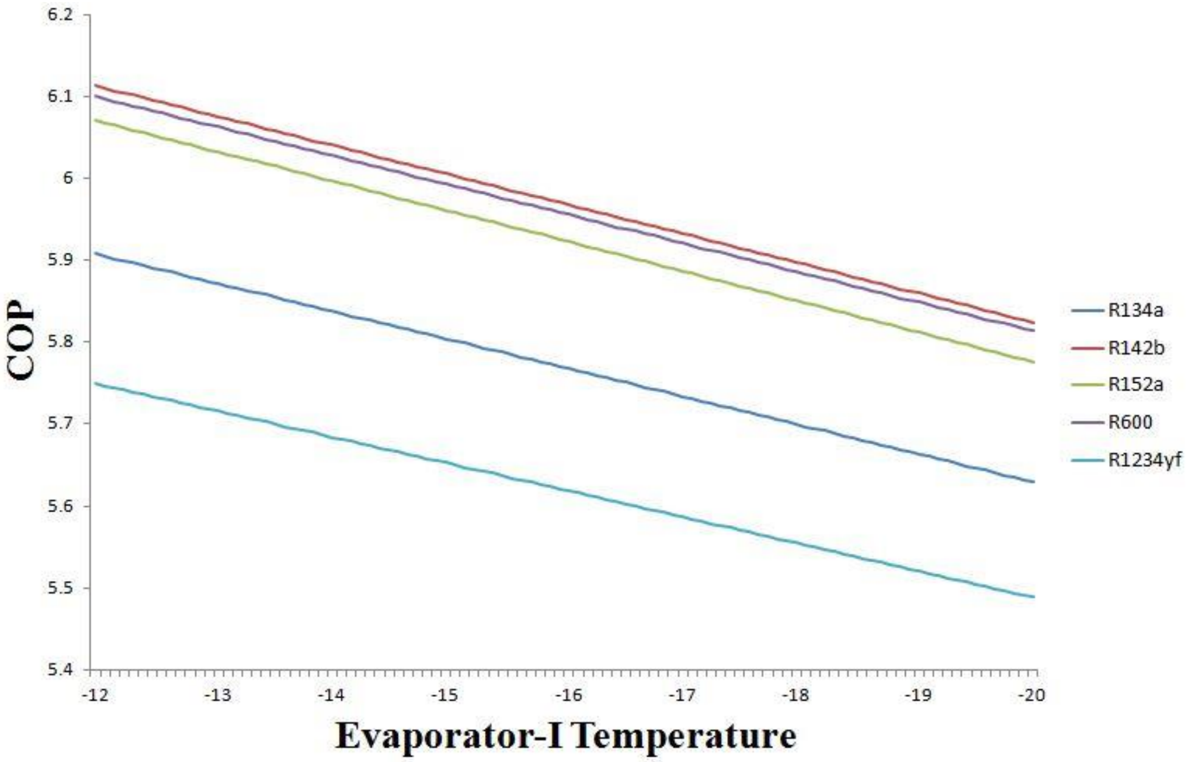

Figure 7: Variation of COP with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

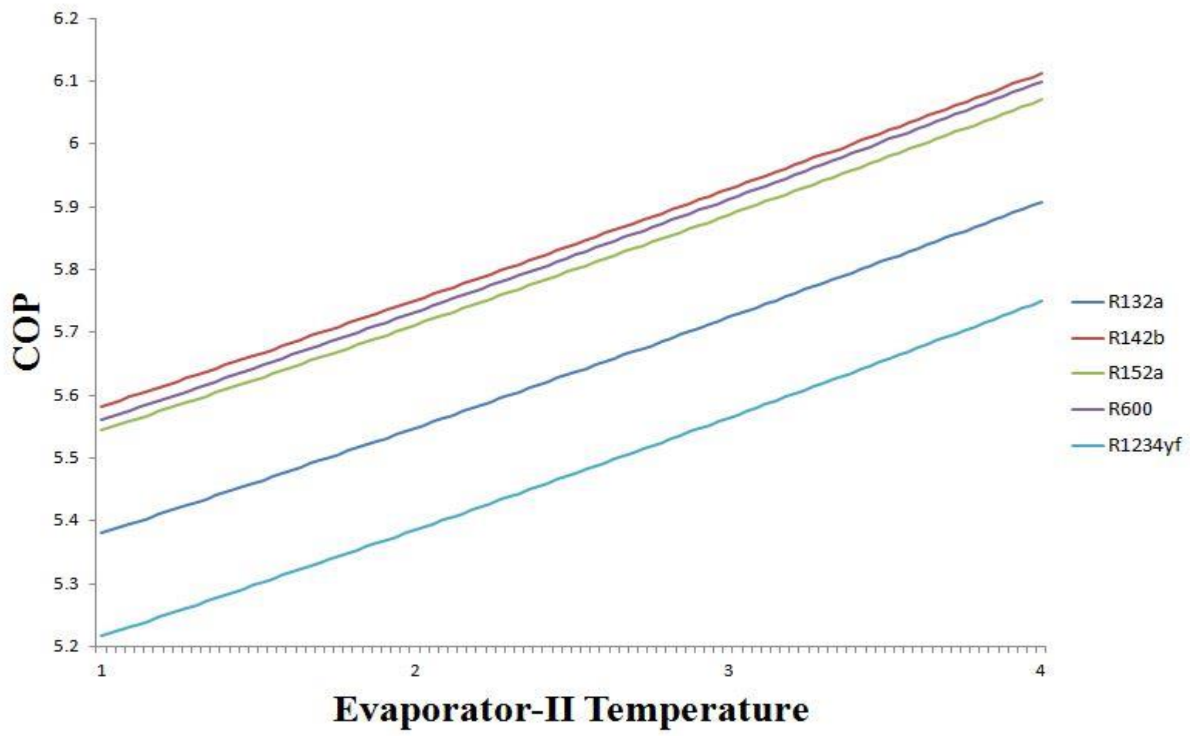

Figure 8: Variation of COP with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

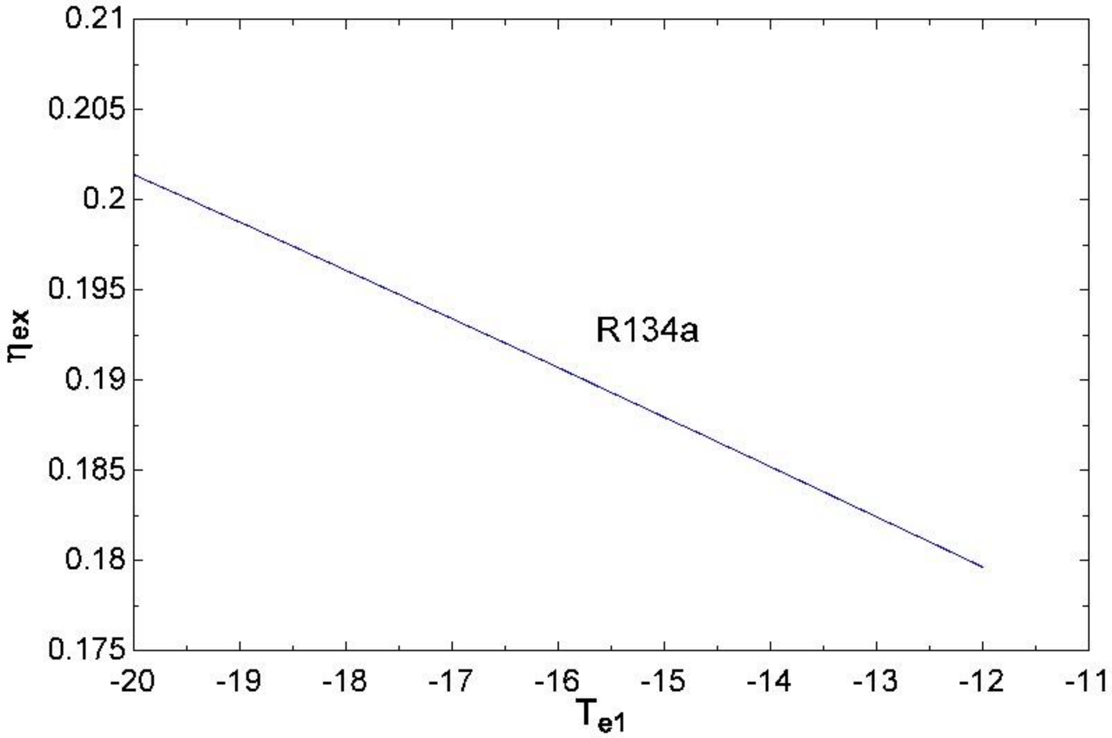

Figure 9: Variation of Exergetic Efficiency with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R134A

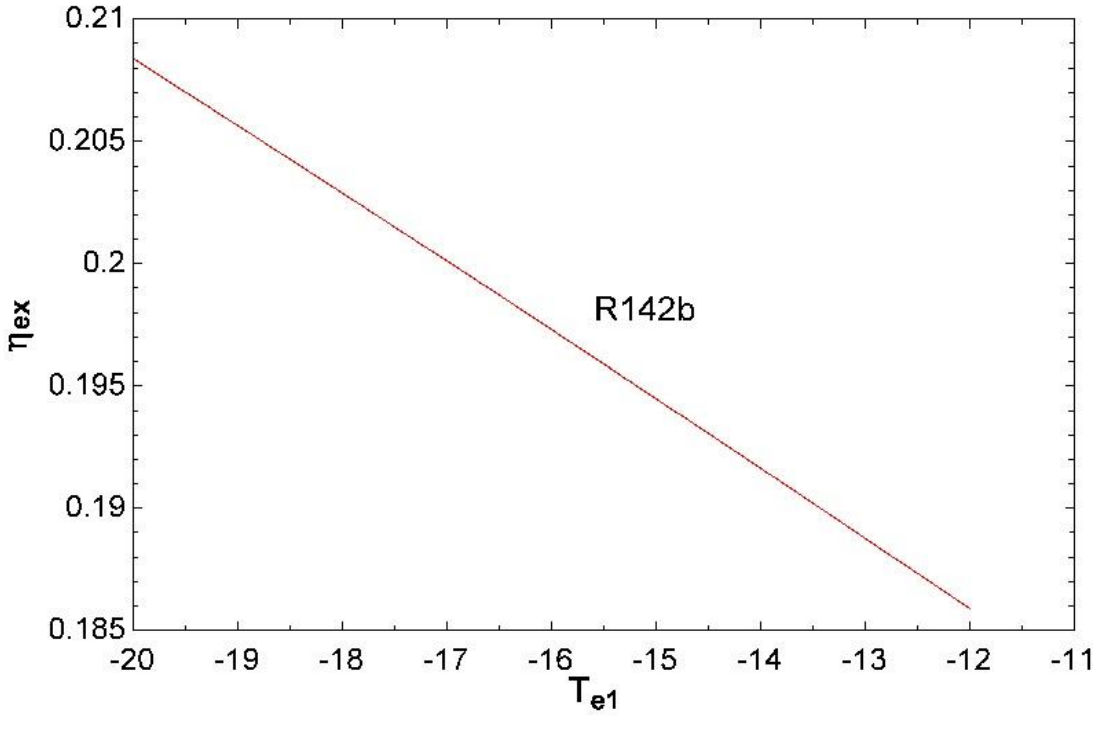

Figure 10: Variation of Exergetic Efficiency with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R142B

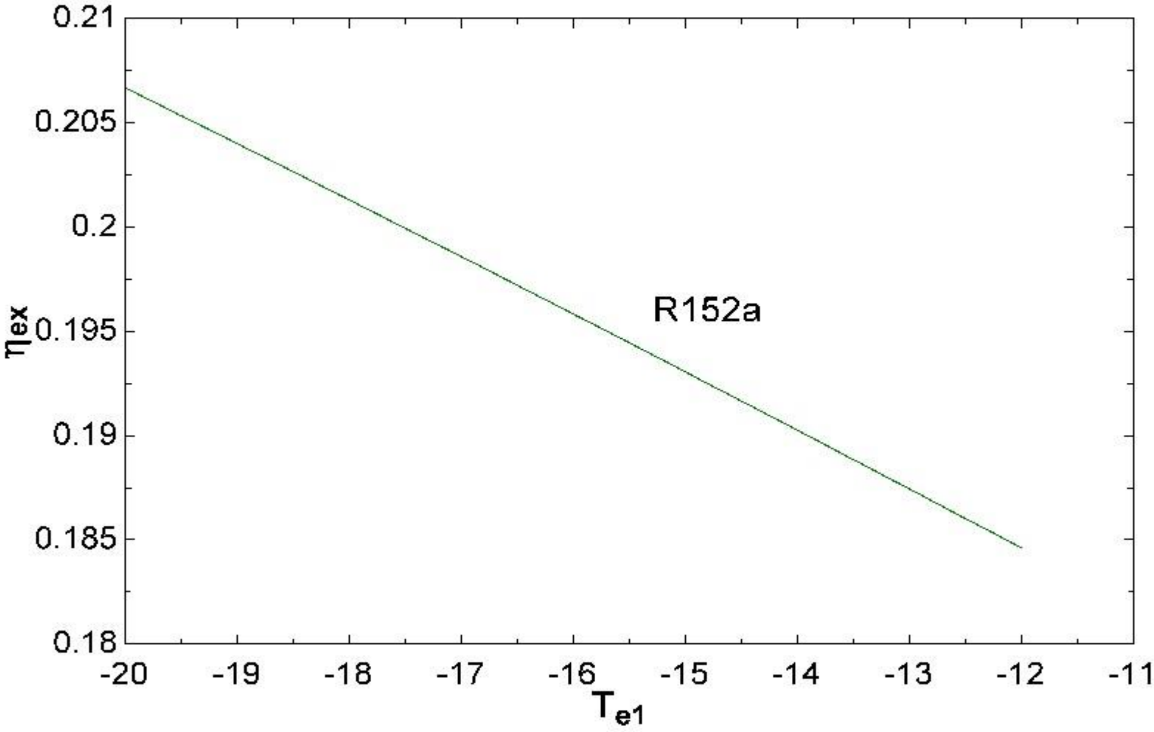

Figure 11: Variation of Exergetic Efficiency with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R152A

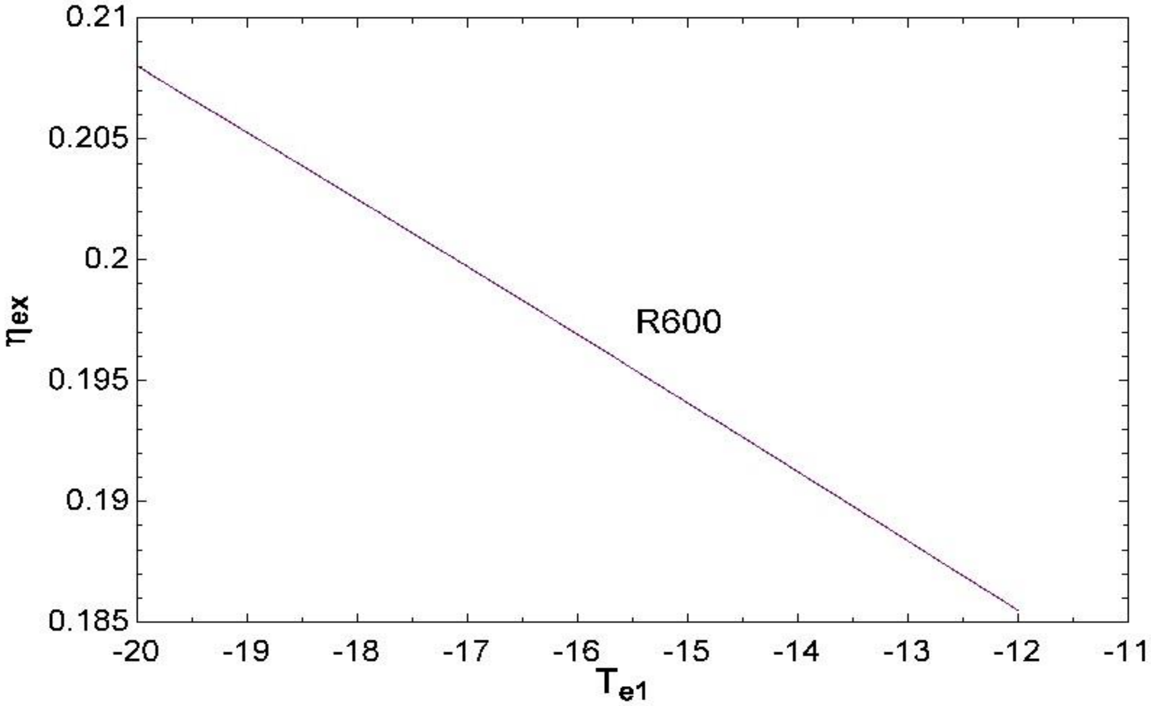

Figure 12: Variation of Exergetic Efficiency with Evaporator Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R600

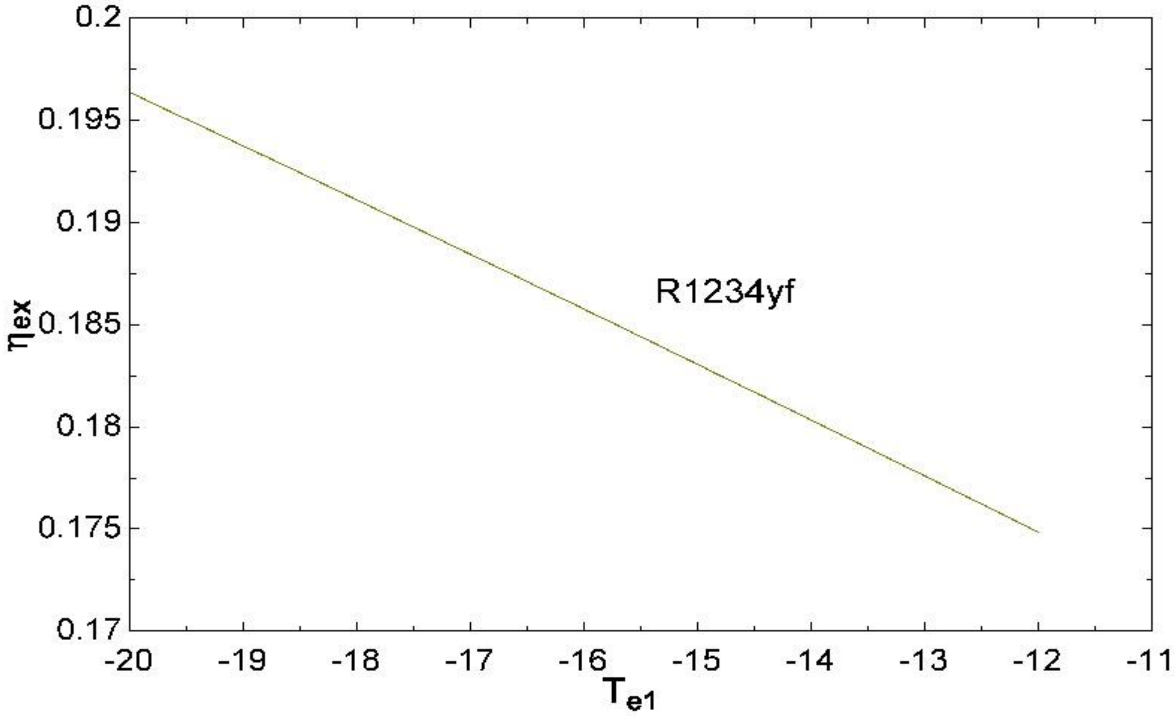

Figure 13: Variation of Exergetic Efficiency with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R1234YF

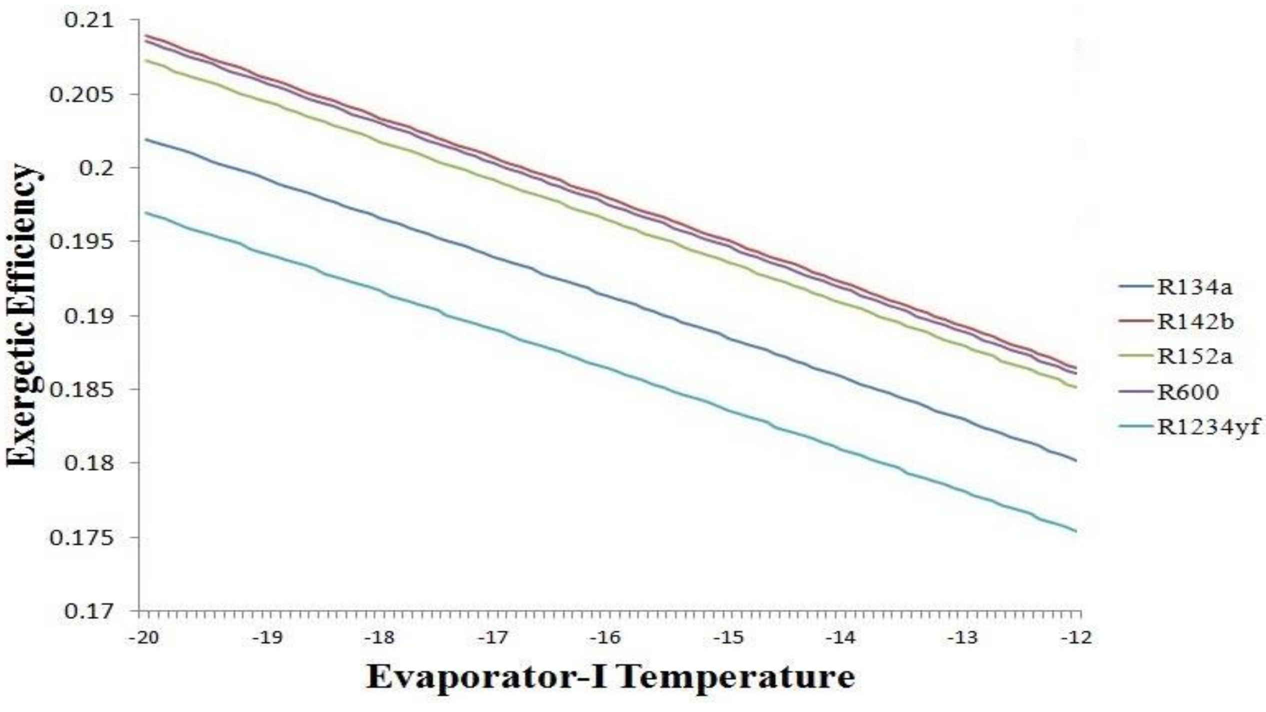

Figure 14: Comparison of Variation of Exergetic Efficiency with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

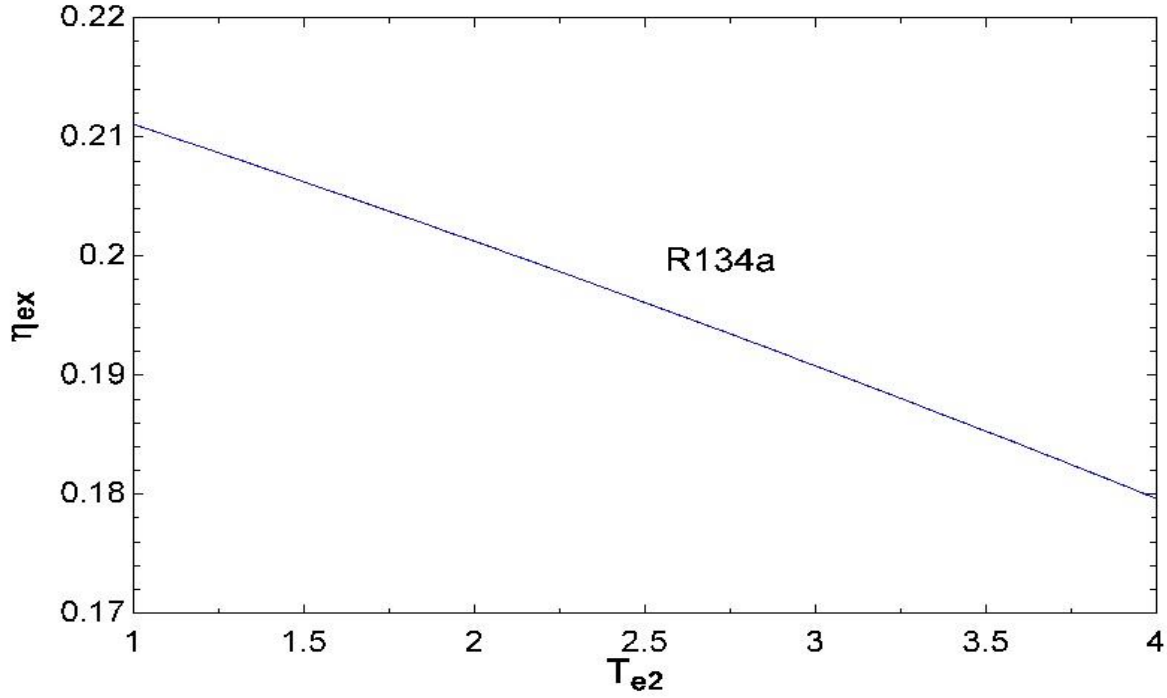

Figure 15: Variation of Exergetic Efficiency with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R134A

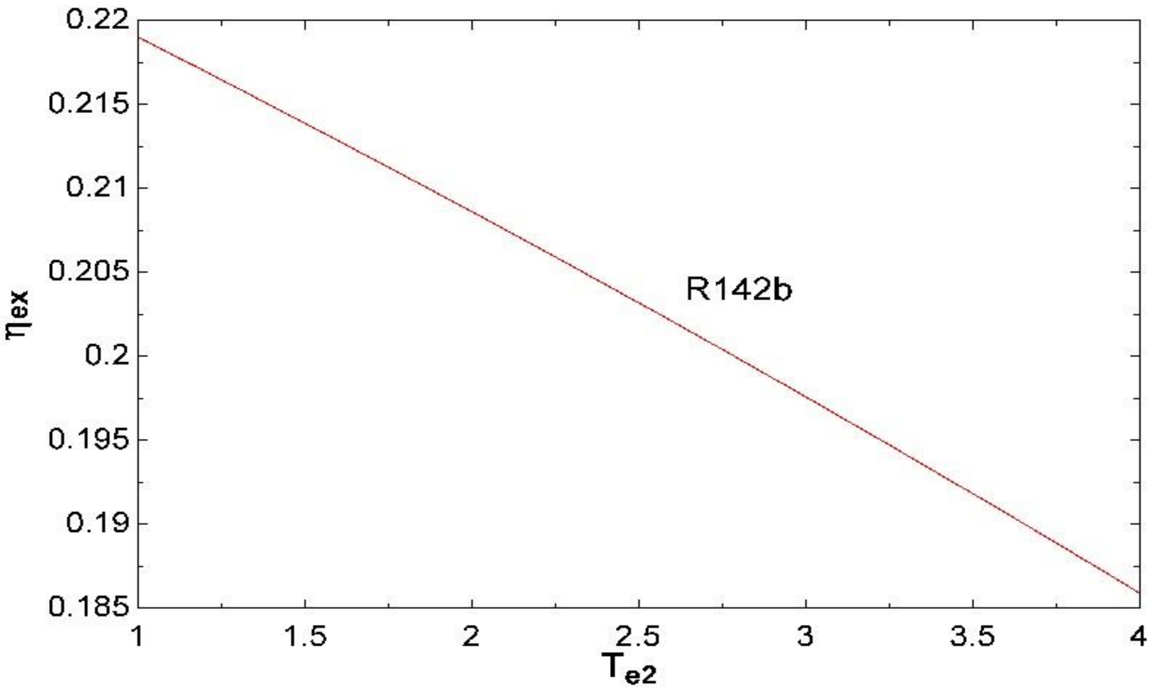

Figure 16: Variation of Exergetic Efficiency with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R142B

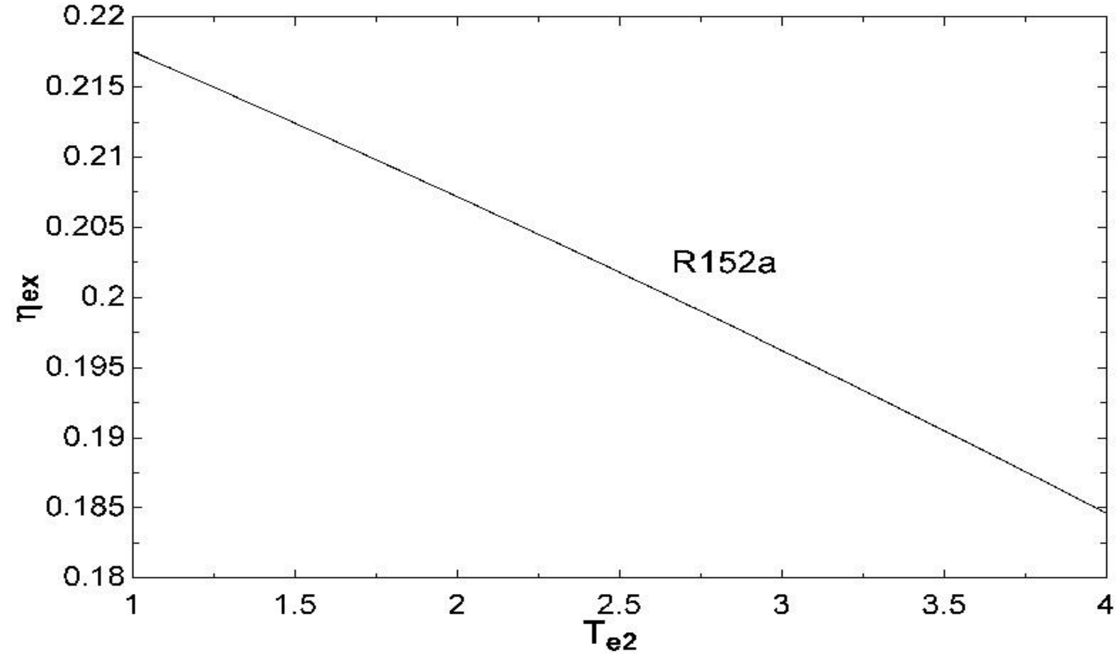

Figure 17: Variation of Exergetic Efficiency with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R152A

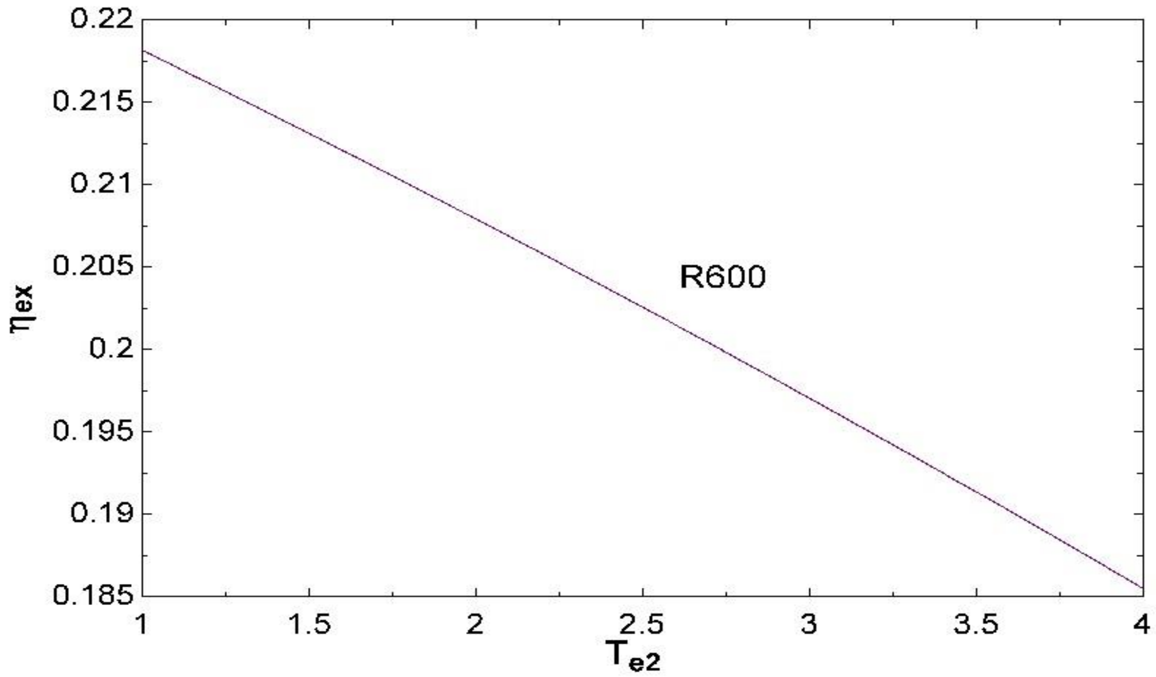

Figure 18: Variation of Exergetic Efficiency with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R600

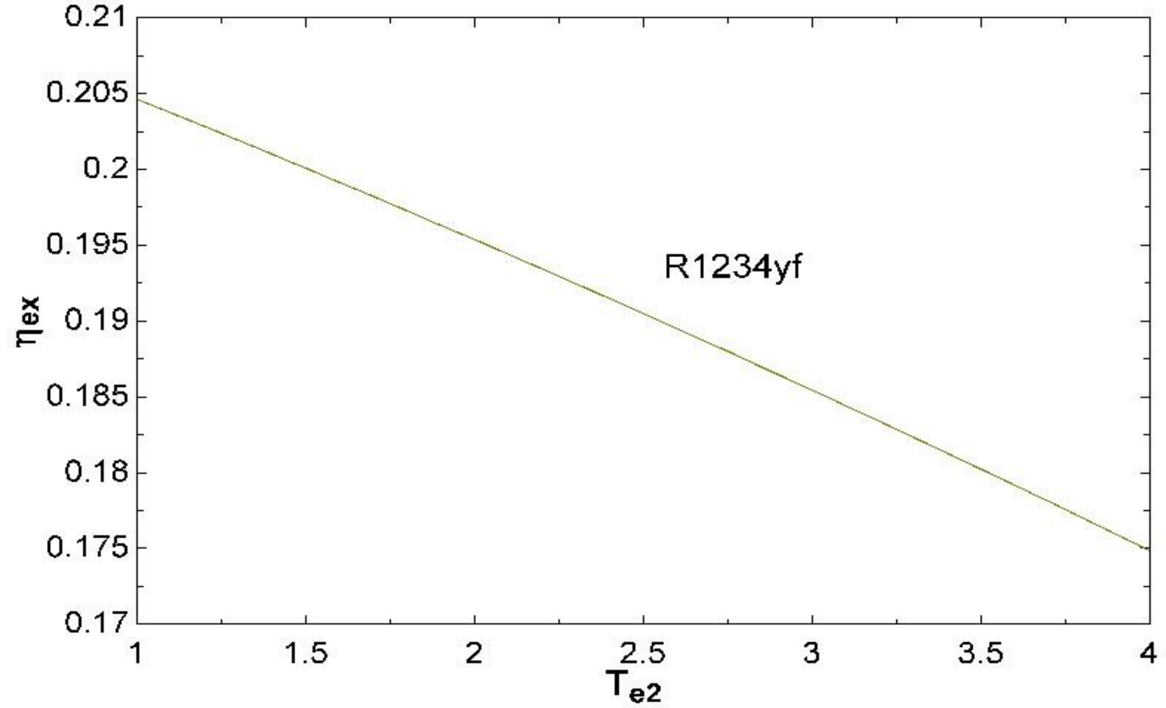

Figure 19: Variation of Exergetic Efficiency with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R1234YF

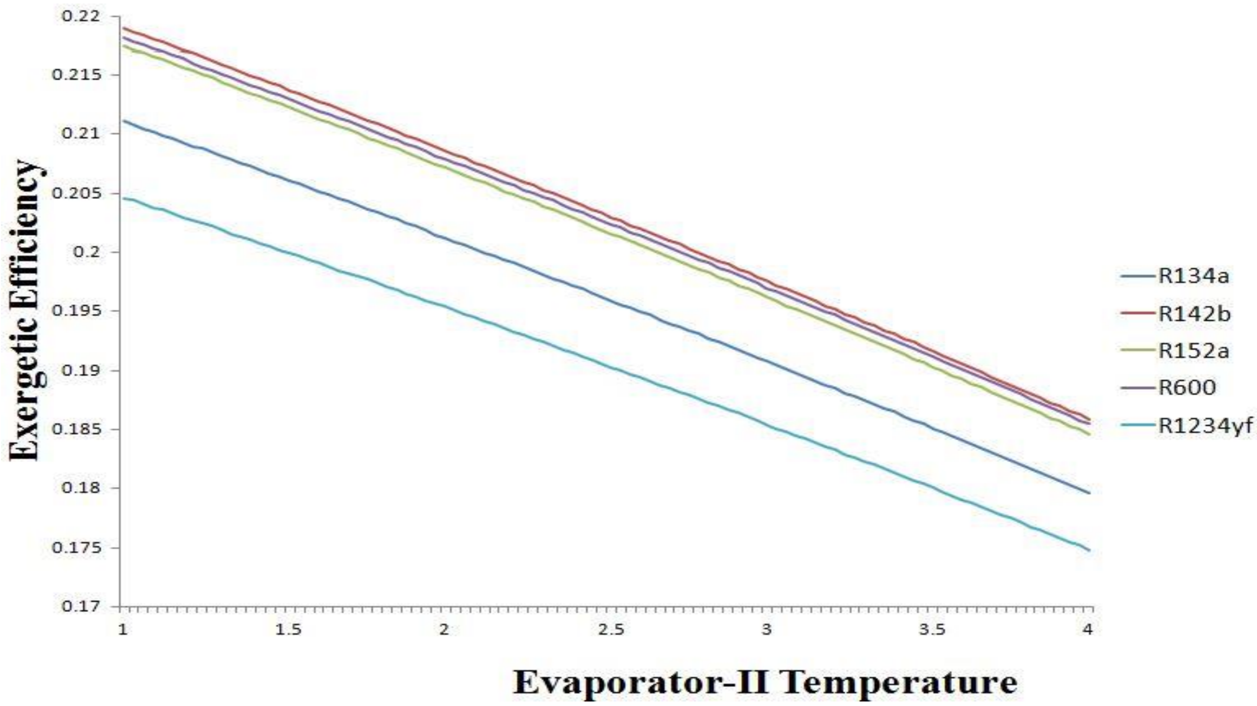

Figure 20 : Comparison of Variation of Exergetic Efficiency with Evaporator Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

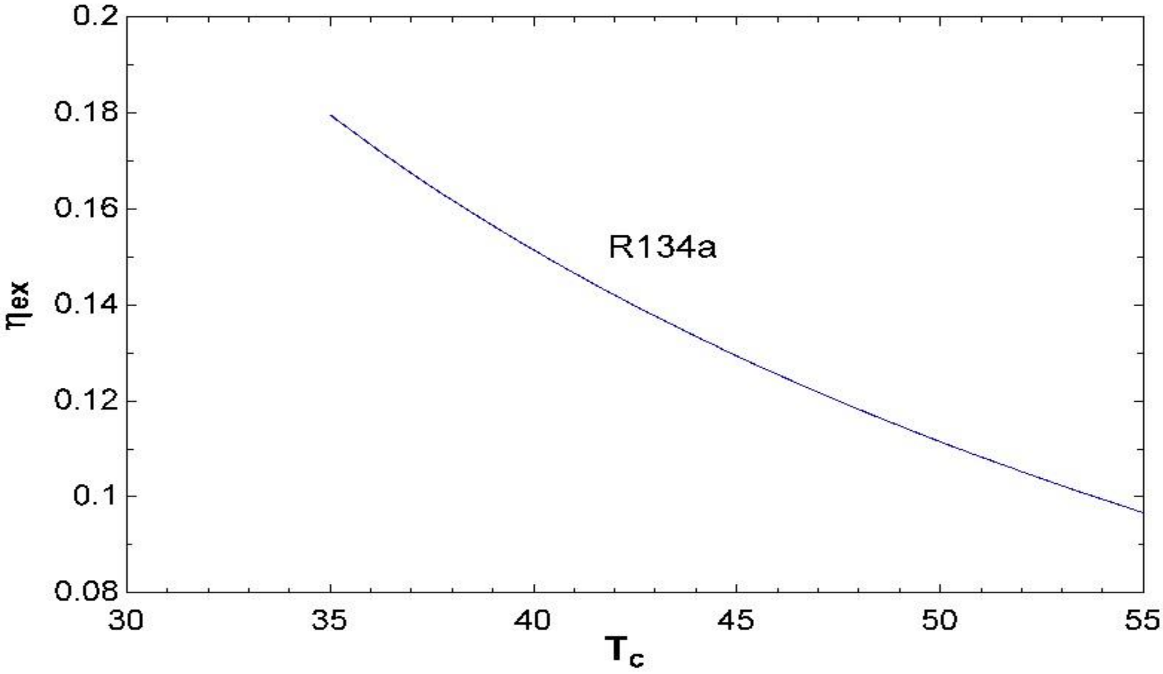

Figure 21: Variation of Exergetic Efficiency with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R134A

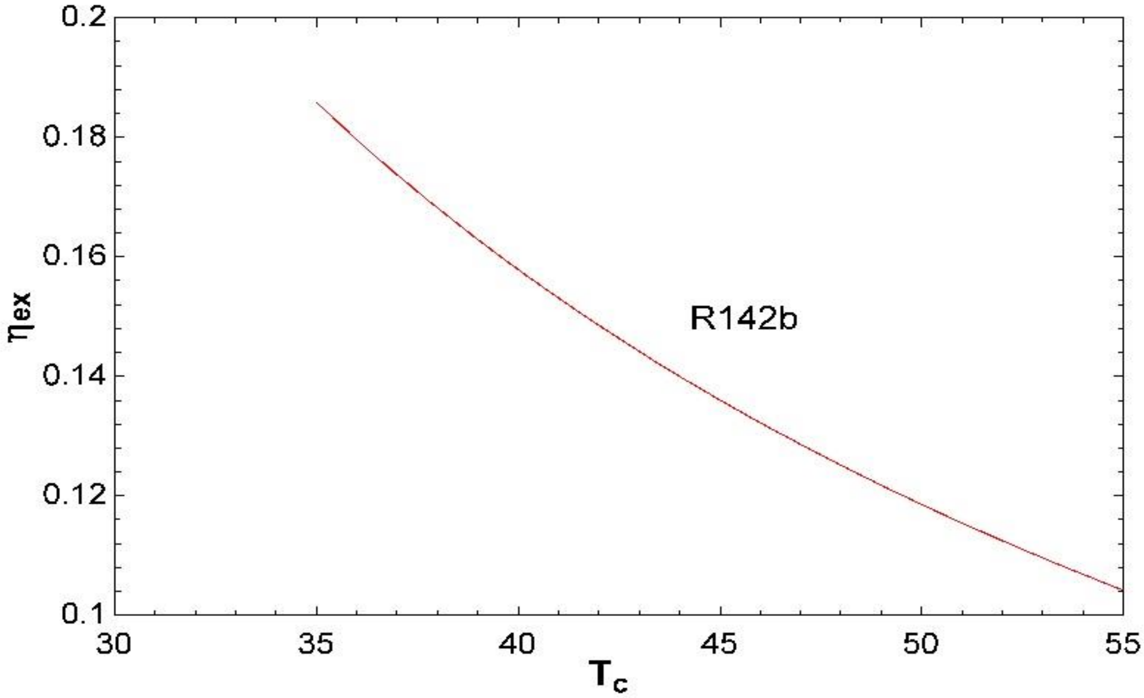

Figure 22: Variation of Exergetic Efficiency with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R142B

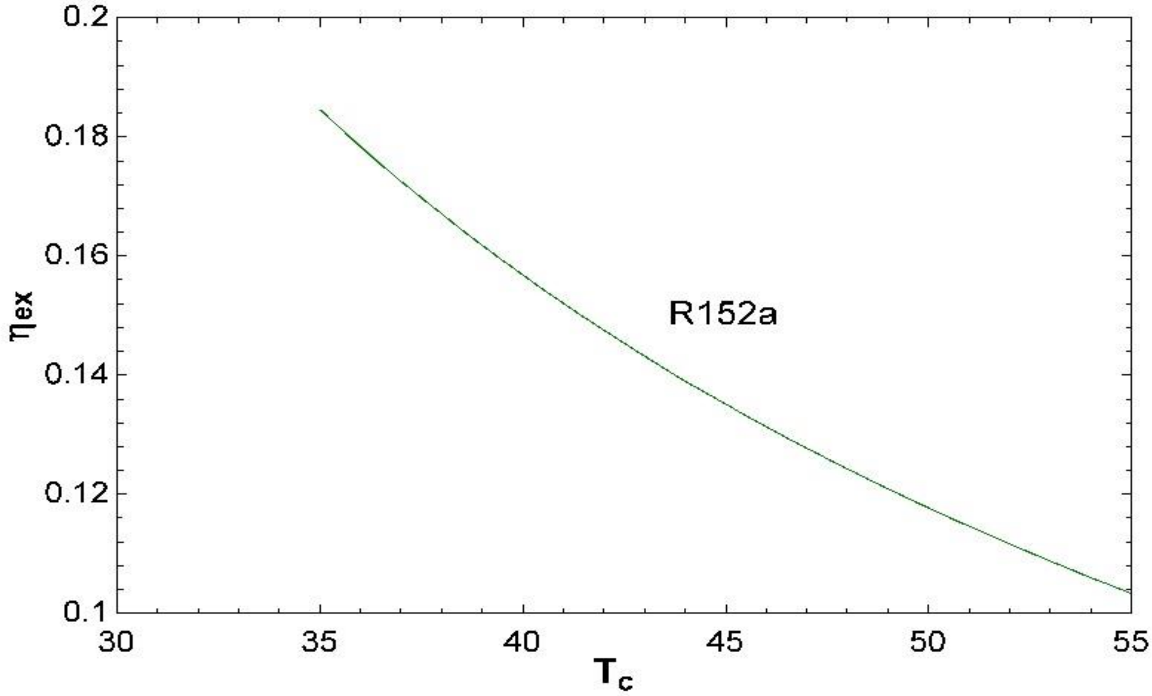

Figure 23: Variation of Exergetic Efficiency with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R152b

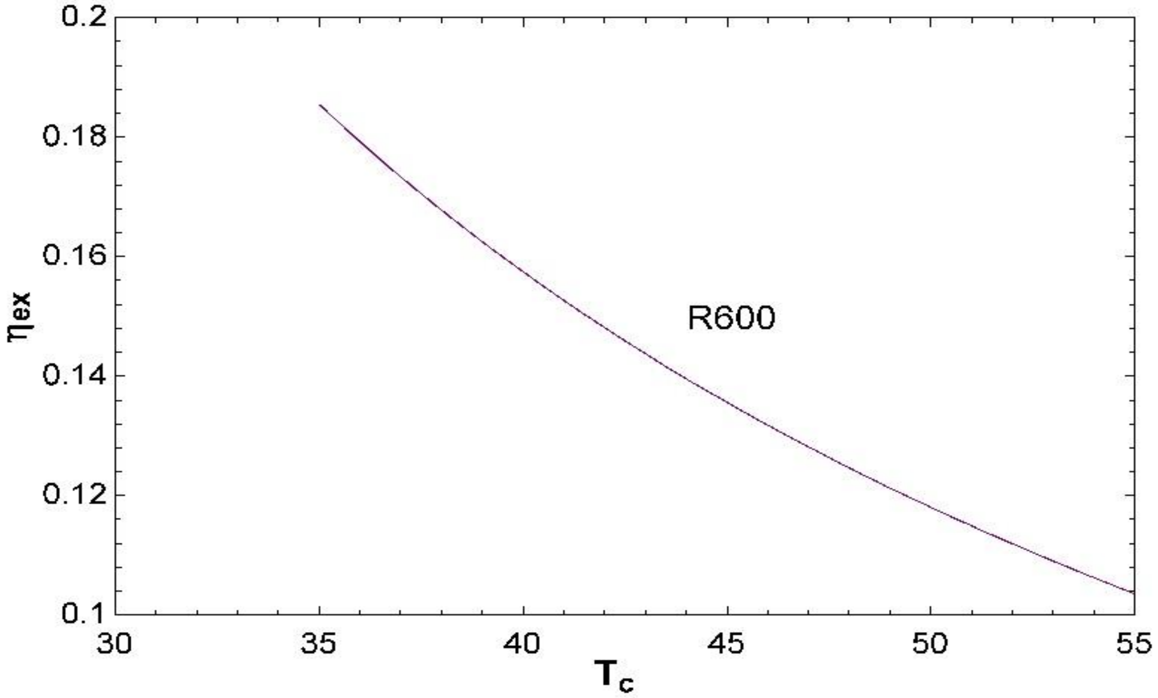

Figure 24: Variation of Exergetic Efficiency with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R600

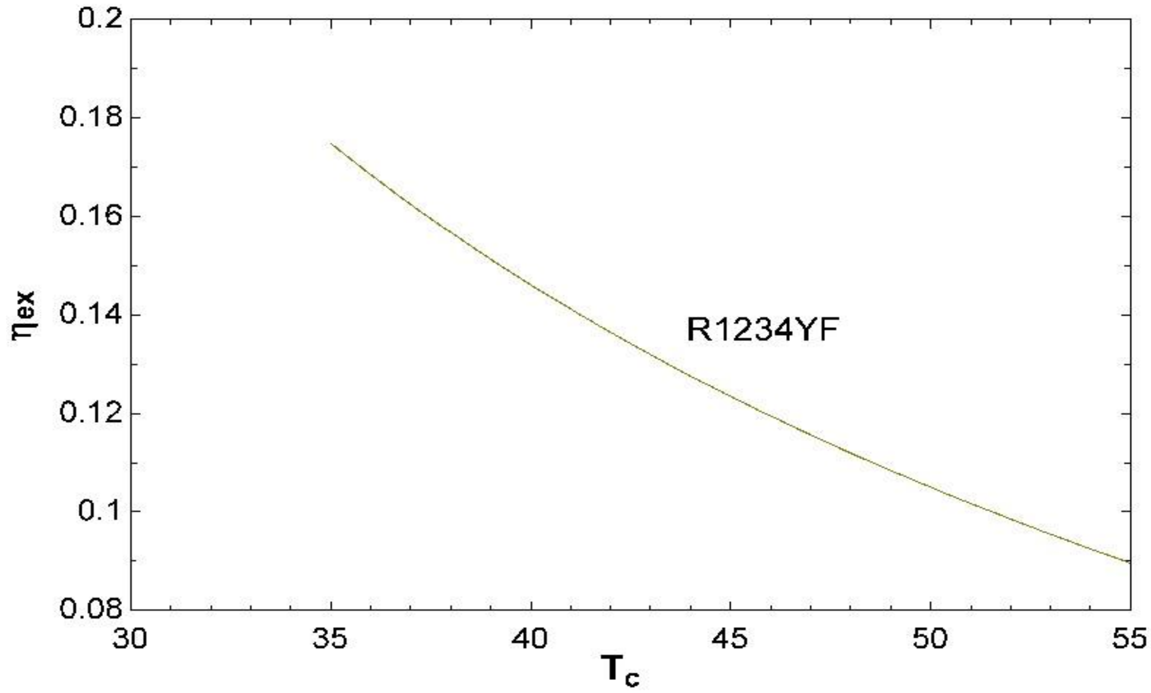

Figure 25: Variation of Exergetic Efficiency with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R1234YF

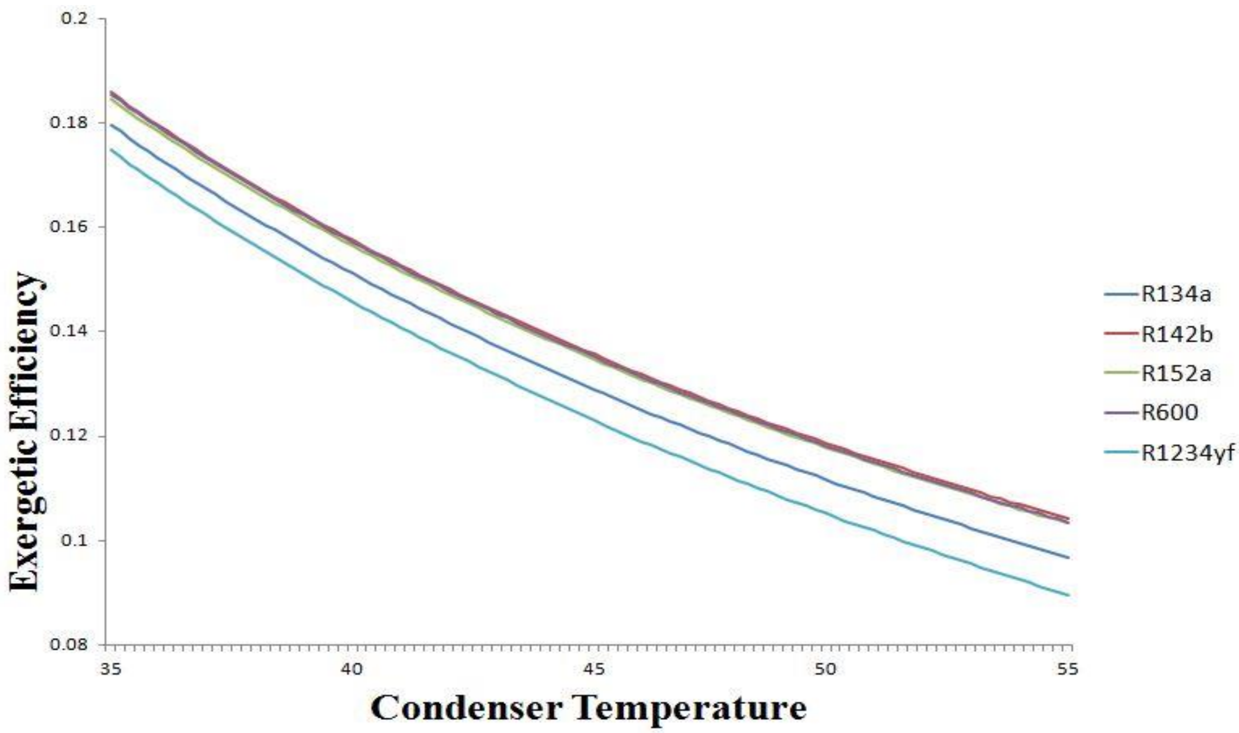

Figure 26: Comparison of Variation of Exergetic Efficiency with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

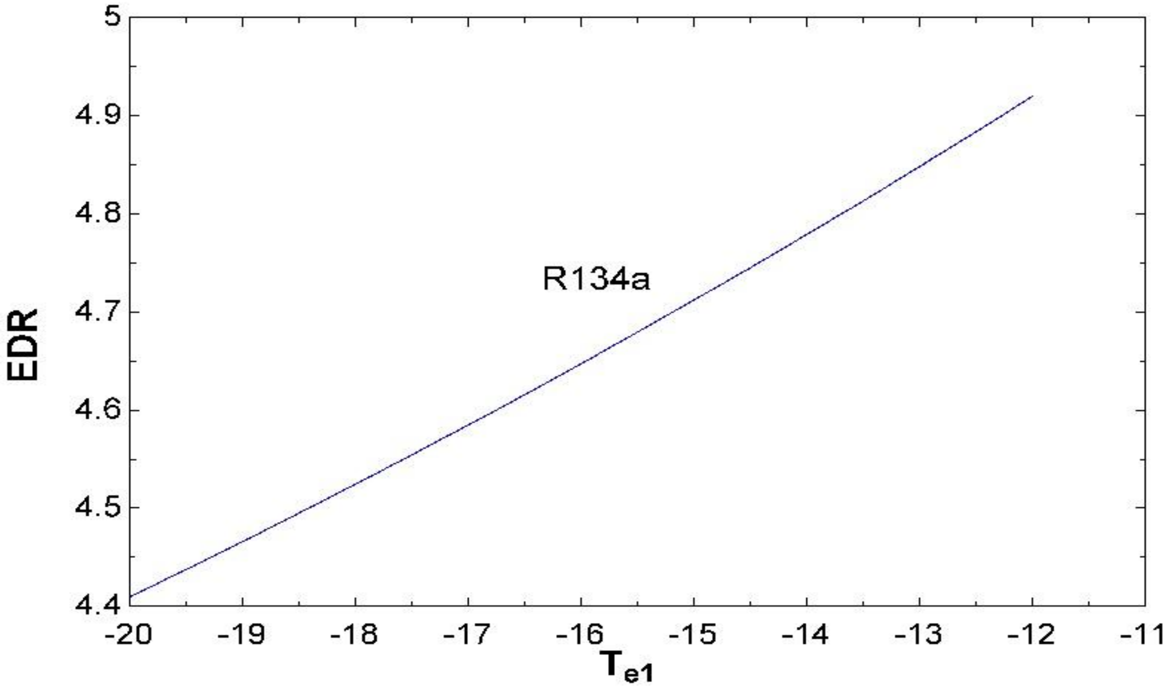

Figure 27: Variation of Exergy Destruction Ratio with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R134A

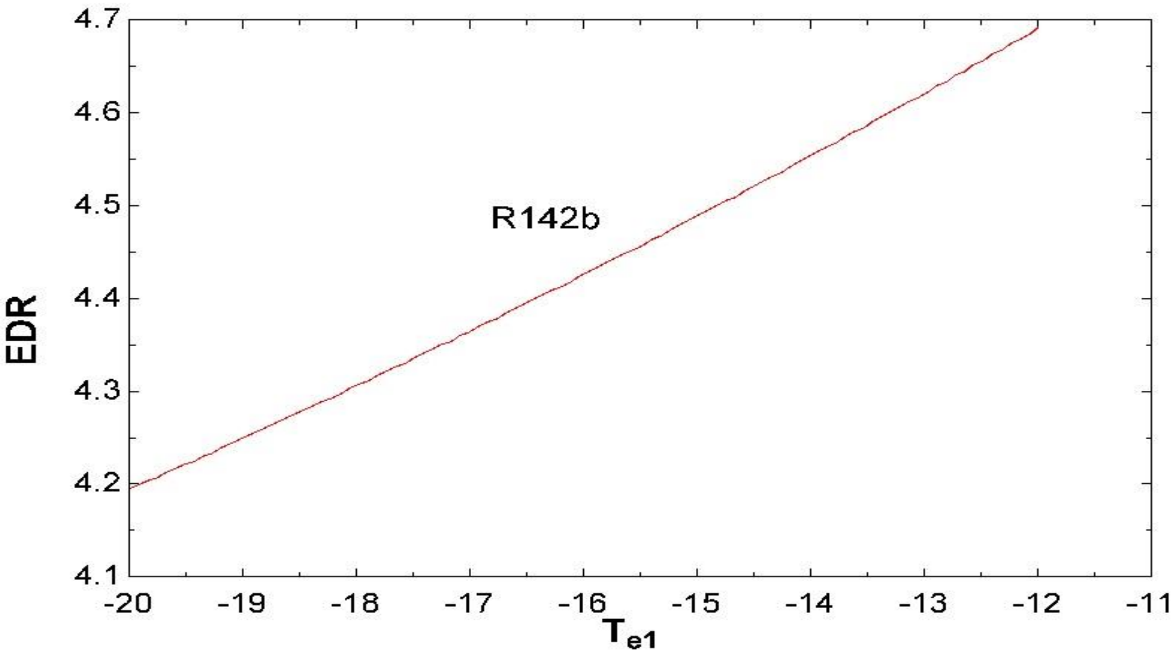

Figure 28: Variation of Exergy Destruction Ratio with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R142B

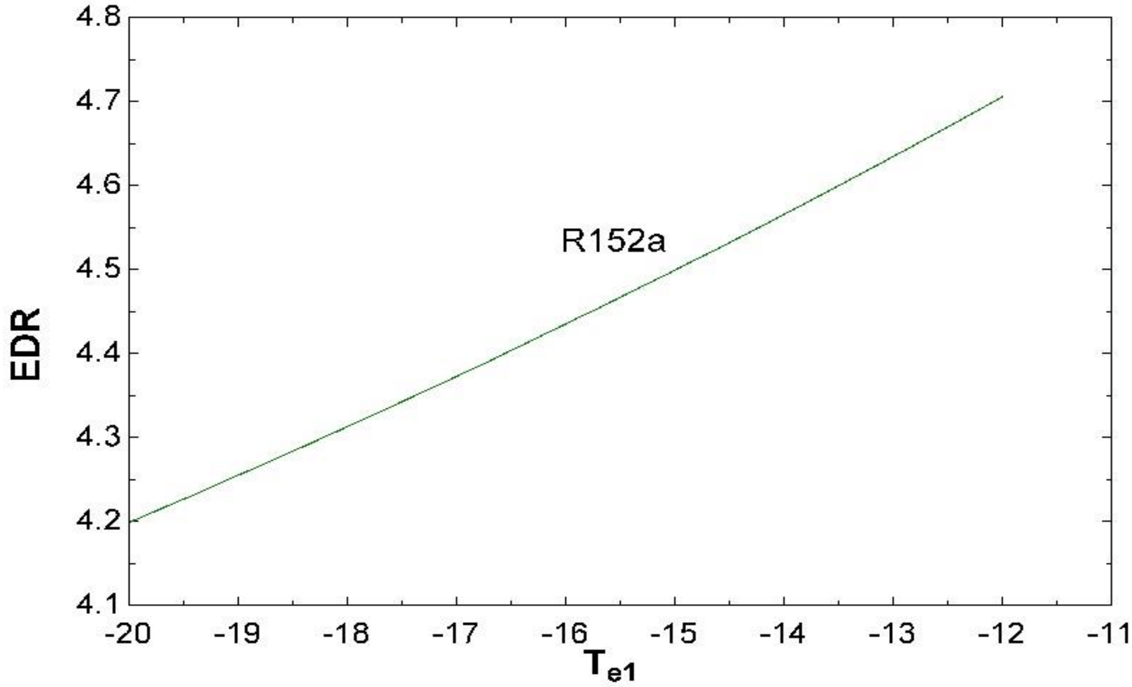

Figure 29: Variation of Exergy Destruction Ratio with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R152A

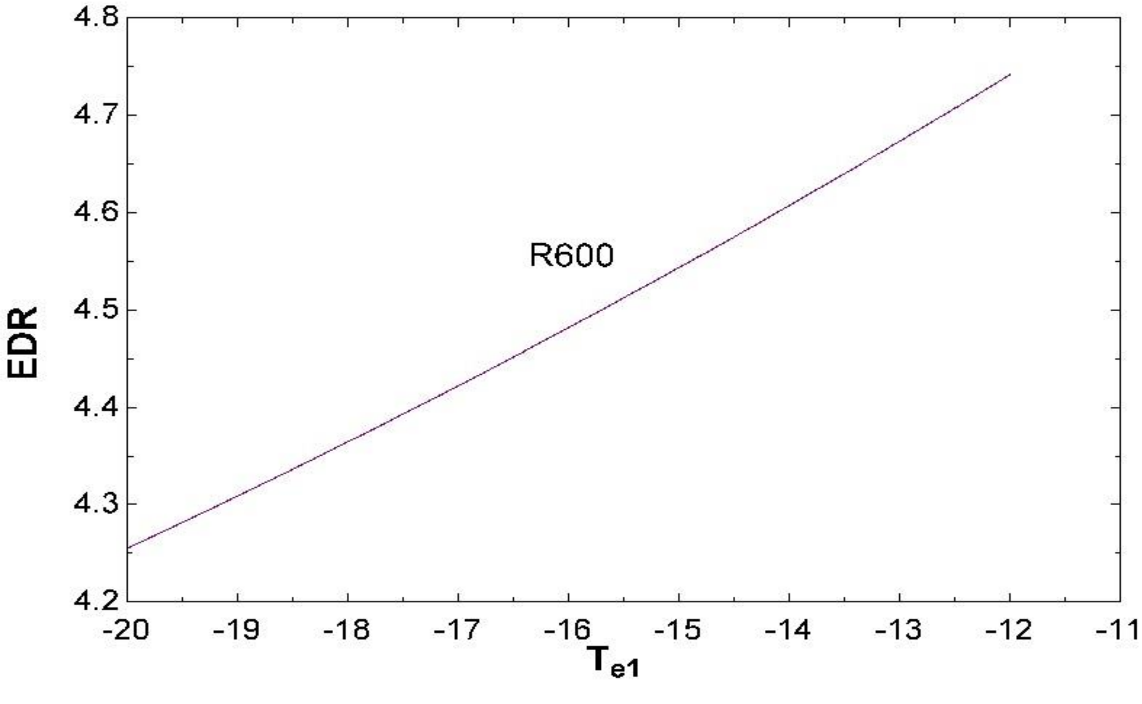

Figure 30: Variation of Exergy Destruction Ratio with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R600

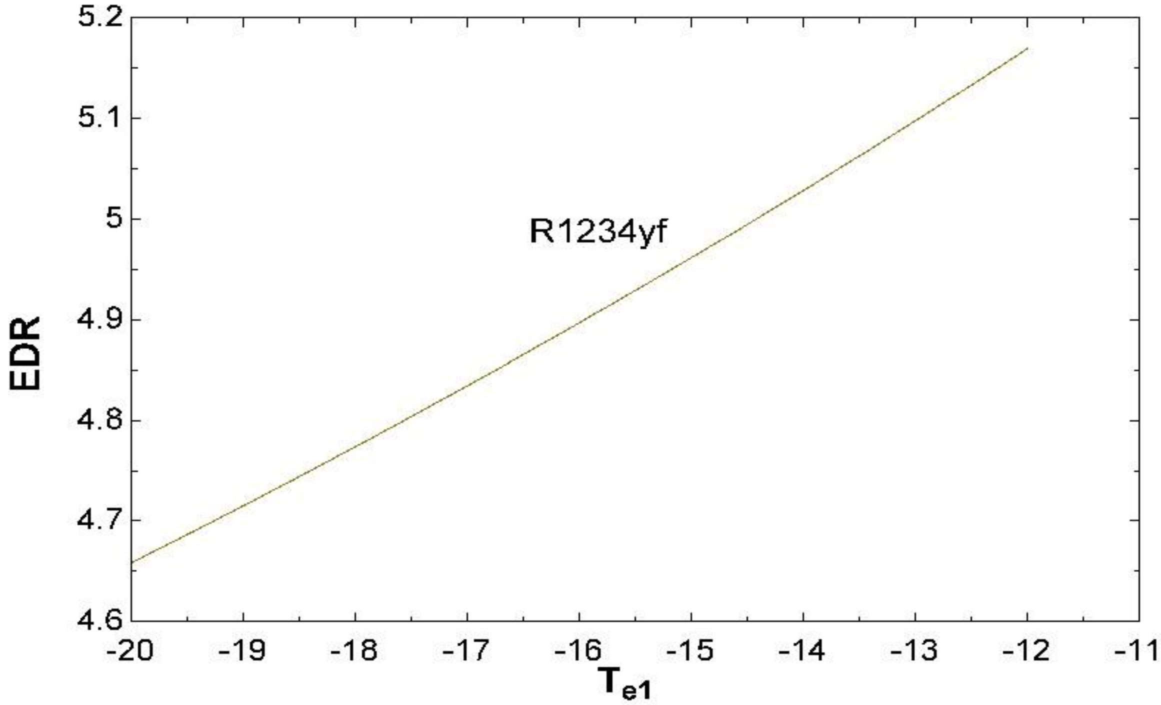

Figure 31: Variation of Exergy Destruction Ratio with Evaporator-I Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R1234YF

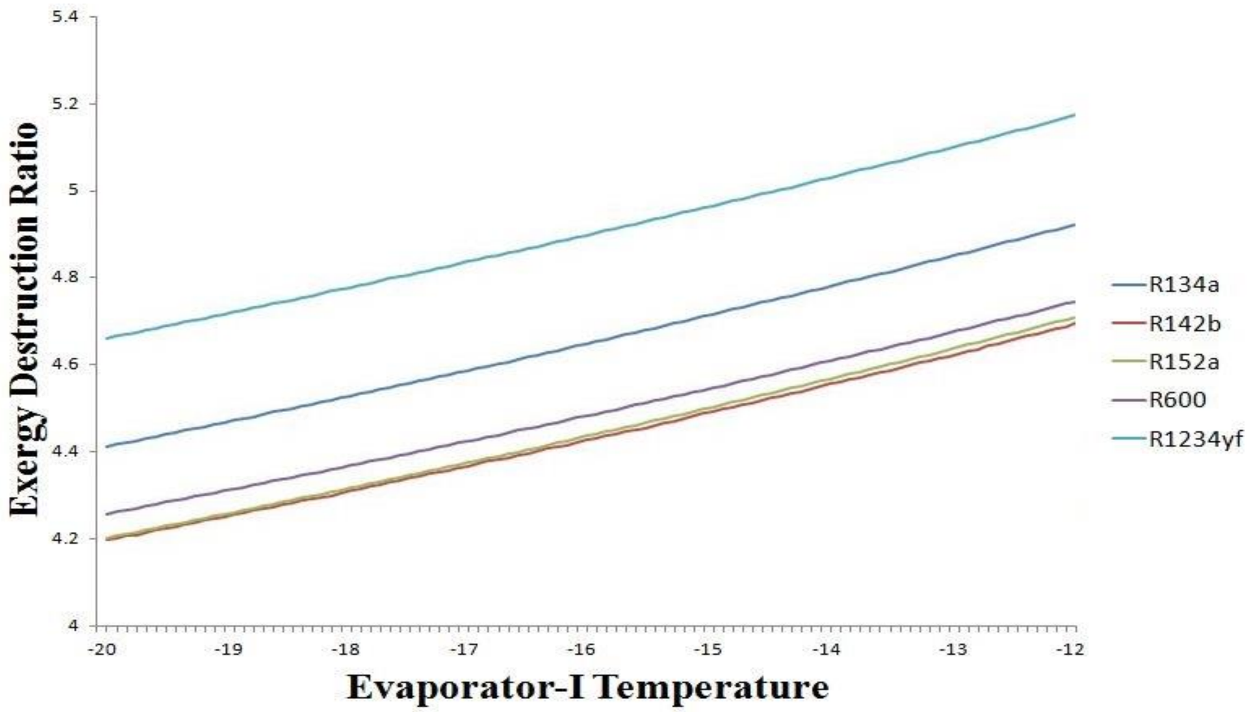

Figure 32: Comparison of Variation of Exergy Destruction Ratio with Evaporator Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

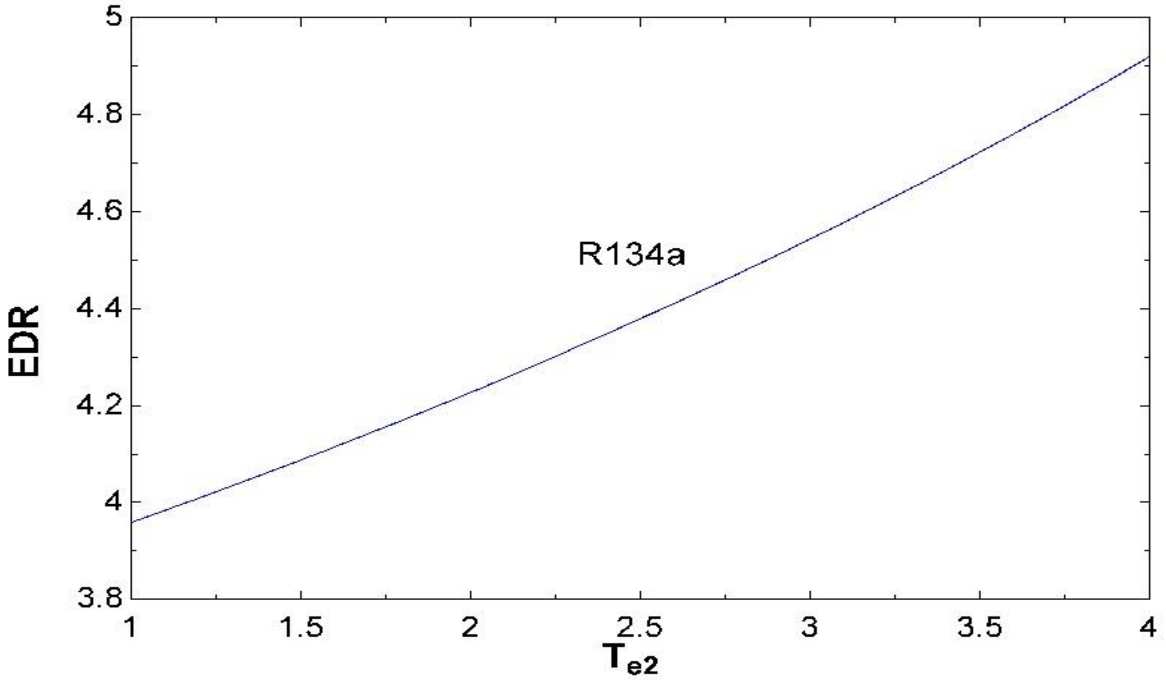

Figure 33: Variation of Exergy Destruction Ratio with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with **R134A**

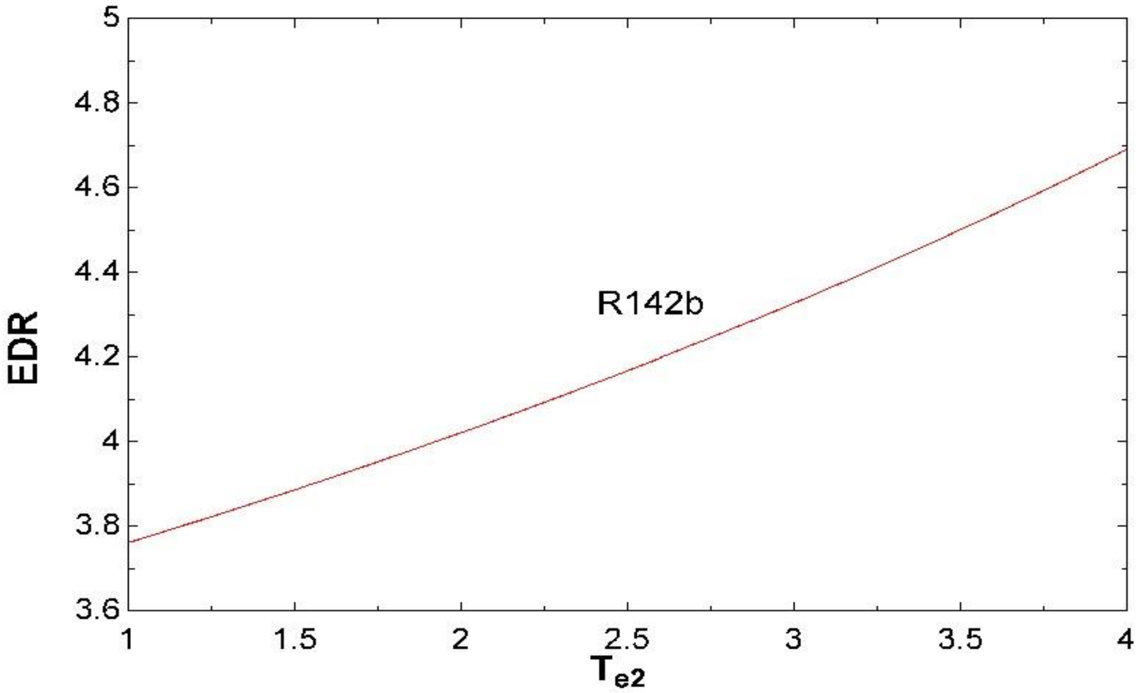

Figure 34: Variation of Exergy Destruction Ratio with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R142B

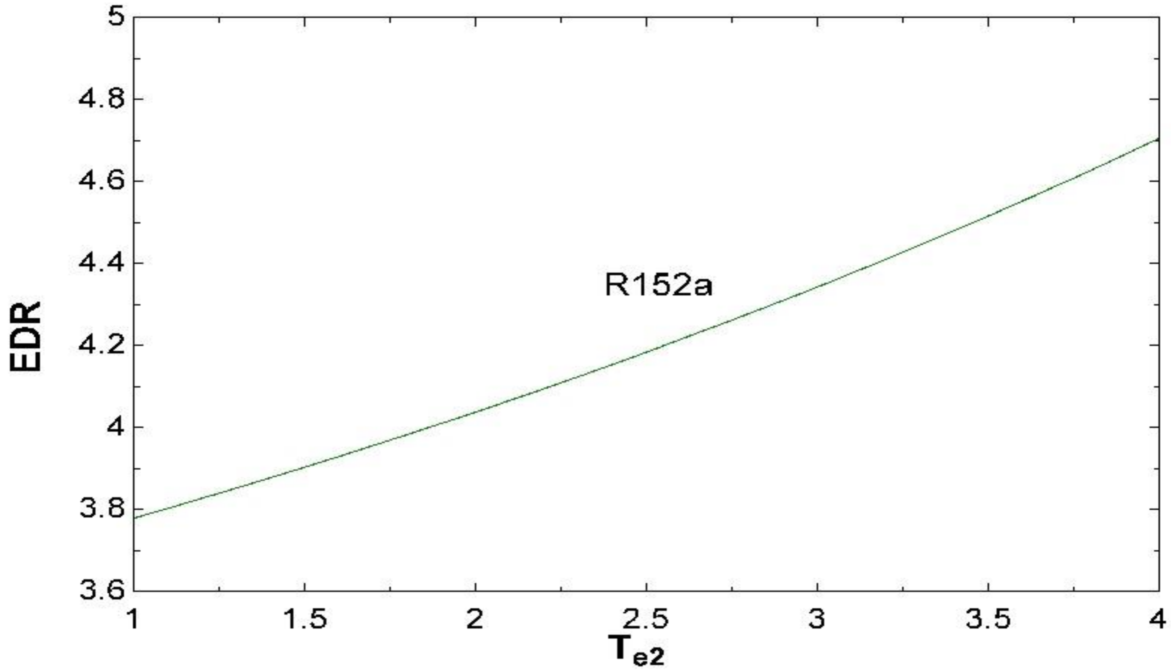

Figure 35: Variation of Exergy Destruction Ratio with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R152A

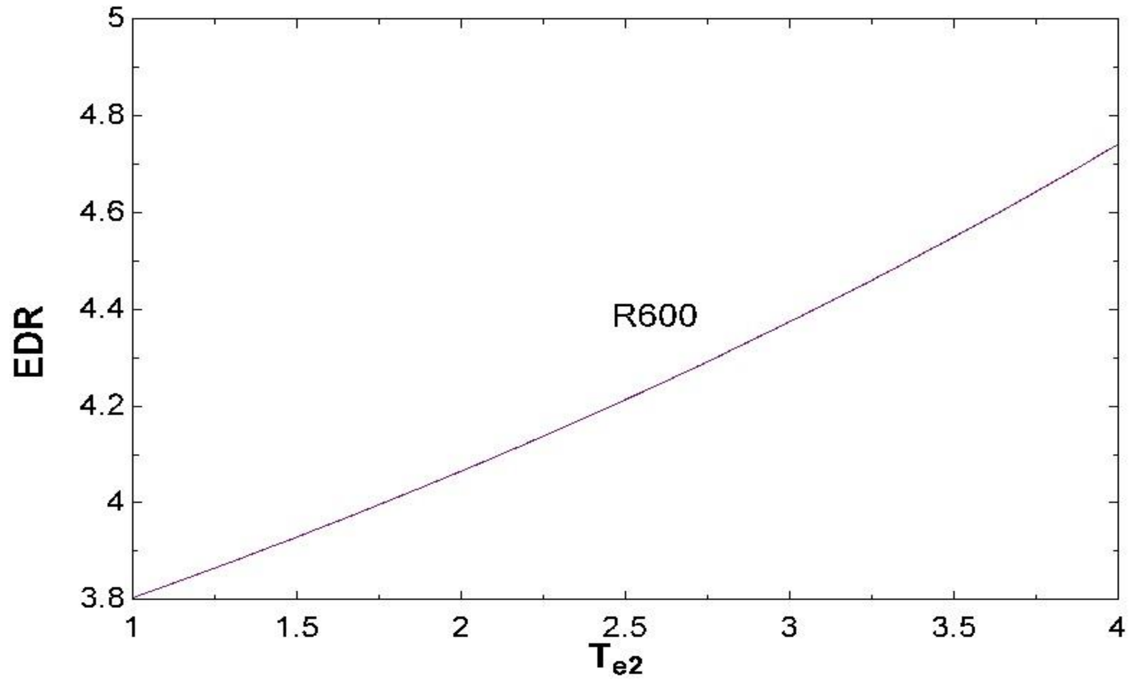

Figure 36: Variation of Exergy Destruction Ratio with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R600

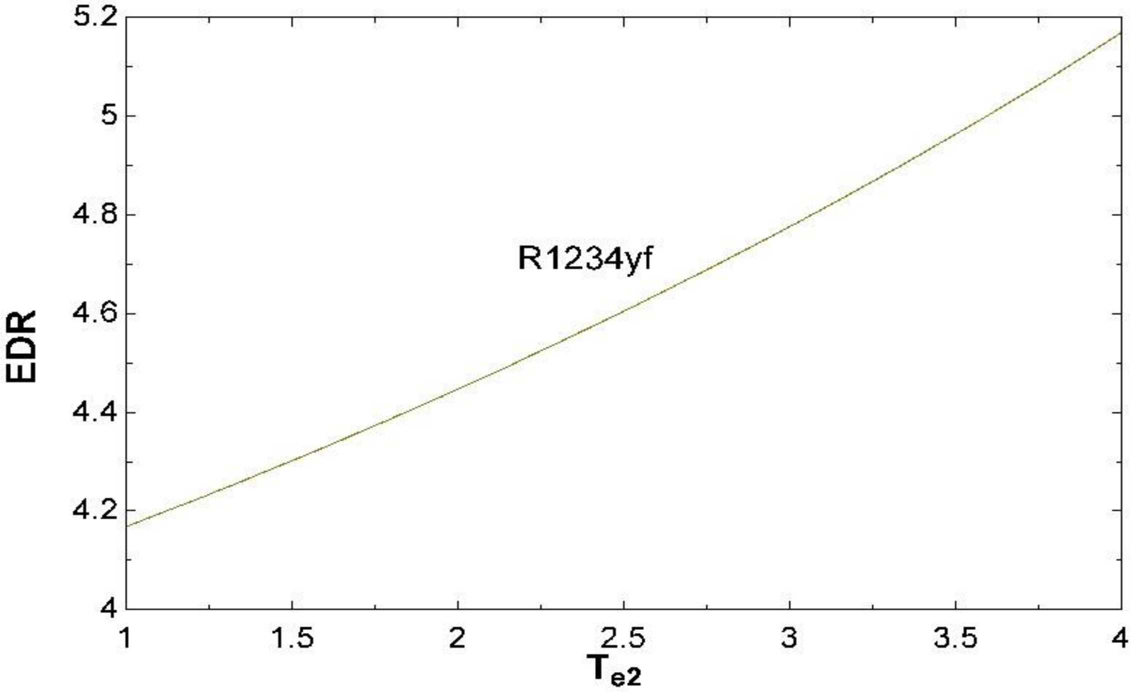

Figure 37: Variation of Exergy Destruction Ratio with Evaporator-II Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R1234YF

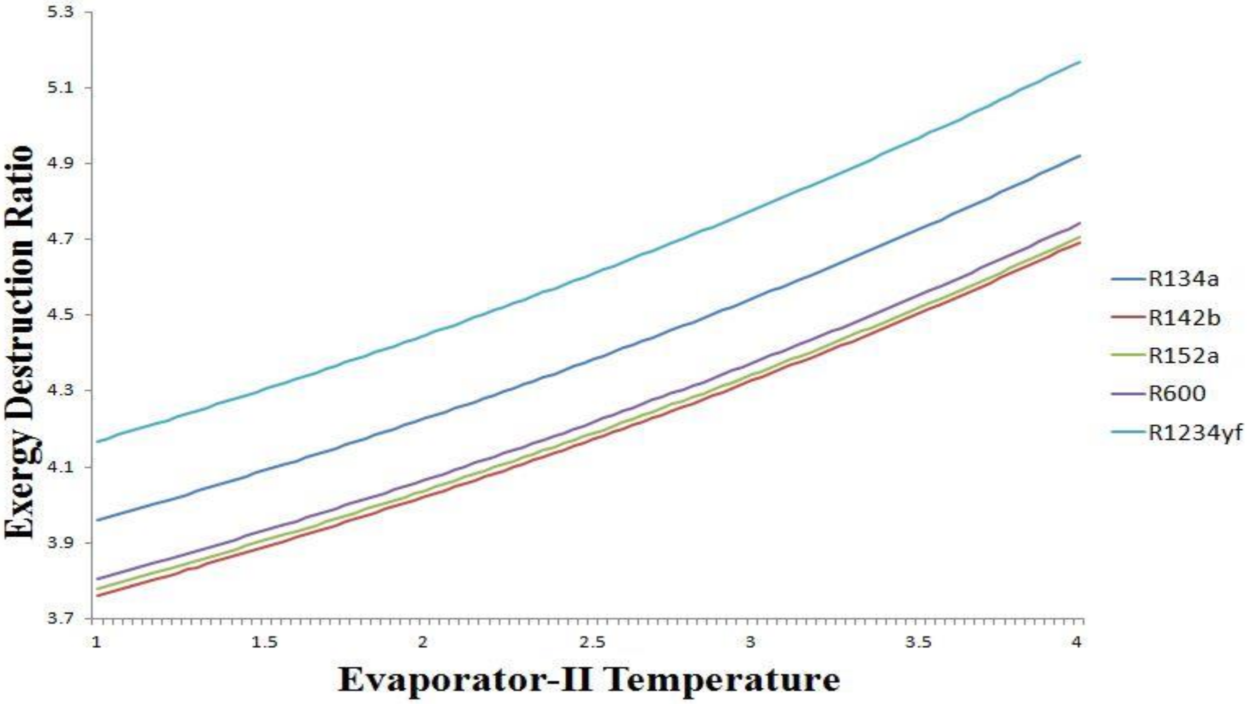

Figure 38: Comparison of Variation of Exergy Destruction Ratio with Evaporator Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

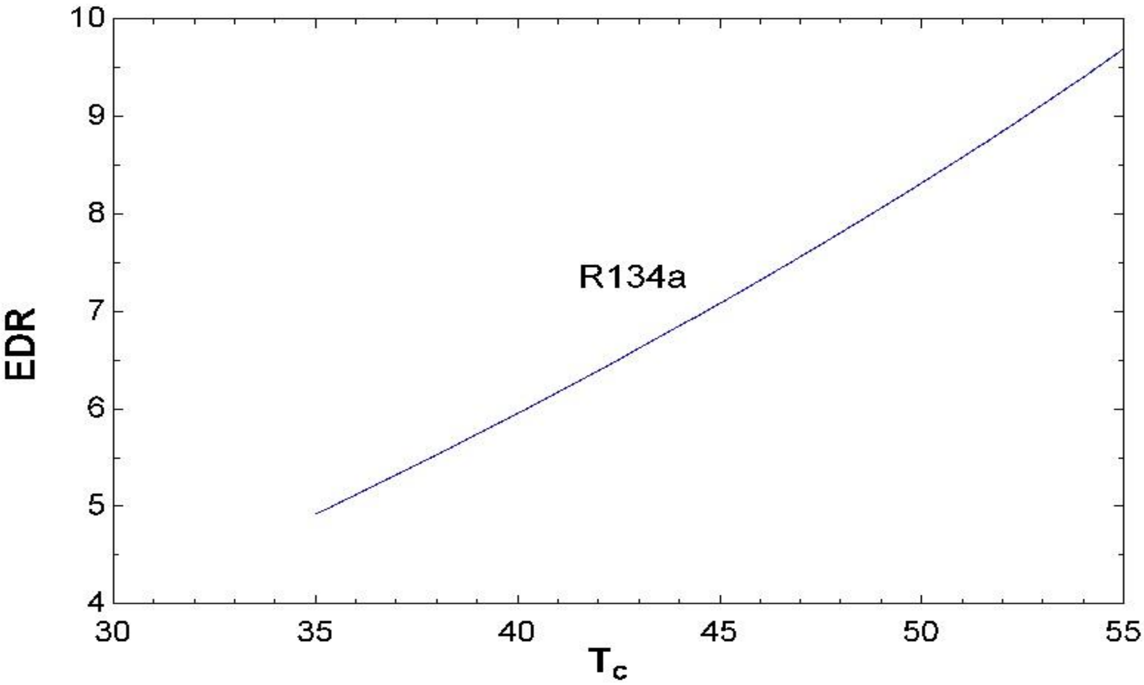

Figure 39: Variation of Exergy Destruction Ratio with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R134A

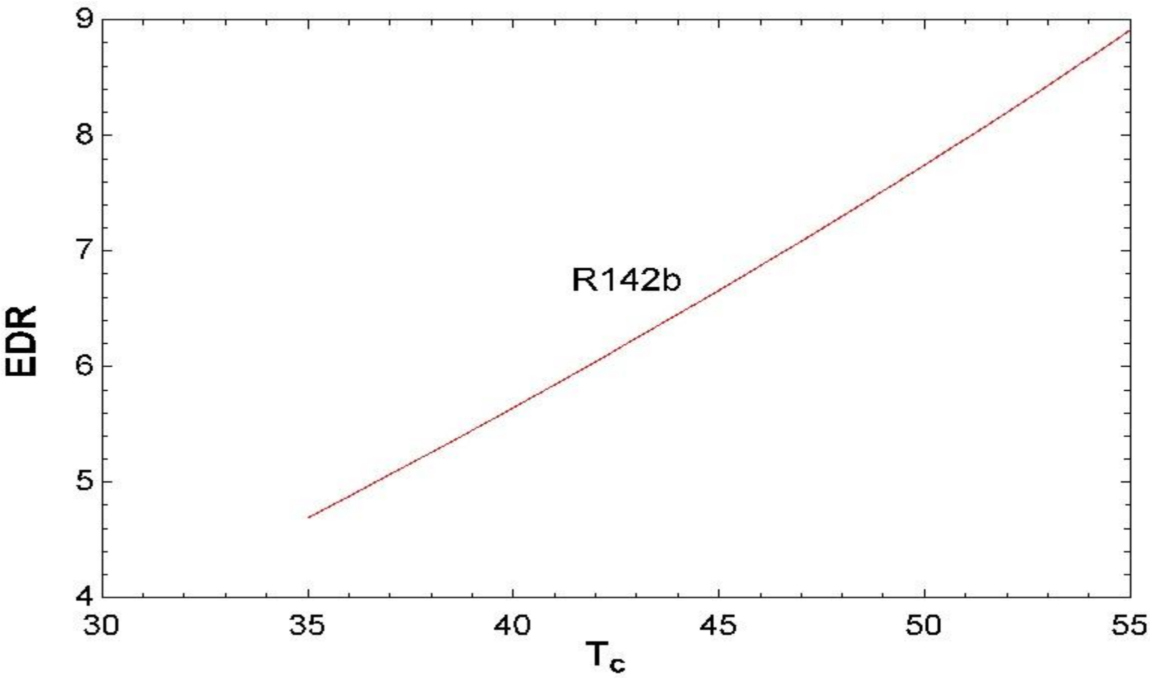

Figure 40: Variation of Exergy Destruction Ratio with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R42b

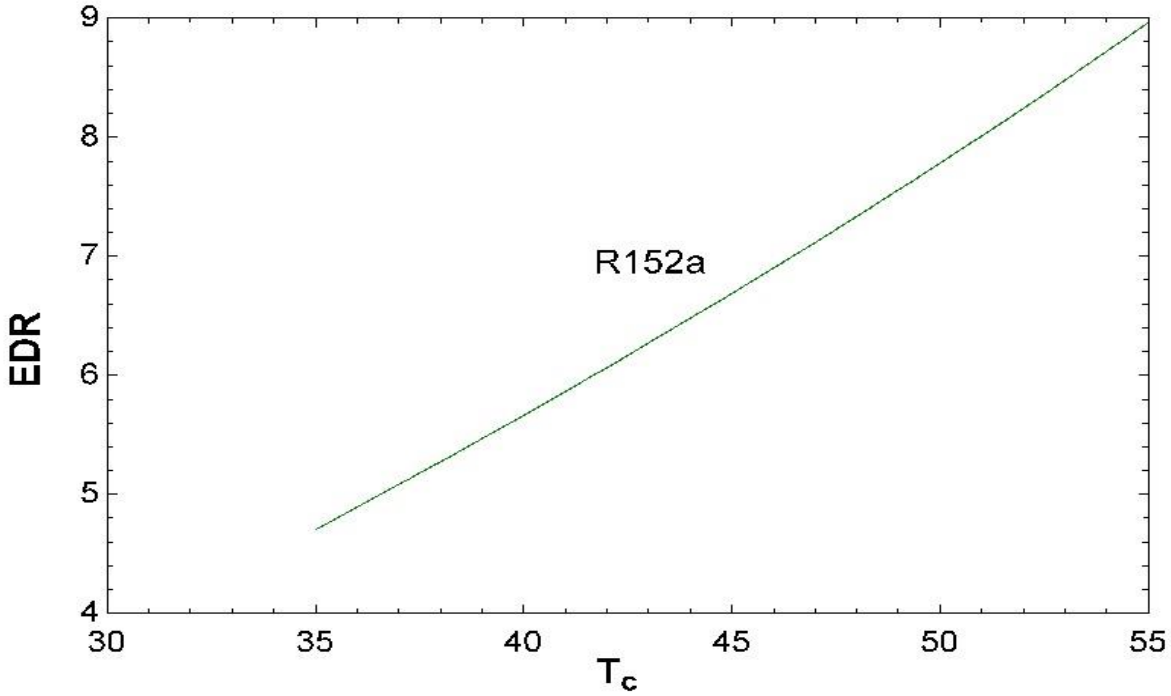

Figure 41: Variation of Exergy Destruction Ratio with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R152A

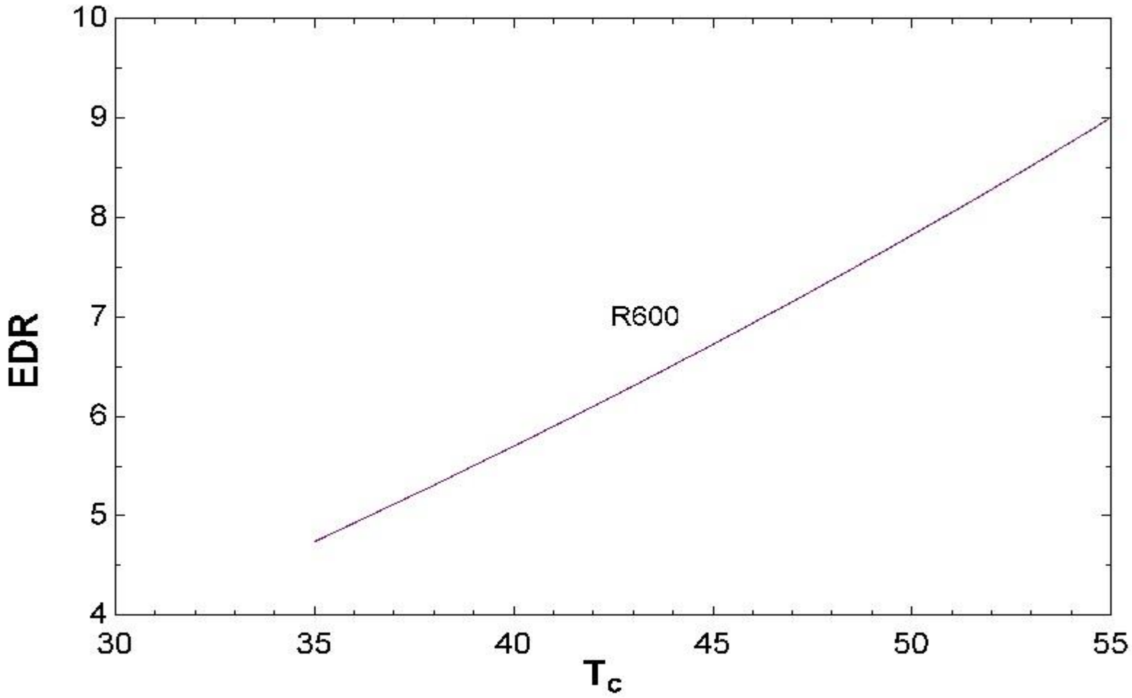

Figure 42: Variation of Exergy Destruction Ratio with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R600

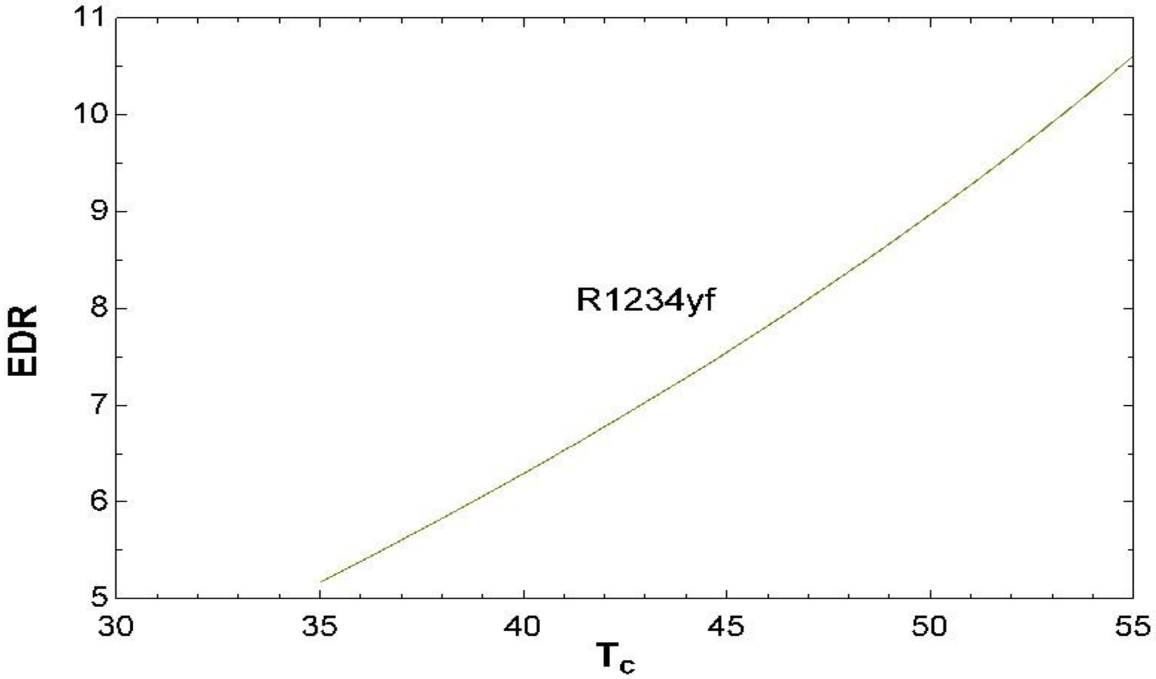

Figure 43: Variation of Exergy Destruction Ratio with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE with R1234YF

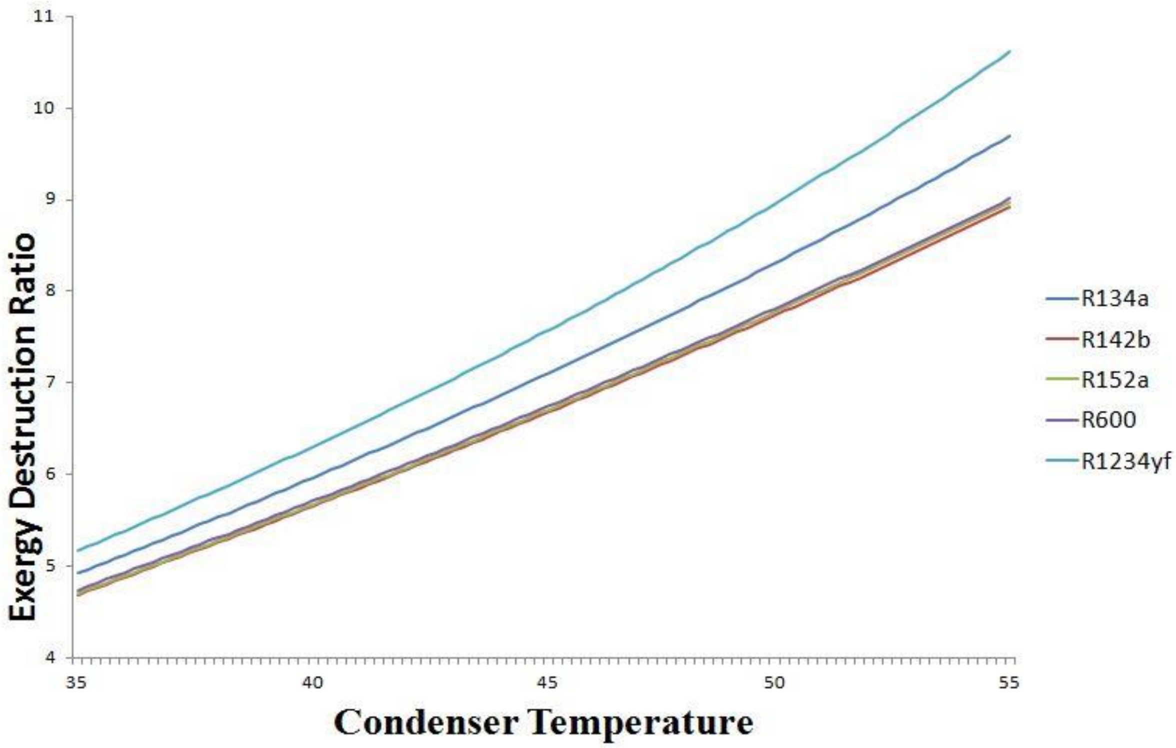

Figure 44: Comparison of Variation of Exergy Destruction Ratio with Condenser Temperature of Multi-Evaporator Refrigeration System with Flash Chamber and LVHE

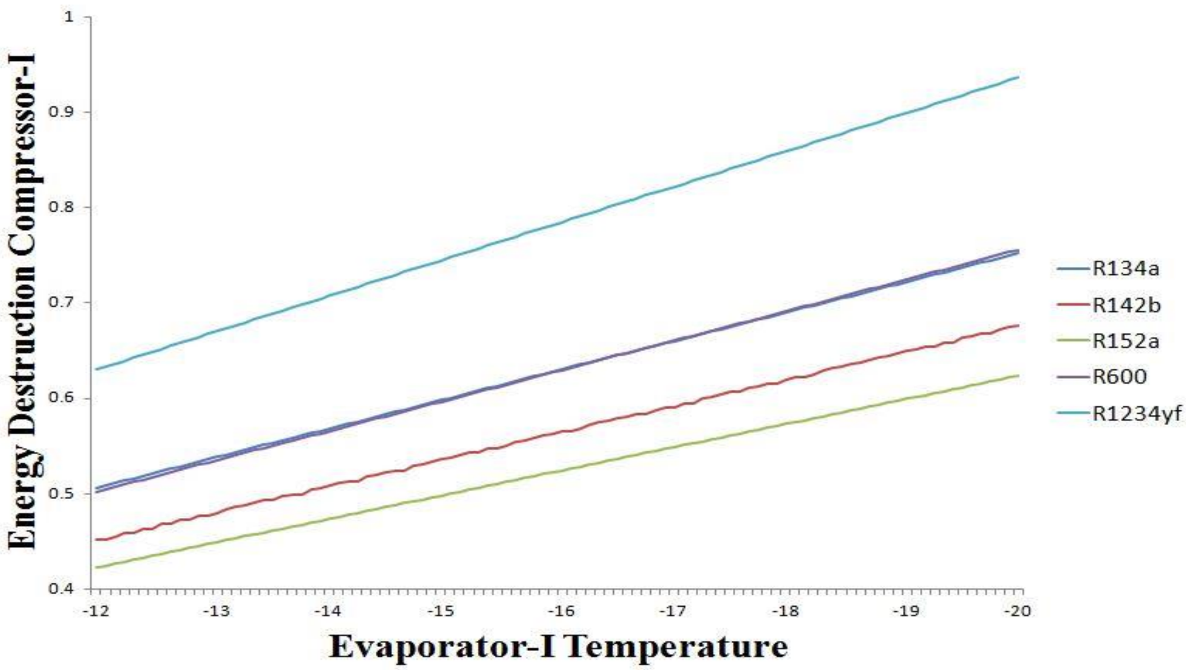

Figure 45: Variation of Exergy Destruction Of Compression-I with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

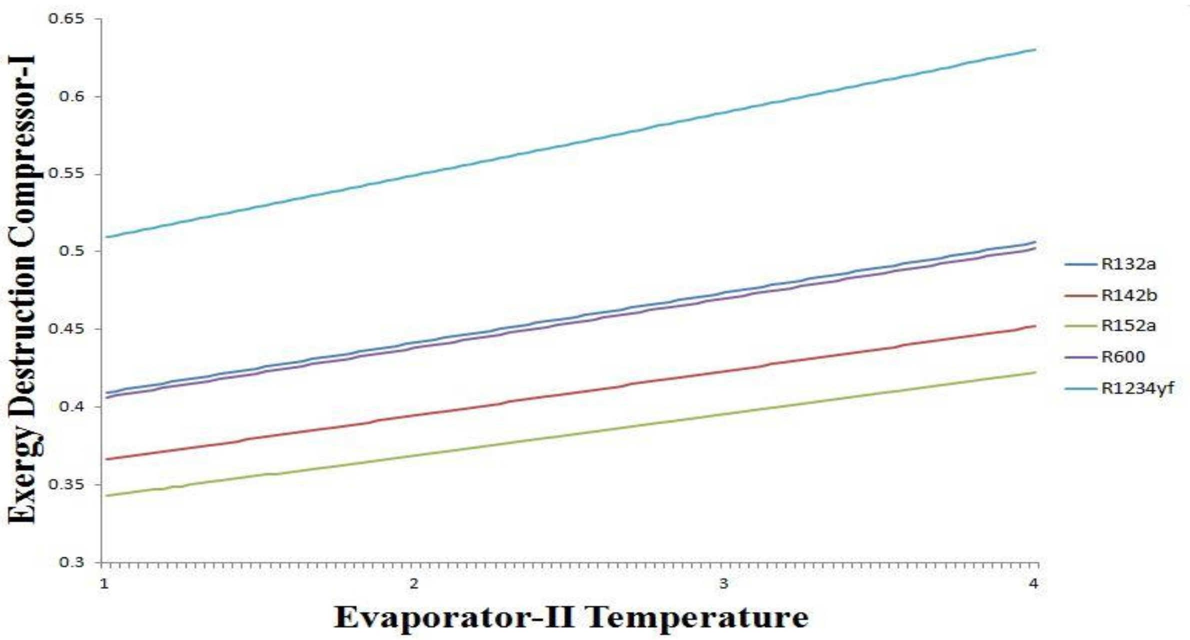

Figure 46: Variation of Exergy Destruction Of Compression-I with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

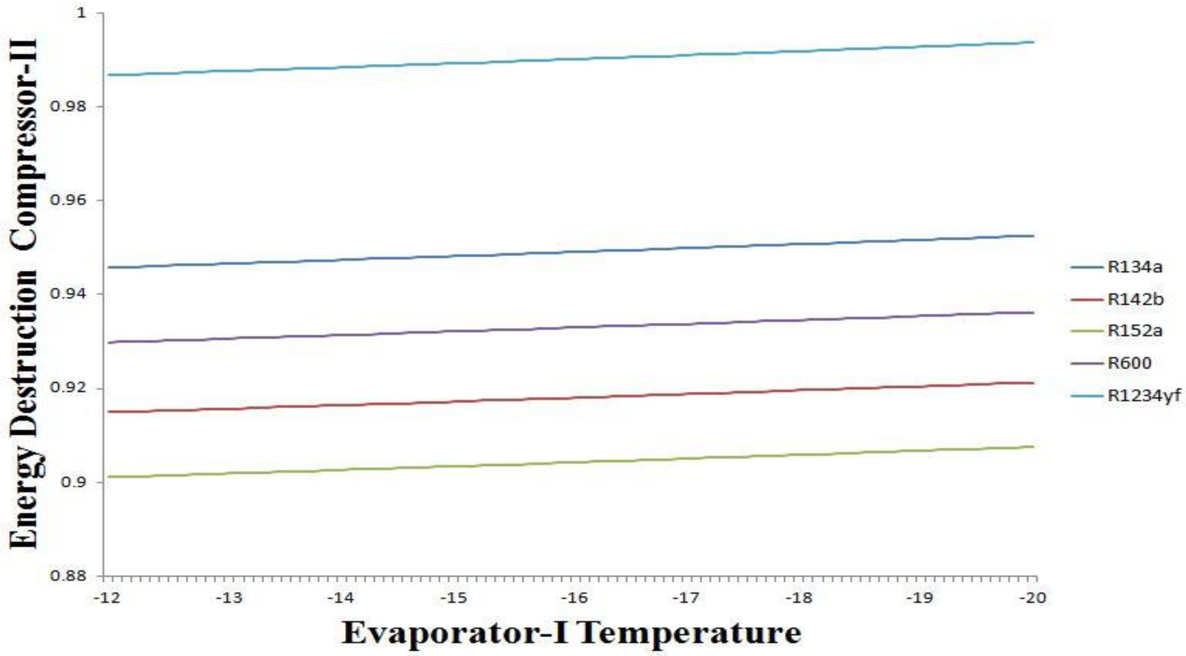

Figure 47: Variation of Exergy Destruction Of Compression-II with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

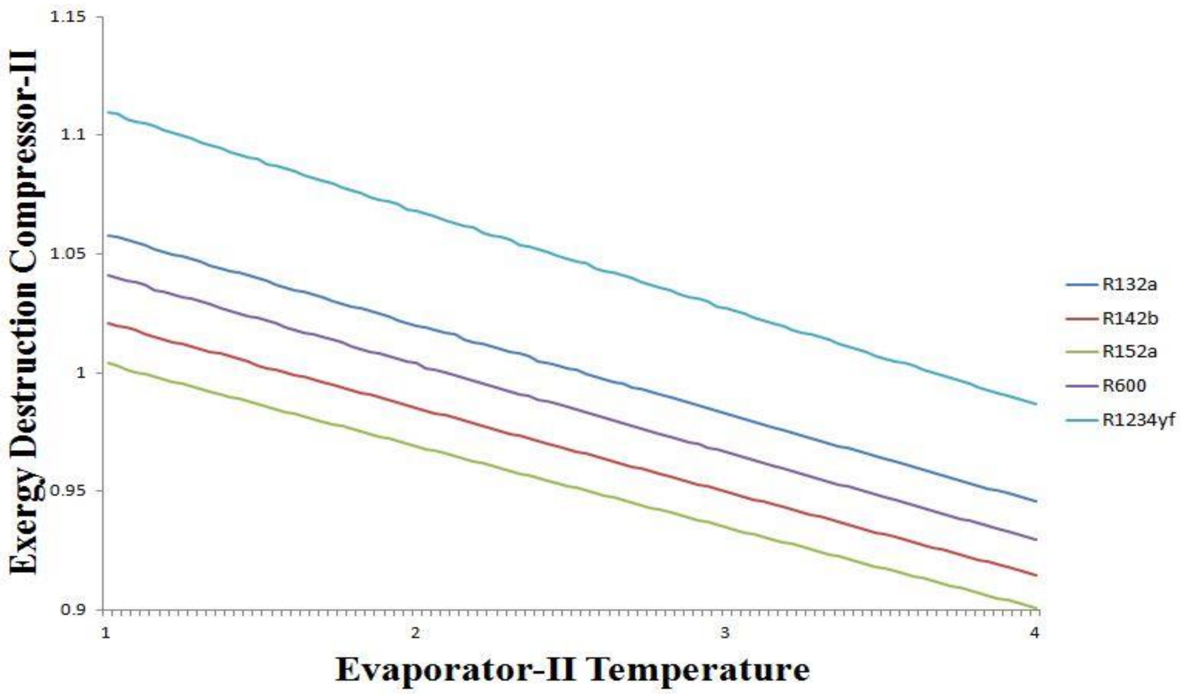

Figure 48: Variation of Exergy Destruction Of Compression-II with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

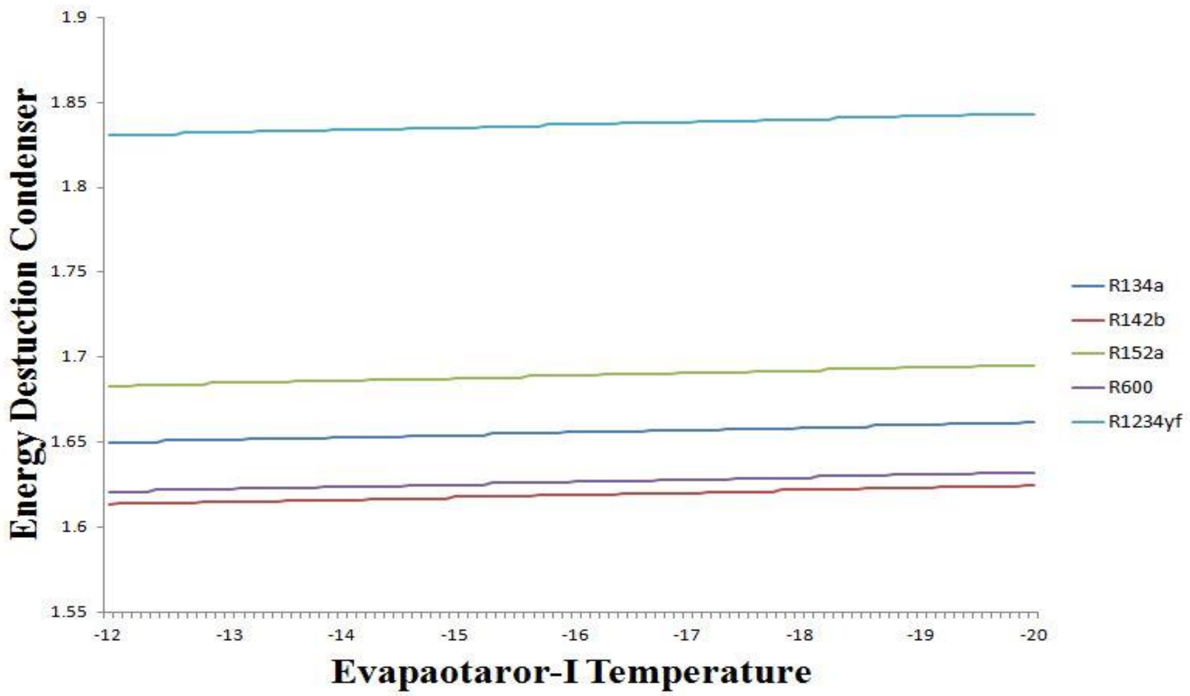

Figure 49: Variation of Exergy Destruction Of Condenser with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

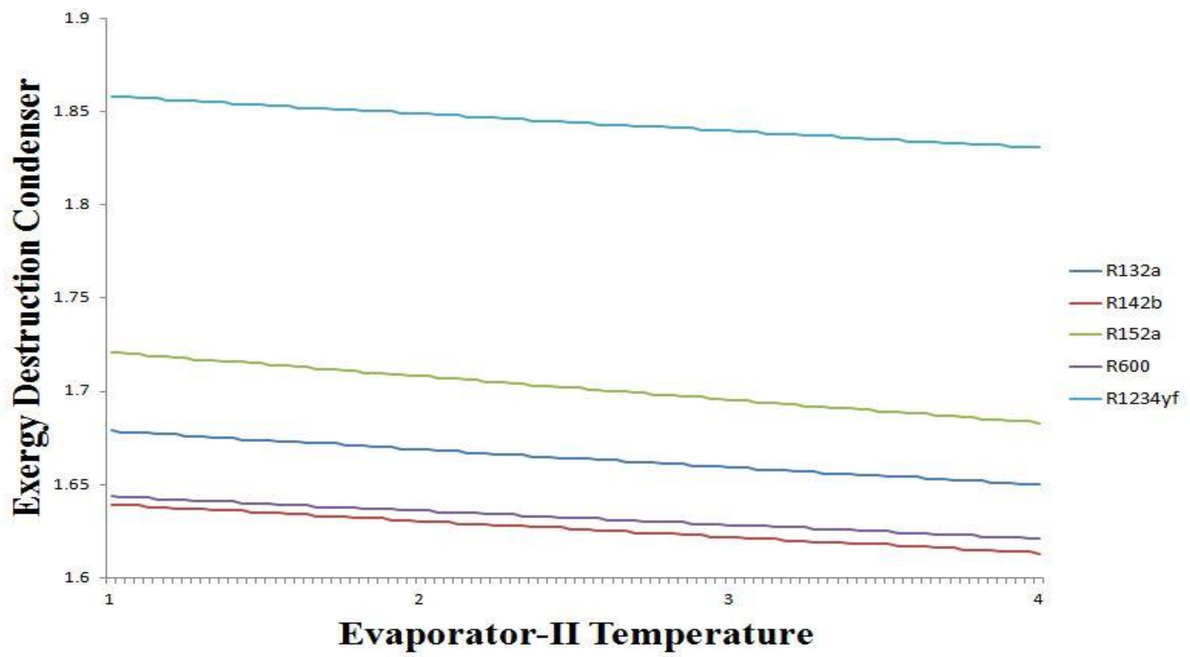

Figure 50: Variation of Exergy Destruction Of Condenser with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

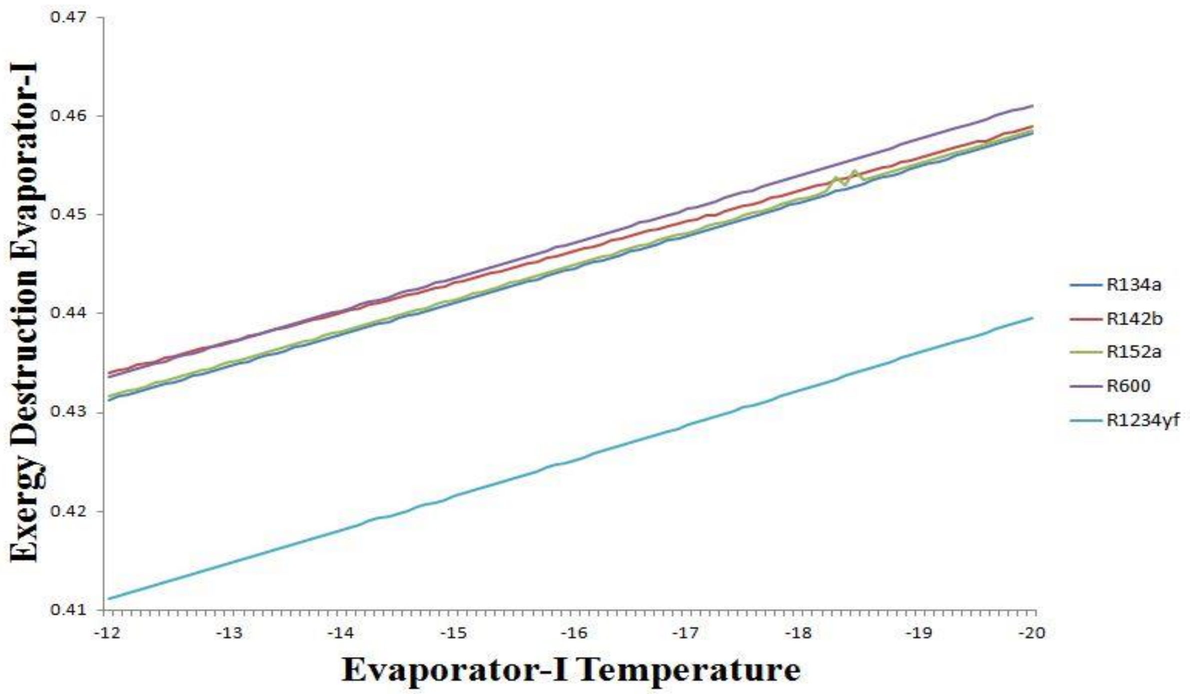

Figure 51: Variation of Exergy Destruction Of Evaporator-I with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

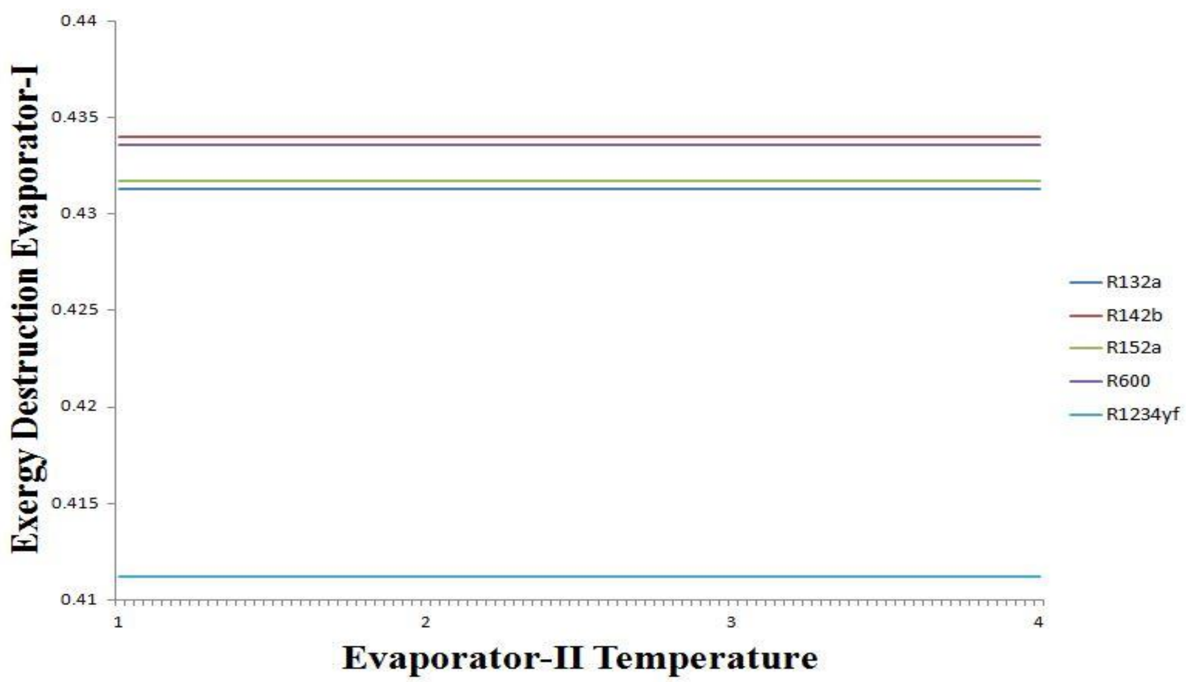

Figure 52: Variation of Exergy Destruction Of Evaporator-I with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

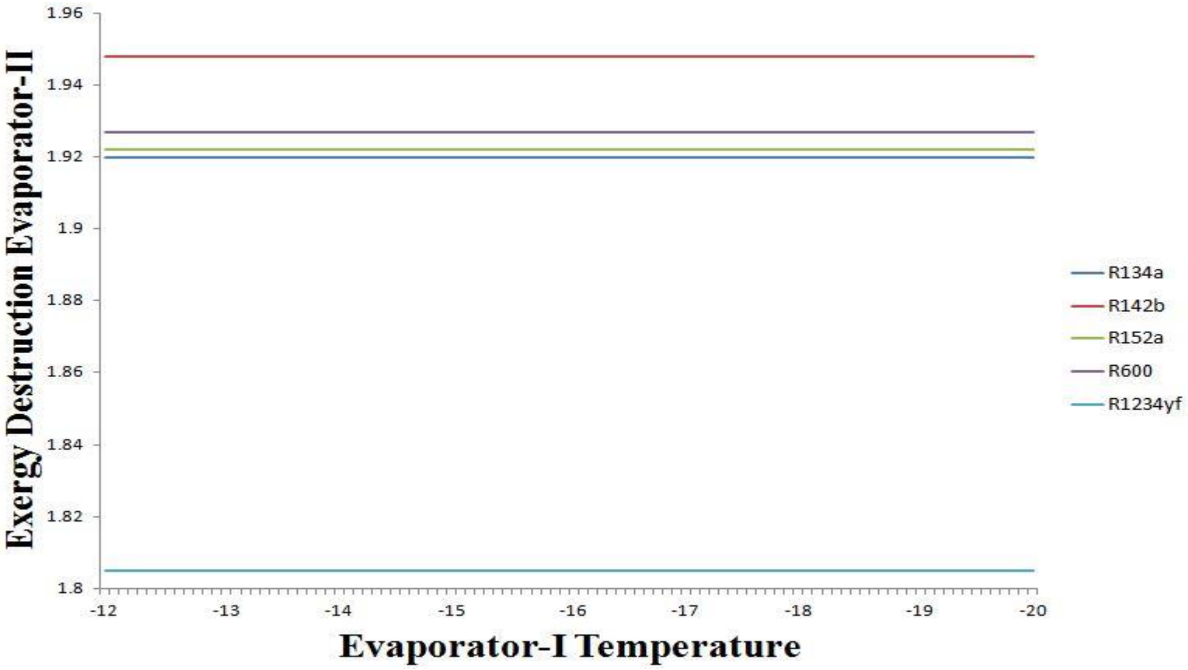

Figure 53: Variation of Exergy Destruction Of Evaporator-II with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

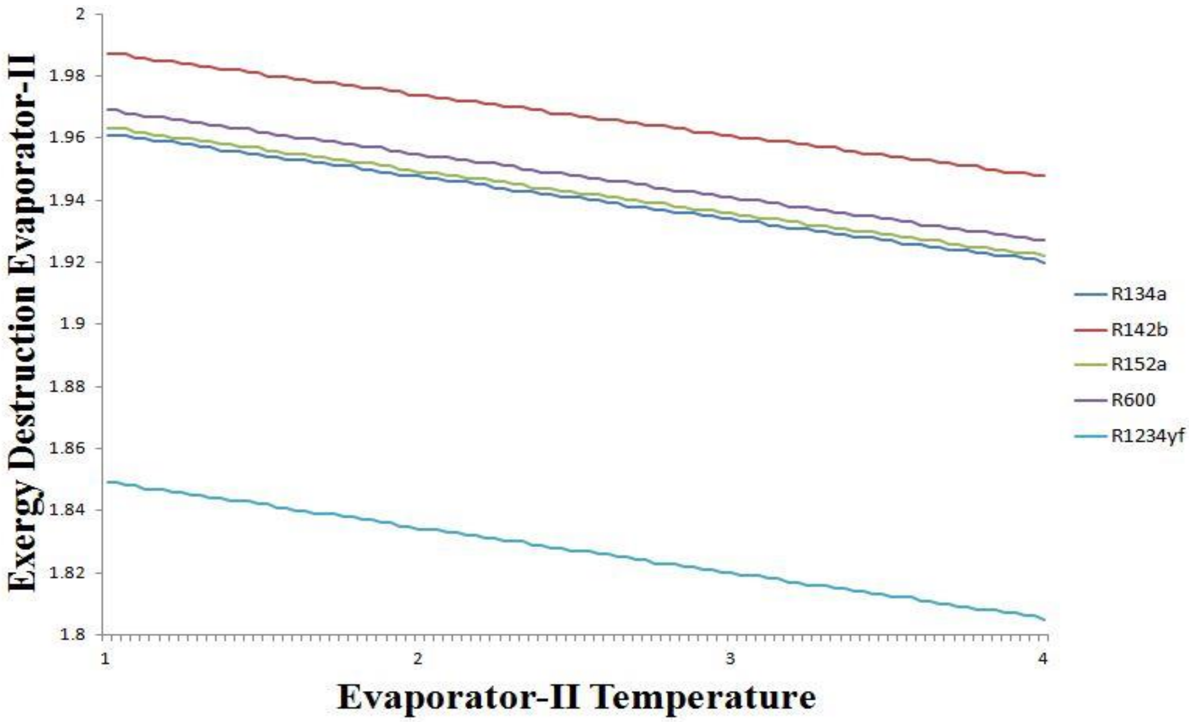

Figure 54: Variation of Exergy Destruction Of Evaporator-II with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

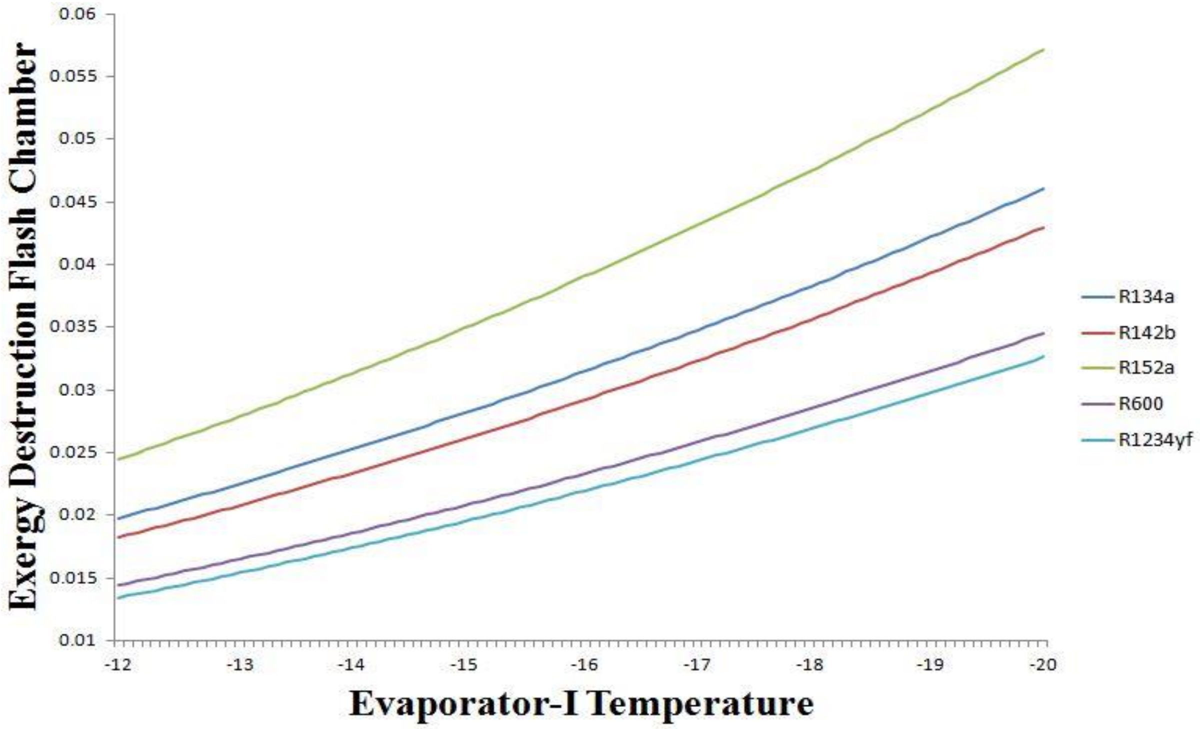

Figure 55: Variation of Exergy Destruction Of Flash Chamber with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

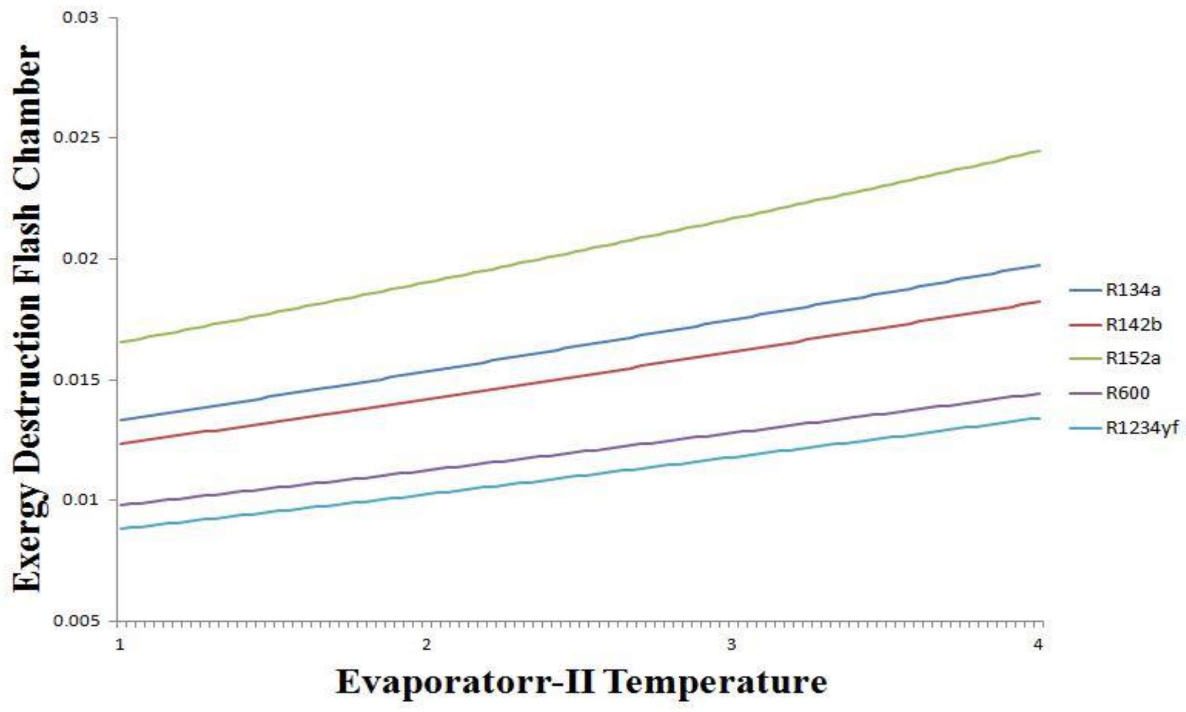

Figure 56: Variation of Exergy Destruction Of Flash Chamber with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

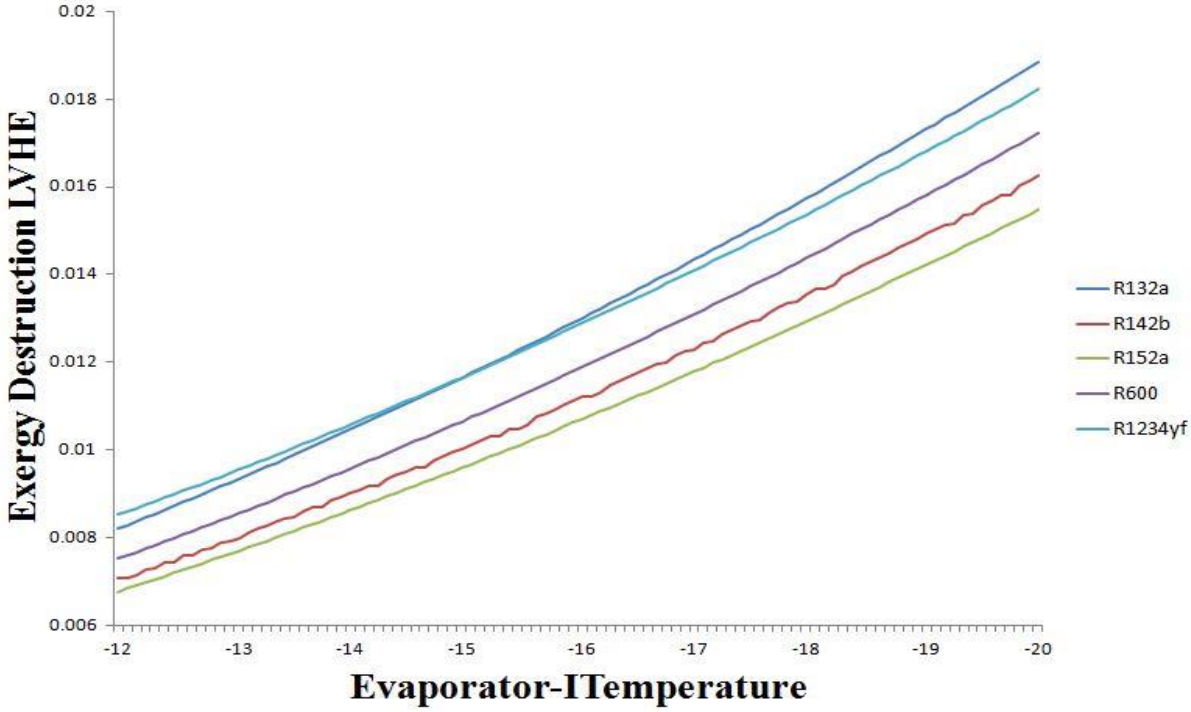

Figure 57: Variation of Exergy Destruction Of LVHE with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

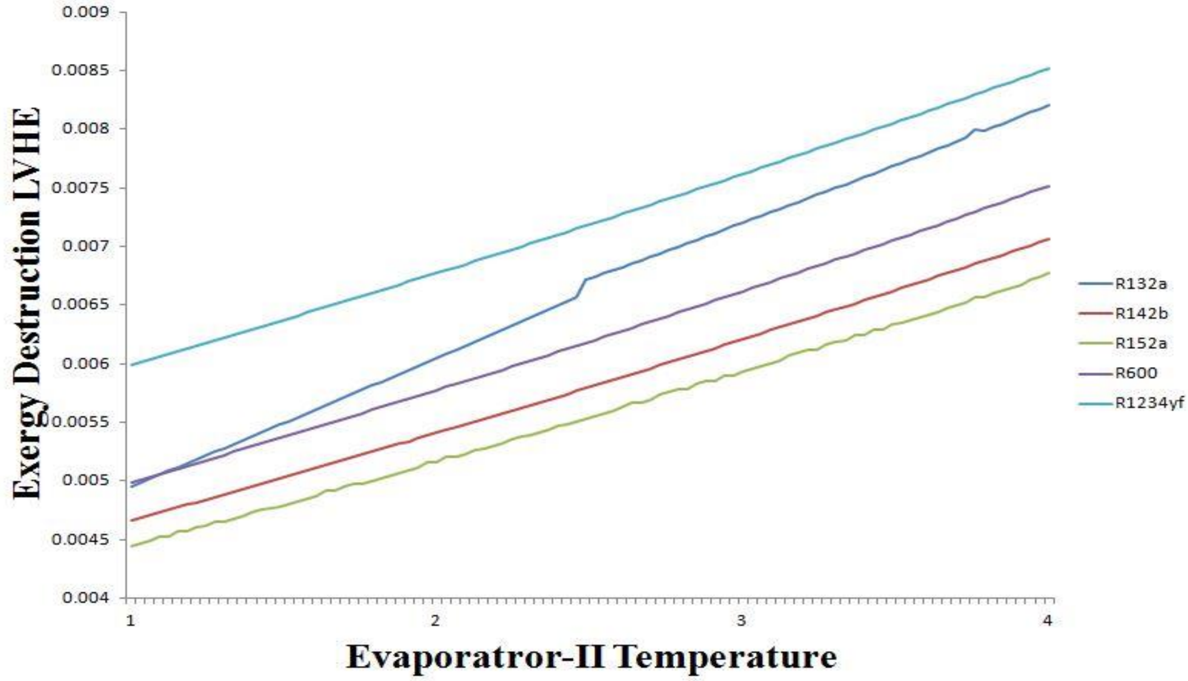

Figure 58: Variation of Exergy Destruction Of LVHE with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

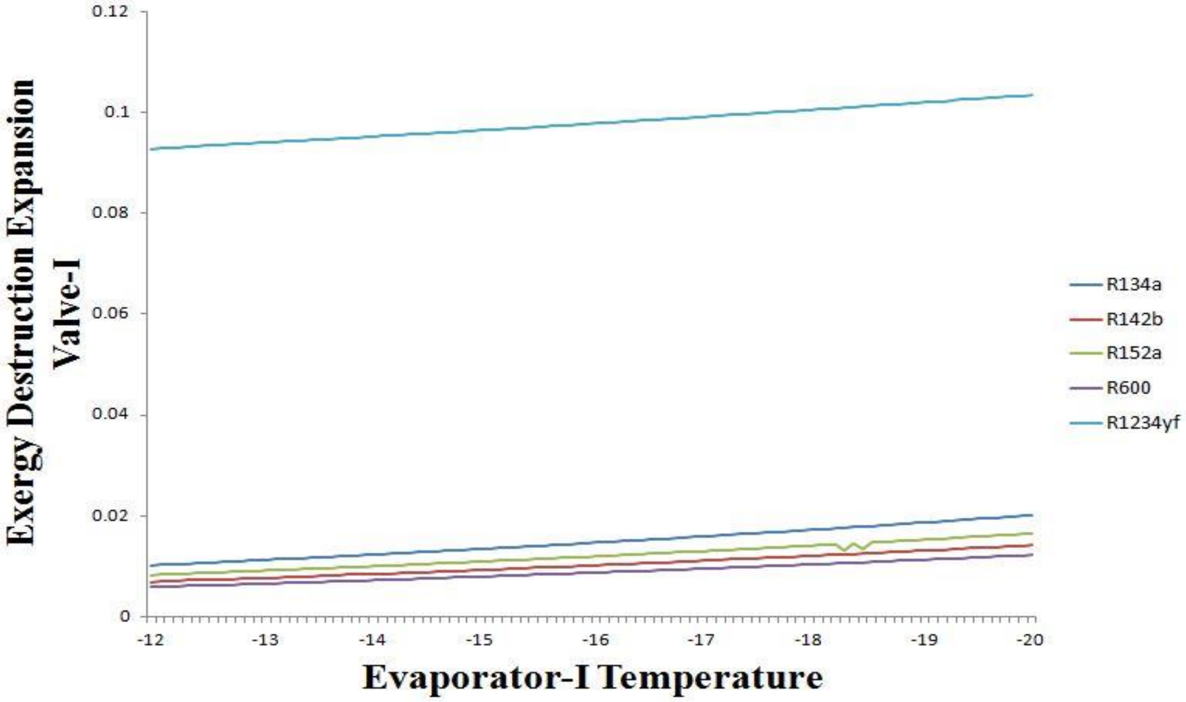

Figure 59: Variation of Exergy Destruction Of Expansion Valve-I with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

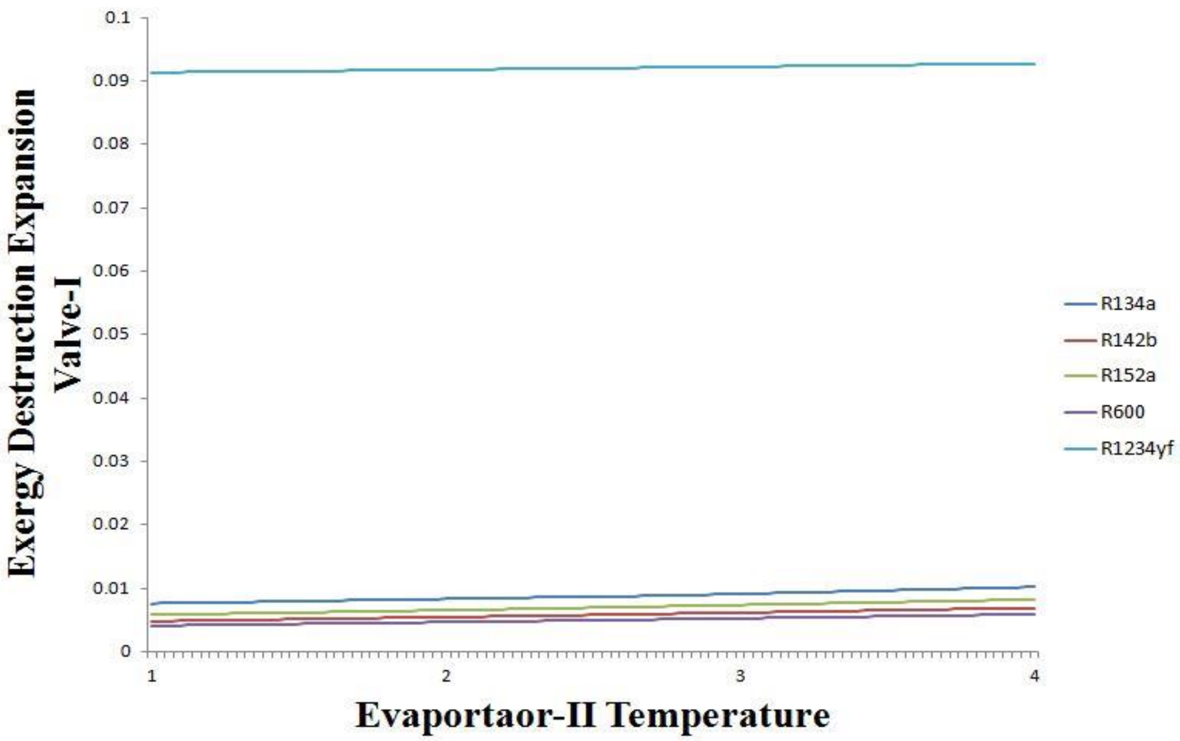

Figure 60: Variation of Exergy Destruction Of Expansion Valve-I with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

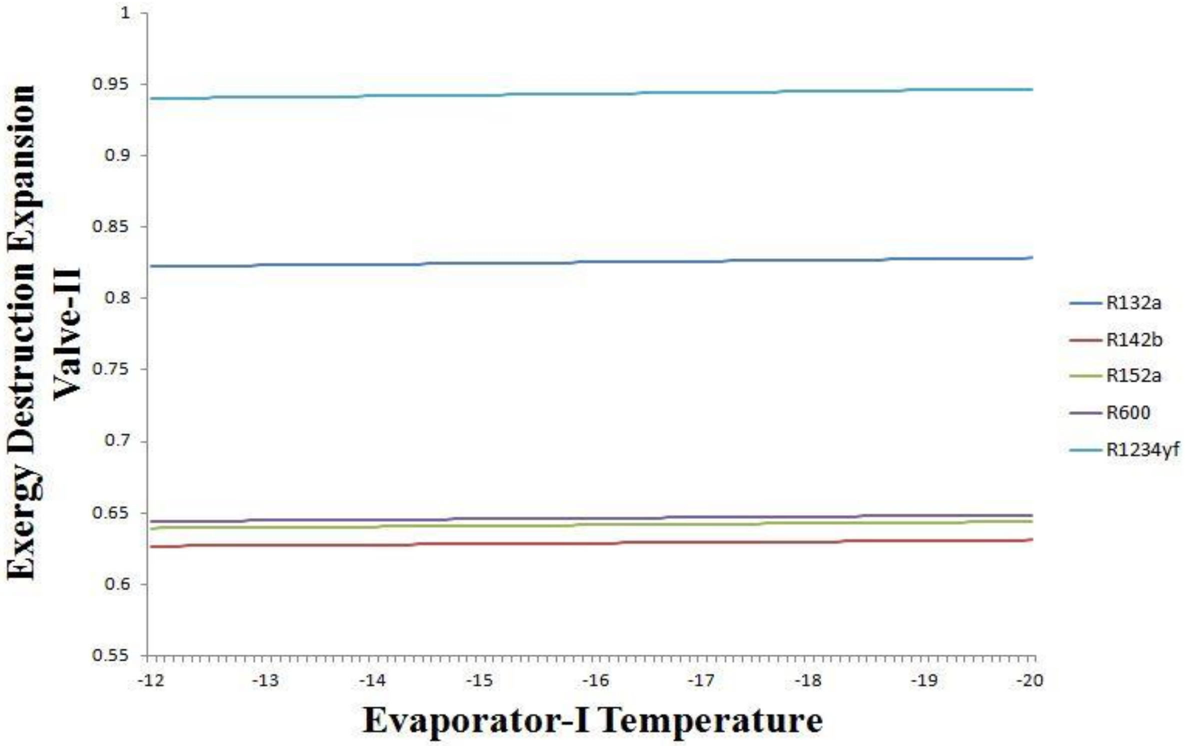

Figure 61: Variation of Exergy Destruction Of Expansion Valve-II with Evaporator-I Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

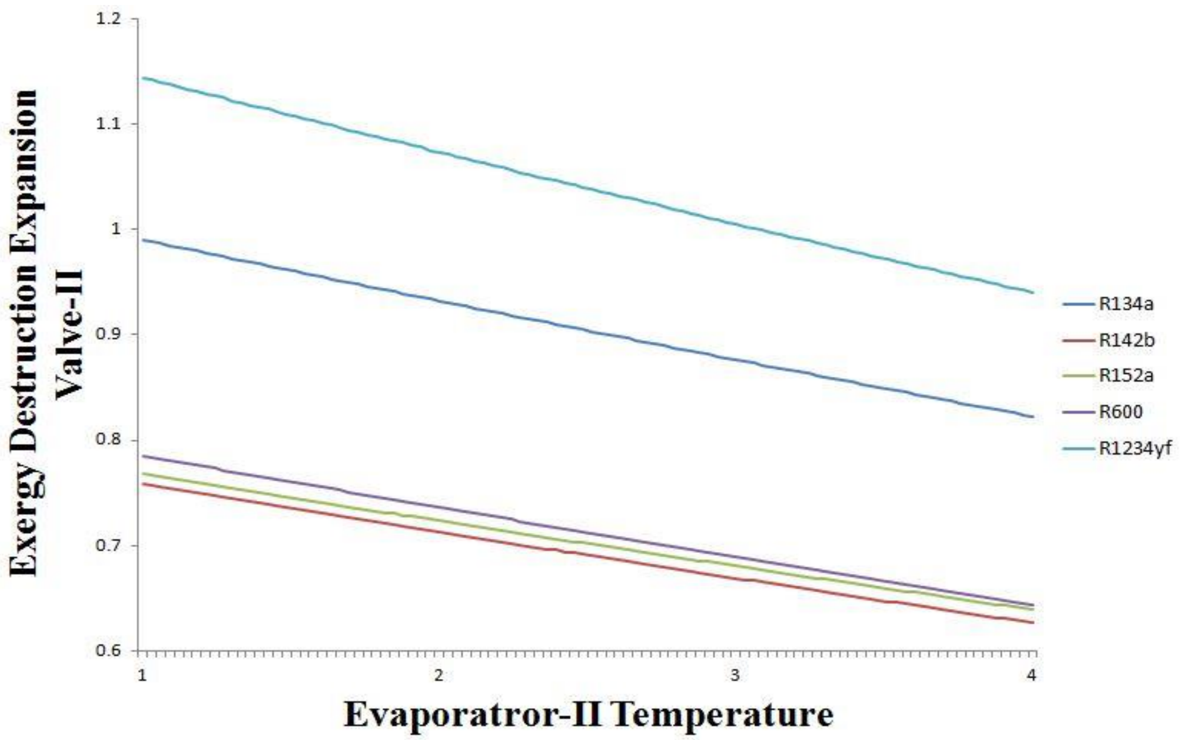

Figure 62: Variation of Exergy Destruction Of Expansion Valve-II with Evaporator-II Temperature in Multi-evaporator vapour compression refrigeration system with Flash Chamber and LVHE

Ecofriendly Refrigerant	Coefficient of Performance			
	Simple System	With Flash Chamber	With LVHE	With Flash Chamber and LVHE
R134a	4.904	5.221	5.814	5.908
R142b	5.137	5.401	5.924	6.113
R152a	5.107	5.375	5.771	6.071
R600	5.111	5.431	6.061	6.102
R1234yf	4.693	5.137	5.565	5.752

Table 3 : Comparison of Coefficient Of Performance with various types of multi-evaporator vapour compression refrigeration system

Ecofriendly Refrigerant	Exergy Destruction Ratio			
	Simple System	With Flash Chamber	With LVHE	With Flash Chamber and LVHE
R134a	3.918	4.716	4.192	4.92
R142b	3.902	4.636	4.123	4.692
R152a	4.012	4.653	4.219	4.706
R600	3.857	4.166	4.022	4.742
R1234yf	3.882	4.507	4.056	5.171

Table 4 : Comparison of Exergy Destruction Ratio with various types of multi-evaporator vapour compression refrigeration system

Ecofriendly Refrigerant	Exergy Efficiency (%)			
	Simple System	With Flash Chamber	With LVHE	With Flash Chamber and LVHE
R134a	14.91	15.88	17.68	17.96
R142b	15.62	16.42	18.01	18.59
R152a	15.53	16.35	17.55	18.46
R600	15.54	16.01	18.43	18.55
R1234yf	14.27	15.24	17.14	17.48

Table 5 : Comparison of Exergetic Efficiency with various types of multi-evaporator vapour compression refrigeration system

Ecofriendly Refrigerant	Coefficient of Performance		
	Q_1 = 2 TR, Q_2 = 10TR	Q_1 = 6 TR, Q_2 = 6 TR	Q_1 = 10 TR, Q_2 = 2 TR
R134a	5.908	5.064	4.432
R142b	6.113	5.232	4.573
R152a	6.071	5.186	4.526
R600	6.1	5.22	4.565
R1234yf	5.75	4.95	4.345

Table 6 : Comparison of Coefficient of performance with different cooling load combinations

Ecofriendly Refrigerant	Exergy Destruction Ratio		
	Q_1 = 2 TR, Q_2 = 10TR	Q_1 = 6 TR, Q_2 = 6 TR	Q_1 = 10 TR, Q_2 = 2 TR
R134a	4.92	3.583	3.001
R142b	4.692	3.381	2.811
R152a	4.706	3.371	2.793
R600	4.742	3.459	2.9
R1234yf	5.17	3.85	3.275

Table 7: Comparison of Exergy Destruction Ratio with different cooling load combinations

Ecofriendly Refrigerant	Exergetic Efficiency (%)		
	Q_1 = 2 TR, Q_2 = 10TR	Q_1 = 6 TR, Q_2 = 6 TR	Q_1 = 10 TR, Q_2 = 2 TR
R134a	17.96	25.93	30.96
R142b	18.59	26.23	31.94
R152a	18.46	26	31.61
R600	18.55	26.18	31.89
R1234yf	17.48	24.81	30.35

Table 8 : Comparison of Exergetic Efficiency with different cooling load combinations

CHAPTER 5

CONCLUSION

In this thesis, an extensive first law (energy) and second law (exergy) analysis of R134A, R142B, R152A, R600 and R1234YF alternative refrigerants in multi-evaporator vapour compression cycle using flash chamber and liquid vapour heat exchanger is presented. Conclusions of this analysis are summarised as follows:

1. Exergetic efficiency (second law efficiency) and COP (first law efficiency) of multi-evaporator vapour compression cycle using flash chamber and Liquid vapour heat exchanger is higher than without flash chamber and LVHE for selected alternative refrigerants.
2. R142B refrigerant have higher COP (first law efficiency) and Exergetic efficiency (second law efficiency) in this system but R1234YF have higher COP (first law efficiency) and Exergetic efficiency (second law efficiency) improvement from basic system.
3. When evaporator at low temperature has smaller capacity than evaporator at high temperature, system has maximum COP and EDR.
4. Also, as compressor work reduces has positive effect on exergetic efficiency. Due to this, exergy efficiency goes on increasing till it achieves optimum temperature.
5. When evaporator at low temperature has greater capacity than evaporator at high temperature, system exergetic efficiency of overall system increases.
6. R1234YF have higher EDR among all selected alternative refrigerants but R152A have higher EDR increment from basic system. R142B has least EDR in this analysis.
7. Trends of curve EDR and exergetic efficiency are almost reverse due to exergetic efficiency is inversely proportional to EDR. Minimum value of EDR gives optimum evaporator temperature.
8. EDR increases by introducing flash chamber and LVHE in simple multi-evaporator vapour compression refrigeration system.
9. R134A is recommended for practical applications as it can be easily available in market and it has slightly less Exergetic efficiency (second law efficiency) than R152A.
10. In descending order of better component (i.e. with low exergy destruction) are LVHE, expansion valves, evaporators, compressors and condenser.

Though R142B have highest COP and exergetic efficiency among all refrigerants, it is not recommended due to its GWP 2400, which is highest among all. Second best refrigerant R600 has only GWP 3. Hence it is recommended over R142B in dairy plant application.

CHAPTER 6

SCOPE FOR FUTURE WORK

1) Further investigation should be carried out for use of mixed refrigerants as a drop in replacement in this system.
2) Flash Chamber and Liquid Vapour Heat Exchanger can be applied to different multi evaporator refrigeration system to find out better multi evaporator system for this combination.
3) Actual Vapour Compression Cycle should be studied for this system by considering pressure drops in evaporators and condenser.
4) By varying refrigeration capacity, keeping all others inputs constant, exergy analysis should be studied.

APPENDIX

Computer Programme

1. Simple Multi Evaporator Refrigeration System

```
"Exergy Analysis of Multiple evaporator with individual compressor, individual expansion valve"

"Given Data"

TR=3.5167
Q_1=2*TR
Q_2=10*TR
eta_1= 0.9
eta_2= 0.85
T_e1=-12
T_e2= 4
T_c= 40
T_o= 25
T_r1=15+T_e1
T_r2=15+T_e2

R$=CONCAT$('R','134a')

P_e1=P_sat(R$,T=T_e1)
P_e2=P_sat(R$,T=T_e2)
P_c=P_sat(R$,T=T_c)

h_1=Enthalpy(R$,x=1,P=P_e1)
h_3=Enthalpy(R$,x=1,P=P_e2)
h_6=Enthalpy(R$,x=0,P=P_c)

s_1=Entropy(R$,x=1,P=P_e1)
s_3=Entropy(R$,x=1,P=P_e2)
s_6=Entropy(R$,x=0,P=P_c)

s_2=s_1
s_4=s_3

h_7=h_6
h_8=h_7

h_2=Enthalpy(R$,s=s_2,P=P_c)
h_4=Enthalpy(R$,s=s_4,P=P_c)

eta_1=(h_2-h_1)/(h_2a-h_1)
eta_2=(h_4-h_3)/(h_4a-h_3)

s_2a=Entropy(R$,h=h_2a,P=P_c)
s_4a=Entropy(R$,h=h_4a,P=P_c)
s_7=Entropy(R$,h=h_7,P=P_e2)
s_8=Entropy(R$,h=h_8,P=P_e1)

Q_1=m_1*(h_1-h_8)
Q_2=m_2*(h_3-h_7)

m_1*h_2a+m_2**h_4a=(m_1+m_2)*h_5
s_5=Entropy(R$,h=h_5,P=P_c)
```

```
w_c1=(m_1*(h_2-h_1))/eta_1
w_c2=(m_2*(h_4-h_3))/eta_2
w_c=w_c1+w_c2

cop=(Q_1+Q_2)/(w_c)


"Exergy Analysis"

"Evaporator"
ED_e1=m_1*(h_8-(T_o+273)*s_8)+Q_1*((1-(T_o+273)/(T_r1+273)))-m_1*(h_1-(T_o+273)*s_1)
ED_e2=m_2*(h_7-(T_o+273)*s_7)+Q_2*((1-(T_o+273)/(T_r2+273)))-m_2*(h_3-(T_o+273)*s_3)

"Compressor"
ED_c1=m_1*((T_o+273)*(s_2a-s_1))
ED_c2=m_2*((T_o+273)*(s_4a-s_3))

"Condensor"
ED_cond=(m_1+m_2)*(h_5-(T_o+273)*s_5)-(m_1+m_2)*(h_6-(T_o+273)*s_6)

"Expension valve"
ED_t1=m_1*((T_o+273)*(s_7-s_6))
ED_t2=m_2*((T_o+273)*(s_8-s_7))

"Total Exergy Destruction"
ED=ED_e1+ED_e2+ED_c1+ED_c2+ED_cond+ED_t1+ED_t2

"Exergy of Product"
EP=Q_1*(1-(T_o+273)/(T_r1+273))+Q_2*(1-(T_o+273)/(T_r2+273))

"Exergetic Effeciency"
eta_ex=-EP/w_c

"Exergy Destruction Ratio"
EDR=-ED/EP
```

2. Multi Evaporator Refrigeration System with Flash Chamber

```
"Exergy Analysis of Multiple evaporators with individual compressor, individual expansion valve flash tank"

"Given Data"

TR=3.5167
Q_1=2*TR
Q_2=10*TR
eta_1= 0.9
eta_2= 0.85
T_e1=-12
T_e2= 4
T_c= 40
T_o= 25
T_r1=15+T_e1
T_r2=15+T_e2

R$=CONCAT$('R','134a')

P_e1=P_sat(R$,T=T_e1)
```

```
h_1=Enthalpy(R$,T=T_e1,x=1)
s_1=Entropy(R$,T=T_e1,x=1)

s_2=s_1
P_e2=P_sat(R$,T=T_e2)
T_2=Temperature(R$,P=P_e2,s=s_2)
h_2=Enthalpy(R$,T=T_2,P=P_e2)
eta_1=(h_2-h_1)/(h_2a-h_1)
s_2a=Entropy(R$,P=P_e2,h=h_2a)

h_3=Enthalpy(R$,T=T_e2,x=1)
s_3=Entropy(R$,T=T_e2,x=1)
s_4=s_3

P_c=P_sat(R$,T=T_c)
T_4=Temperature(R$,P=P_c,s=s_4)
h_4=Enthalpy(R$,T=T_4,P=P_c)
eta_2=((h_4-h_3)/(h_4a-h_3))
s_4a=Entropy(R$,P=P_c,h=h_4a)
h_5=Enthalpy(R$,T=T_c,x=0)
s_5=Entropy(R$,T=T_c,x=0)

h_6=h_5
s_6=Entropy(R$,P=P_e2,h=h_6)
h_7=Enthalpy(R$,T=T_e2,x=0)
s_7=Entropy(R$,T=T_e2,x=0)
h_8=h_7
s_8=Entropy(R$,P=P_e1,h=h_8)

"Mass flow rate for compressor 1"
m_1=Q_1/(h_1-h_8)
"Mass flow rate for compressor 2"
m_e2=Q_2/(h_3-h_6)
"Mass flow rate for evaporator 2"
m_e2=m_2-m_1
"Work done for compressor 1"
W_1=m_1*(h_2a-h_1)
"Work done for compressor 2"
W_2=m_2*(h_4a-h_3)
"Total work done"
W_t=W_1+W_2
"Total Refrigerating capacity"
RC=Q_1+Q_2
"Coefficient of performance"
COP=RC/W_t

"Exergy Analysis"

"Evaporator"
ED_e1=m_1*(h_8-(T_o+273)*s_8)+Q_1*((1-(T_o+273)/(T_r1+273)))-m_1*(h_1-(T_o+273)*s_1)
ED_e2=m_e2*(h_6-(T_o+273)*s_6)+Q_2*((1-(T_o+273)/(T_r2+273)))-m_e2*(h_3-(T_o+273)*s_3)

"Compressor"
ED_c1=m_1*((T_o+273)*(s_2a-s_1))
ED_c2=m_2*((T_o+273)*(s_4a-s_3))

"Condensor"
ED_cond=m_2*(h_4a-(T_o+273)*s_4a)-m_2*(h_5-(T_o+273)*s_5)

"Expension valve"
```

```
ED_t1=m_1*((T_o+273)*(s_8-s_7))
ED_t2=m_2*((T_o+273)*(s_6-s_5))

"Flash Tank"
ED_flash=(m_2*(h_6-(T_o+273)*s_6)+m_1*(h_2a-(T_o+273)*s_2a))-((m_1*(h_7-
(T_o+273)*s_7)+m_2*(h_3-(T_o+273)*s_3)))

"Total Exergy Destruction"
ED=ED_e1+ED_e2+ED_c1+ED_c2+ED_cond+ED_t1+ED_t2+ED_flash

"Exergy of Product"
EP=Q_1*(1-(T_o+273)/(T_r1+273))+Q_2*(1-(T_o+273)/(T_r2+273))

"Exergetic Effeciency"
eta_ex=-EP/W_t

"Exergy Destruction Ratio"
EDR=-ED/EP
```

3. Multi Evaporator Refrigeration System with Liquid Vapour Heat Exchanger

```
"Exergy Analysis of Multiple evaporators with individual compressor, individual expansion valve liquid
vapour heat exchanger"

"Given Data"

TR=3.5167
Q_1=2*TR
Q_2=10*TR
eta_1= 0.9
eta_2= 0.85
e=.85
T_e1=-12
T_e2= 4
T_c= 40
T_o= 25
T_r1=15+T_e1
T_r2=15+T_e2

R$=CONCAT$('R','134a')

P_e1=P_sat(R$,T=T_e1)
P_e2=P_sat(R$,T=T_e2)
P_c=P_sat(R$,T=T_c)

s_1=Entropy(R$,x=1,P=P_e1)
s_3a=Entropy(R$,x=1,P=P_e2)
s_5=Entropy(R$,x=1,P=P_c)
s_6=Entropy(R$,x=0,P=P_c)

h_1=Enthalpy(R$,x=1,P=P_e1)
h_3a=Enthalpy(R$,x=1,P=P_e2)
h_5=Enthalpy(R$,x=1,P=P_c)
h_6=Enthalpy(R$,x=0,P=P_c)

e=(T_11-T_e1)/(T_c-T_e1)

s_11=Entropy(R$,T=T_11,P=P_e1)
```

```
h_11=Enthalpy(R$,T=T_11,P=P_e1)

s_2=s_11
h_2=Enthalpy(R$,s=s_2,P=P_e2)
eta_1=(h_2-h_11)/(h_2a-h_11)
s_2a=Entropy(R$,h=h_2a,P=P_e2)

(h_6-h_66)=(h_11-h_1)
s_66=Entropy(R$,h=h_66,P=P_c)

h_7=h_66
h_8=h_66

s_8=Entropy(R$,h=h_8,P=P_e1)
s_7=Entropy(R$,h=h_7,P=P_e2)

Q_1=m_1*(h_1-h_8)
Q_2=m_2*(h_3a-h_7)

m_2*h_3a+m_1*h_2a=(m_1+m_2)*h_3
s_3=Entropy(R$,h=h_3,P=P_e2)
s_4=s_3
h_4=Enthalpy(R$,s=s_4,P=P_c)
eta_2=(h_4-h_3)/(h_4a-h_3)
s_4a=Entropy(R$,h=h_4a,P=P_c)

w_c1=(m_1*(h_2-h_11))/eta_1
w_c2=((m_1+m_2)*(h_4-h_3))/eta_2
w_c=w_c1+w_c2

cop=(Q_1+Q_2)/(w_c)

"Exergy Analysis"

"Evaporator"
ED_e1=m_1*(h_8-(T_o+273)*s_8)+Q_1*((1-(T_o+273)/(T_r1+273)))-m_1*(h_1-(T_o+273)*s_1)
ED_e2=m_2*(h_7-(T_o+273)*s_7)+Q_2*((1-(T_o+273)/(T_r2+273)))-m_2*(h_3a-(T_o+273)*s_3a)

"Compressor"
ED_c1=m_1*((T_o+273)*(s_2a-s_11))
ED_c2=m_2*((T_o+273)*(s_4a-s_3))

"Condensor"
ED_cond=m_2*(h_4a-(T_o+273)*s_4a)-m_2*(h_6-(T_o+273)*s_6)

"Expension valve"
ED_t1=m_1*((T_o+273)*(s_7-s_66))
ED_t2=m_2*((T_o+273)*(s_8-s_7))

"Lquid vapour heat exchanger"
ED_LVHE=m_1*(h_6-(T_o+273)*s_6)+m_1*(h_1-(T_o+273)*s_1)-m_1*(h_66-(T_o+273)*s_66)-
m_1*(h_11-(T_o+273)*s_11)

"Total Exergy Destruction"
ED=ED_e1+ED_e2+ED_c1+ED_c2+ED_cond+ED_t1+ED_t2+ED_LVHE

"Exergy of Product"
EP=Q_1*(1-(T_o+273)/(T_r1+273))+Q_2*(1-(T_o+273)/(T_r2+273))
```

"Exergetic Effeciency"
eta_ex=-EP/w_c

"Exergy Destruction Ratio"
EDR=-ED/EP

4. Multi Evaporator Refrigeration System with Flash Chamber and Liquid Vapour Heat Exchanger

"Exergy Analysis of Multiple evaporators with individual compressor, individual expansion valve flash tank and liquid vapour heat exchanger"

"Given Data"

```
TR=3.5167
Q_1=2*TR
Q_2=10*TR
eta_1=0.9
eta_2=0.85
e=.85
T_e1=-12
T_e2=4
T_c=35
T_o=25
T_r1=15+T_e1
T_r2=15+T_e2
R$=CONCAT$('R','134a')
P_e1=P_sat(R$,T=T_e1)
e=(T_1a-T_e1)/(T_e2-T_e1)
h_1=Enthalpy(R$,T=T_e1,x=1)
s_1=Entropy(R$,T=T_e1,x=1)
h_1a=Enthalpy(R$,T=T_1a,P=P_e1)
s_1a=Entropy(R$,T=T_1a,P=P_e1)
s_2s=s_1a
P_e2=P_sat(R$,T=T_e2)
T_2s=Temperature(R$,P=P_e2,s=s_2s)
h_2s=Enthalpy(R$,T=T_2s,P=P_e2)
eta_1=(h_2s-h_1a)/(h_2-h_1a)
s_2=Entropy(R$,P=P_e2,h=h_2)
h_3=Enthalpy(R$,T=T_e2,x=1)
s_3=Entropy(R$,T=T_e2,x=1)
s_4s=s_3
P_c=P_sat(R$,T=T_c)
T_4s=Temperature(R$,P=P_c,s=s_4s)
h_4s=Enthalpy(R$,T=T_4s,s=s_4s)
eta_2=((h_4s-h_3)/(h_4-h_3))
s_4=Entropy(R$,P=P_c,h=h_4)
h_5=Enthalpy(R$,T=T_c,x=0)
s_5=Entropy(R$,T=T_c,x=0)
h_6=h_5
s_6=Entropy(R$,P=P_e2,h=h_6)
h_7=Enthalpy(R$,T=T_e2,x=0)
s_7=Entropy(R$,T=T_e2,x=0)
"energy balance in LVHE"
(h_7-h_7a)=(h_1a-h_1)
T_7a=Temperature(R$,h=h_7a,P=P_e2)
s_7a=Entropy(R$,T=T_7a,P=P_e2)
h_8=h_7a
s_8=Entropy(R$,P=P_e1,h=h_8)
```

```
"Mass flow rate for compressor 1"
m_1=Q_1/(h_1-h_8)

"Energy balance in flash tank"
m*h_6+m_1*h_2=m*h_3+m_1*h_7

"Mass flow rate for compressor 2"
m_e2=Q_2/(h_3-h_6)
"Mass flow rate for evaporator 2"
m_e2=m_2-m
"Work done for compressor 1"
W_1=m_1*(h_2-h_1a)
"Work done for compressor 2"
W_2=m_2*(h_4-h_3)
"Total work done"
W_t=W_1+W_2
"Total Refrigerating capacity"
RC=Q_1+Q_2
"Coefficient of performance"
COP=RC/W_t

"Exergy Analysis"
"Evaporator"
ED_e1=m_1*(h_8-(T_o+273)*s_8)+Q_1*((1-(T_o+273)/(T_r1+273)))-m_1*(h_1-(T_o+273)*s_1)
ED_e2=m_e2*(h_6-(T_o+273)*s_6)+Q_2*((1-(T_o+273)/(T_r2+273)))-m_e2*(h_3-(T_o+273)*s_3)

"Compressor"
ED_c1=m_1*((T_o+273)*(s_2-s_1))
ED_c2=m_2*((T_o+273)*(s_4-s_3))

"Condensor"
ED_cond=m_2*(h_4-(T_o+273)*s_4)-m_2*(h_5-(T_o+273)*s_5)

"Expension valve"
ED_t1=m_1*((T_o+273)*(s_8-s_7a))
ED_t2=m_2*((T_o+273)*(s_6-s_5))

"Flash Tank"
ED_flash=m*(h_6-(T_o+273)*s_6)+m_1*(h_2-(T_o+273)*s_2)-m_1*(h_7-(T_o+273)*s_7)-m*(h_3-
(T_o+273)*s_3)

"Lquid vapour heat exchanger"
ED_LVHE=m_1*(h_7-(T_o+273)*s_7)+m_1*(h_1-(T_o+273)*s_1)-m_1*(h_7a-(T_o+273)*s_7a)-
m_1*(h_1a-(T_o+273)*s_1a)

"Total Exergy Destruction"
ED=ED_e1+ED_e2+ED_c1+ED_c2+ED_cond+ED_t1+ED_t2+ED_flash+ED_LVHE

"Exergy of Product"
EP=Q_1*(1-(T_o+273)/(T_r1+273))+Q_2*(1-(T_o+273)/(T_r2+273))

"Exergetic Effeciency"
eta_ex=-EP/W_t

"Exergy Destruction Ratio"
EDR=-ED/EP
```

CHAPTER 6

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