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Methods for Improving Thermal Performance of Three Stage Vapour Compression Refrigeration Systems with Flash-Intercooler Using Energy– Exergy Analysis of Eight Ecofriendly Refrigerants

R. S. Mishra, Kapil Chopra** and V. Sahni***

ABSTRACT

The exergy analysis is a powerful tool for finding irreversibilities occurred in the components as well as complete system. Global warming and ozone depletion is a big issues for saving our environment. In this paper using first law and second law analysis , the comparison of eight environmental friendly refrigerants on multiple stage vapour compression refrigerator with flash intercooler and individual throttle valves (system-1) and multiple stage vapour compression refrigerator with flash intercooler and multiple throttle valves (system-2) has been carried out. For eight selected refrigerants irreversibilities occurred in the system -1 is higher than the system-2 and first law efficiency (COP) and exergy efficiency of system-1is lower than sytem-2.The Exergetic performance of R600 and R717 is better in comparison of other selected ecofriendly refrigerants for both systems where as ecofriendly R125 refrigerant showed lowest thermal performances in terms of COP (energetic efficiency), and exergetic efficiency (second law efficiency) and higher irreversibilities in terms of exergey destruction ratio (EDR) . As ecofriendly R717 refrigerant is toxic in nature and restricted to limited applications and hydrocarbon R600 is slightly lower performance than R717 and 2-3% higher performance than R134a refrigerant is also flammable in nature can be used without taking of any safety precautions.Therefore R134a may also be used for practical applications. Also R134A is easily available, The performance of R1234yf (GWP four with zero ozone depletion potential) gives lower thermal performance than R134a

Keywords: *Thermodynamic Analysis; Reduction in Irreversibilities; Performance Improvement; Energy-Exergy Analysis; Vapour Compression Systems.*

1.0 Introduction

Nowadays most of the energy utilize in cooling and air conditioning in industrial as well as for domestic applications, in addition to energy consumption, using of refrigerants in cooling and air conditioning having high GWP and ODP which are responsible for increasing global warming and ozone depletion. The primary requirements of ideal refrigerants are having good physical and chemical properties. Due to good physical and chemical properties such as non-corrosiveness, non-toxicity, non- flammability, low boiling point, Chlorofluorocarbons (CFCs) have been used over the last many decades, but hydro chloro fluoro carbons (HCFCs) and Chlorofluorocarbons (CFCs) having large amount of chlorine content as well as high global warming potential and ozone depletion potential, so after 90s refrigerants under these categories these kinds of refrigerants are almost prohibited [1].

2.0 Literature Review

Most of the study has been carried out for the performance evaluation of vapour compression refrigeration system using energetic analysis, but with the help of first law analysis irreversibility destruction or losses in components of system unable to determined [2-5], Therefore exergetic analysis is

**Correspoinding Author: Department of Mechanical Production & Industrial and Automobiles Engineering, Delhi Technological University, Delhi, India (E-mail: rsmishra1651956@yahoo.co.in)*
***Department of Mechanical Engineering, Sant Longowal Institute of Engineering & Technology, Longowal, India*
***Department of Mechanical Engineering, Sant Longowal Institute of Engineering & Technology, Longowal, India*

the advanced approach for thermodynamic performances This paper mainly deals with exergy analysis of the comparison of eight environmental friendly refrigerants on multiple stage vapour compression refrigerator with flash intercooler and individual throttle valves (system-1) and multiple stage vapour compression refrigerator with flash intercooler and multiple throttle valves (system-2) for optimizing irreversibility.

Table 1: Physical and Environmental Characteristics of Eight Ecofriendly Refrigerants Used in Vapour Compression Refrigeration System

Refrigerant	Chemical formula	Molecular mass (g/mol)	NBP (°C)	T_{cri} (°C)	P_{cri} (MPa)	ASHRAE safety code
R410a	R-32/125	72.58	-60.9	72.5	4.95	A1
R290	$CH_3CH_2CH_3$	44.1	-42.2	96.7	4.25	A3
R600a	C_4H_{10}	58.122	-11.74	134.661	3.62	A3
R1234yf	$C_3H_2F_4$	114.04	-29.4	94.85	3.38	A2L
R600	C_4H_{10}	58.122	-0.49	151.98	3.79	A3
R134a	CH_2FCF_3	102.03	-26.1	101.1	4.06	A1
R125	C_2HF_5	120.02	-48.09	66.023	3.61	A1
R717	NH_3	17.03	-33.327	132.25	11.33	B2

The utility of exergy analysis (i.e. second law analysis) on vapour compression refrigeration systems is well defined because it gives the idea for improvements in efficiency due to modifications in existing design in terms of reducing exergy destructions in the components. In addition to this second law analysis also provides new thought for development in the existing system [6]. Xuan and Chen [7] carried out experimental study for replacement of R502 by mixture of HFC-161 and observed that the mixture of HFC-161 gives similar thermodynamic performances and also higher performance than using ecofriendly R404a refrigerant at lower and higher evaporative temperature respectively Cabello et al.[8] experimentally investigated the effect of condensing pressure, evaporating pressure and degree of superheating on single stage vapour compression refrigeration system using R22, R134a and R407C and observed that mass flow rate is greatly affected by change in suction conditions of compressor and found that higher compression ratio using R407C gives lower first law performance (COP) than R22 Spatz and Motta [9] focused on comparison of heat transfer and pressure drop characteristics through experimental investigation of vapour compression refrigeration system through experimental investigation in the medium temperature range for replacement of R12 using three ecofriendly refrigerants. And observed that the ecofriendly R410a gives better performance than, R404a and R290a. Han et al. [10] conducted experiments under different working conditions and concluded that R407C is a replacement of R12 in the vapour compression refrigeration system without any modification in the same system.

Cabello et al [11] had studied the effect of operating parameters on COP, work input and cooling capacity of single-stage vapour compression refrigeration system and observed a great influence of performance parameters due change in suction pressure, condensing and evaporating temperatures.

Arora and Kaushik [12] carried out energy and exergy analysis of vapour compression refrigeration system with liquid vapour heat exchanger for specific temperature range of evaporator and condenser. And found that the R502 is the best refrigerant than R404A and R507A, Getu and Bansal [13] had optimized the design operating parameters of R744-R717 cascade refrigeration system, using regression analysis Mohanraj et al [14] conducted experiments on domestic refrigerator and concluded that under different environmental temperatures the first law efficiency in terms of COP of system using mixture of R290 and R600a in the ratio of 45.2:

54.8 by weight indicating up to 3.6% greater than same system using R134arefrigerants, also discharge temperature of compressor with mixture of R290 and R600a is lower in the range of 8.5-13.4K than same compressor with R134a.Padilla et al [15] used energy analysis of domestic vapour compression refrigeration system with R12 and R413a and concluded that the thermal performance in terms of power consumption, and energy efficiency of R413A is better than Rl 2.

3.0 Objectives of Research Investigations Objectives of Research Investigations

In this paper great emphasis put on saving of energy and using of ecofriendly refrigerants due to increase of energy crises, global warming and depletion of ozone layer. In this investigation the work input required running the vapour compression refrigeration system reduced by using compound compression and further decreased by flash intercooling between compressors. COP of system can also be enhanced by compressing the refrigerant very close to the saturation line this can be achieved by compressing the refrigerants in more stages with intermediate intercoolers. The refrigeration effect can be increase by maintaining the condition of refrigerants in more liquid stage at the entrance of evaporator which can be achieved by expanding the refrigerant very close to the liquid line. The expansion can be brought close to the liquid line by subcooling the refrigerant and removing the flashed vapours by incorporating the flash chamber in the working cycle. The evaporator size can be reduced because unwanted vapours formed are removed before the liquid refrigerant enters in the evaporator. Multi-stage vapour compression with flash intercooler and individual throttle valves (system-1) consists of three compressors arranged in compound compression, individual throttle valves, condenser and evaporators as shown in Fig.l. Multiple evaporators at different temperatures with compound compression, flash intercooler and multiple throttle valves (system-2) consists of three compressors arranged in compound compression, multiple throttle valves, condenser and evaporators as shown in Fig.2.

3.1 First and second law analysis

For carrying out energetic and exergetic analysis, computational models of system-1 and system-2 has been developed and impact of chosen refrigerants on these systems has been analyzed using computational analysis and following assumptions are made:

1. Load on the low, intermediate and high temperature evaporators are 10TR, 20 TR and 30 TR respectively.
2. Dead state temperature (TO): 25 oC
3. temperature (Tr-Te):5 oC.
4. Adiabatic efficiency of compressor: 76%.
5. Dead state enthalpy (00) and entropy (sO) of the refrigerants have been calculated corresponding to the dead state temperature (TO) of 25 oC.
6. Variation in kinetic and potential energy is negligible.
7. Expansion process is adiabatic
8. Temperature of low, intermediate and high temperature evaporators are -10 oC,0 oC and 10 oC respectively.
9. Condenser temperature : 40 oC
10. Degree of sub cooling : 10 oC Exergy at any state is given as

$$X= (\Phi-\Phi\_0)-T\_0 (s-s\_0) \quad (1)$$

Energy analysis

First law of thermodynamic gives the idea of energy balance of system.

Mass flow analysis of system-1

$$\dot{m}_{c1} = \dot{m}_{e1} = \frac{\dot{Q}_{e1}}{(\Phi_1 - \Phi_{10})} \quad (2)$$

$$\dot{m}_{e2} = \frac{\dot{Q}_{e2}}{(\Phi_3 - \Phi_9)} \quad (3)$$

$$\dot{m}_{f1} = \frac{\dot{m}_{c1}(\Phi_2 - \Phi_3)}{(\Phi_3 - \Phi_9)} \quad (4)$$

$$\dot{m}_{c2} = \dot{m}_{c1} + \dot{m}_{e2} + \dot{m}_{f1} \quad (5)$$

$$\dot{m}_{e3} = \frac{\dot{Q}_{e3}}{(\Phi_5 - \Phi_8)} \quad (6)$$

$$\dot{m}_{f2} = \frac{\dot{m}_{c2}(\Phi_4 - \Phi_5)}{(\Phi_5 - \Phi_8)} \quad (7)$$

$$\dot{m}_{c3} = \dot{m}_{c2} + \dot{m}_{e3} + \dot{m}_{f2} \quad (8)$$

Energy consumption for sytem-1

$$P_{c1} = \frac{\dot{m}_{c1}(\Phi_2 - \Phi_1)}{60} \quad (9)$$

$$P_{c2} = \frac{\dot{m}_{c2}(\Phi_4 - \Phi_3)}{60} \quad (10)$$

$$P_{c3} = \frac{\dot{m}_{c3}(\Phi_6 - \Phi_5)}{60} \quad (11)$$

Energetic efficiency of system-1

$$COP = \frac{\dot{Q}_e}{P_c * 60} \quad (12)$$

Fig 1: Schematic Diagram of Multiple Evaporators with Compound Compression, Flash Intercooler and Individual Throttle Valves (System-1)

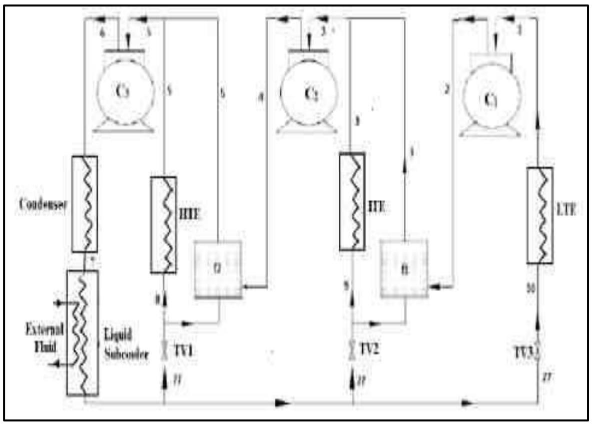
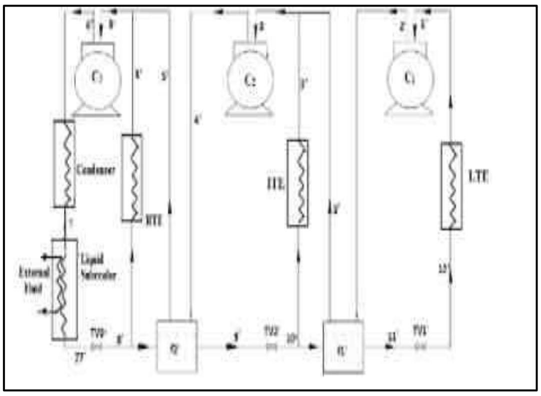


Fig 2: Schematic Diagram of Multiple Evaporators with Compound Compression, Flash Intercooler and Multiple Throttle Valves (System-2)



Rate of exergy loss due to irreversibility $(T_o\dot{S}_{gen})$ in various components of system-1

The concept of exergy was given by second law of thermodynamics,

The exergy is always decreases due to thermodynamic irreversibilityies occurred in the components as well as in the whole system. Exergy is a measure of usefulness, quality or potential of a stream to cause change and an effective measure of the potential of a substance to impact the environment [12]. Using entropy generation Concept in the three stages vapour compression refrigeration systems using flash intercooler is given below for various components Compressors

$$(T_o\dot{S}_{gen})_{c1} = \dot{W}_{c1} + \dot{m}_{c1}(X_2 - X_1) \quad (13)$$

$$(T_o\dot{S}_{gen})_{c2} = \dot{W}_{c2} + \dot{m}_{c2}(X_4 - X_3) \quad (14)$$

$$(T_o\dot{S}_{gen})_{c3} = \dot{W}_{c3} + \dot{m}_{c3}(X_6 - X_5) \quad (15)$$

$$\Psi_c = (T_o\dot{S}_{gen})_{c1} + (T_o\dot{S}_{gen})_{c2} + (T_o\dot{S}_{gen})_{c3} \quad (16)$$

Evaporators

$$(T_o\dot{S}_{gen})_{e1} = \dot{m}_{e1}(X_1 - X_{10}) - \dot{Q}_{e1}\left(1 - \frac{T_o}{T_{r1}}\right) \quad (17)$$

$$(T_o\dot{S}_{gen})_{e2} = \dot{m}_{e2}(X_3 - X_9) - \dot{Q}_{e2}\left(1 - \frac{T_o}{T_{r2}}\right) \quad (18)$$

$$(T_o\dot{S}_{gen})_{e3} = \dot{m}_{e3}(X_5 - X_8) - \dot{Q}_{e3}\left(1 - \frac{T_o}{T_{r3}}\right) \quad (19)$$

$$\Psi_e = (T_o\dot{S}_{gen})_{e1} + (T_o\dot{S}_{gen})_{e2} + (T_o\dot{S}_{gen})_{e3} \quad (20)$$

Condenser

$$\Psi_{cond} = (T_o\dot{S}_{gen})_{cond} = \dot{m}_{c3}(X_6 - X_7) - \dot{Q}_e\left(1 - \frac{T_o}{T_r}\right) \quad (21)$$

Throttle Valves

$$(T_o\dot{S}_{gen})_{tv1} = \dot{m}_{e1}(X_{77} - X_{10}) \quad (22)$$

$$(T_o\dot{S}_{gen})_{tv2} = (\dot{m}_{e2} + \dot{m}_{f1})(X_{77} - X_9) \quad (23)$$

$$(T_o\dot{S}_{gen})_{tv3} = (\dot{m}_{e3} + \dot{m}_{f2})(X_{77} - X_8) \quad (24)$$

$$\Psi_{tv} = (T_o\dot{S}_{gen})_{tv1} + (T_o\dot{S}_{gen})_{tv2} + (T_o\dot{S}_{gen})_{tv3} \quad (25)$$

Liquid subcooler

$$\Psi_{lsc} = (T_o\dot{S}_{gen})_{sc} = \dot{m}_{c3}(X_7 - X_{77}) \quad (26)$$

Flash intercoolers

$$(T_o\dot{S}_{gen})_{f1} = \dot{m}_{f1}(X_9 - X_3) + \dot{m}_{c1}(X_2 - X_3) \quad (27)$$

$$(T_o\dot{S}_{gen})_{f2} = \dot{m}_{f2}(X_8 - X_5) + \dot{m}_{c1}(X_4 - X_5) \quad (28)$$

$$\Psi_f = (T_o\dot{S}_{gen})_{f1} + (T_o\dot{S}_{gen})_{f2} \quad (29)$$

Total irreversibility destruction in system-1

$$\sum \Psi_k = \Psi_e + \Psi_c + \Psi_{cond} + \Psi_{tv} + \Psi_{lsc} + \Psi_f \quad (30)$$

$$\dot{m}_{c1} = \dot{m}_{e1} = \frac{\dot{Q}_{e1}}{(\Phi_1 - \Phi_{12})} \quad (31)$$

$$\dot{m}_{e2} = \frac{\dot{Q}_{e2}}{(\Phi_3 - \Phi_{10})} + \dot{m}_{c1}\left(\frac{x_{10}}{1 - x_{10}}\right) \quad (32)$$

$$\dot{m}_{f1} = \frac{\dot{m}_{c1}(\Phi_2 - \Phi_3)}{(\Phi_3 - \Phi_{10})} \quad (33)$$

$$\dot{m}_{c2} = \dot{m}_{c1} + \dot{m}_{e2} + \dot{m}_{f1} \quad (34)$$

$$\dot{m}_{e3} = \frac{\dot{Q}_{e3}}{(\Phi_5 - \Phi_8)} + \dot{m}_{c2}\left(\frac{x_8}{1 - x_8}\right) \quad (35)$$

$$\dot{m}_{f2} = \frac{\dot{m}_{c2}(\Phi_4 - \Phi_5)}{(\Phi_5 - \Phi_8)} \quad (36)$$

Power required for running the compressors

$$P_{c1} = \frac{\dot{m}_{c1}(\Phi_2 - \Phi_1)}{60} \quad (37)$$

$$P_{c2} = \frac{\dot{m}_{c2}(\Phi_4 - \Phi_3)}{60} \quad (38)$$

$$P_{c3} = \frac{\dot{m}_{c3}(\Phi_6 - \Phi_5)}{60} \quad (39)$$

$$\text{Energetic efficiency} = \frac{\dot{Q}_e}{P_c * 60} \quad (40)$$

3.2 Rate of exergy loss due to irreversibilties $(T_o\dot{S}_{gen})$ in various components of system-2

Compressors

$$(T_o\dot{S}_{gen})_{c1'} = \dot{W}_{c1'} + m_{c1'}(X_{2'} - X_{1'}) \quad (41)$$

$$(T_o\dot{S}_{gen})_{c2'} = \dot{W}_{c2'} + m_{c2'}(X_{4'} - X_{3'}) \quad (42)$$

$$(T_o\dot{S}_{gen})_{c3'} = \dot{W}_{c3'} + m_{c3'}(X_{6'} - X_{5'}) \quad (43)$$

$$\Psi_{c'} = (T_o\dot{S}_{gen})_{c1'} + (T_o\dot{S}_{gen})_{c2'} + (T_o\dot{S}_{gen})_{c3'} \quad (44)$$

Evaporators

$$(T_o\dot{S}_{gen})_{e1'} = \dot{m}_{e1'}(X_{1'} - X_{12'} - \dot{Q}_{e1'}\left(1 - \frac{T_0}{T_{r1'}}\right) \quad (45)$$

$$(T_o\dot{S}_{gen})_{e2'} = \dot{m}_{e2'}(X_{3'} - X_{10'}) - \dot{Q}_{e2'}\left(1 - \frac{T_0}{T_{r2'}}\right) \quad (46)$$

$$(T_o\dot{S}_{gen})_{e3'} = \dot{m}_{e3'}(X_{5'} - X_{8'}) - \dot{Q}_{e3'}\left(1 - \frac{T_0}{T_{r3'}}\right) \quad (47)$$

$$\Psi_{e'} = (T_o\dot{S}_{gen})_{e1'} + (T_o\dot{S}_{gen})_{e2'} + (T_o\dot{S}_{gen})_{e3'} \quad (48)$$

Condenser

$$\Psi_{cond'} = (T_o\dot{S}_{gen})_{cond'}$$

$$= \dot{m}_{c3'}(X_{6'} - X_{7'}) - \dot{Q}_{e'}\left(1 - \frac{T_0}{T_{r'}}\right) \quad (49)$$

Throttle Valves

$$(T_o\dot{S}_{gen})_{tv1'} = \dot{m}_{e1'}(X_{11'} - X_{12'}) \quad (50)$$

$$(T_o\dot{S}_{gen})_{tv2'} = \dot{m}_{c2'}(X_{9'} - X_{10'}) \quad (51)$$

$$(T_o\dot{S}_{gen})_{tv3'} = \dot{m}_{c3'}(X_{77'} - X_{8'}) \quad (52)$$

$$\Psi_{tv'} = (T_o\dot{S}_{gen})_{tv1'} + (T_o\dot{S}_{gen})_{tv2'} + (T_o\dot{S}_{gen})_{tv3'} \quad (53)$$

Liquid subcooler

$$\Psi_{lsc'} = (T_o\dot{S}_{gen})_{lsc'} = \dot{m}_{c3'}(X_{7'} - X_{77'}) \quad (54)$$

Flash intercoolers

$$(T_o\dot{S}_{gen})_{f1'} = \dot{m}_{f1'}(X_{10'} - X_{3'}) + \dot{m}_{c1'}(X_{2'} - X_{3'}) \quad (55)$$

$$(T_o\dot{S}_{gen})_{f2'} = \dot{m}_{f2'}(X_{8'} - X_{5'}) + \dot{m}_{c2'}(X_{4'} - X_{5'}) \quad (56)$$

$$\Psi_{f'} = (T_o\dot{S}_{gen})_{f1'} + (T_o\dot{S}_{gen})_{f2'} \quad (57)$$

Total irreversibility destruction in system-1

$$\sum \Psi_{k'} = \Psi_{e'} + \Psi_{c'} + \Psi_{cond'} + \Psi_{tv'} + \Psi_{lsc'} + \Psi_{f'} \quad (58)$$

Exergetic efficiency

$$\text{Exergetic efficiency} = \frac{\text{Exergy of cooling load of evaporato}}{\text{Compressors work}} \quad (59)$$

$$\text{Exergetic efficiency of system} - 1 = \frac{(\dot{Q}_{e1} + \dot{Q}_{e2} + \dot{Q}_{e3}) - T_o\left(\frac{\dot{Q}_{e1}}{T_{r1}} + \frac{\dot{Q}_{e2}}{T_{r2}} + \frac{\dot{Q}_{e3}}{T_{r3}}\right)}{P_c * 60} \quad 60)$$

$$\text{Rational efficiency of system} - 2 = \frac{(\dot{Q}_{e1'} + \dot{Q}_{e2'} + \dot{Q}_{e3'}) - T_o\left(\frac{\dot{Q}_{e1'}}{T_{r1'}} + \frac{\dot{Q}_{e2'}}{T_{r2'}} + \frac{\dot{Q}_{e3'}}{T_{r3'}}\right)}{P_{c'} * 60} \quad 61)$$

4.0 Results and Discussions

Both systems (system-l& system-2) were analytically analyzed and the variation in low, intermediate and high temperature evaporator with coefficient of performance for eight ecofriendly refrigerants in system-1 and system-2 is shown in Figs.3-5 and Figs.6-8 respectively. And it was observed that COP (energetic efficiency) of system-2 is higher than system-1. The COP of both system-1 and system-2 increase with increase in evaporator temperature for chosen refrigerants. It was also observed that R600 and R717 show better performance and R125 gives lowest thermodynamic performance in term of energetic efficiency than other refrigerants for both systems. The maximum percentage difference of COP was observed in high temperature evaporator of system-2 and system-1 is 9.59% for R125 at 15 °C, The effect of second law efficiency (exergetic efficiency) with change in temperature of low, intermediate and high temperature evaporator of system-1 and system-2 shown by Figs 9-lland Fig.11-14 respectively.. It is also observed that second law efficiency decrease with increase in evaporator temperature. R600 and R125 have maximum and minimum second law efficiency for both systems similar to performance evaluation in terms of energetic efficiency. It was also found that temperature variation in low and intermediate evaporator put great impact on second law efficiency in comparison with high temperature evaporator, for both systems. Irreversibility in system is work required to displace the atmosphere or lost work during the process. The irreversibility analysis of system-1 and system-2 is presented by Figs. 15-17 and Figs. 18-20 respectively. It was experienced that irreversibility of both system-1 and system-2 increase with increase in temperature of evaporator.R125 shows maximum irreversibility, on the other hand R600 and R717 show minimum irreversibility in systems compared with other ecofriendly refrigerants. It is also observed that irreversibility in system-1 is 1.4-2.1%, 1.3-2.2% and 1.6-2.0% using R600 and 1.8-3%, 1.7-3.1%, 2.2-2.7% using R125 is lower than system-2 for low, intermediate and high temperature evaporator respectively. This marginal irreversibility differences between system-1 and system-2 could be neglected. The impact of change in condenser temperature in range of 25 °C to 45 on coefficient of performance, second law efficiency and system irreversibility is shown in Figs.21-26 for sytem-1 and system-2 using ecofriendly refrigerants.

This analysis reveals that COP and second law efficiency decreases with increase in condenser temperature on the other hand exergy destruction (system irreversibility) increase with increase in condenser temperature for system-1 & sytem-2

Fig 3: Variation of Low Temperature Evaporator with Energetic Efficiency of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (System-1)

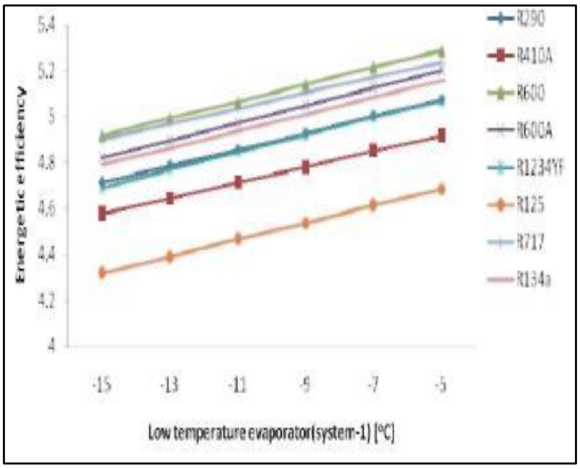


Fig 4: Variation of Intermediate Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves with Variation of Energetic Efficiency (System-1)

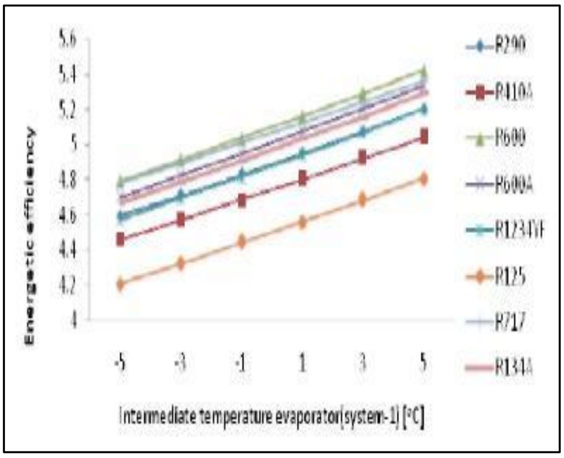


Fig 5: Variation of High Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (System-1) With Variation of Energetic Efficiency (COP)

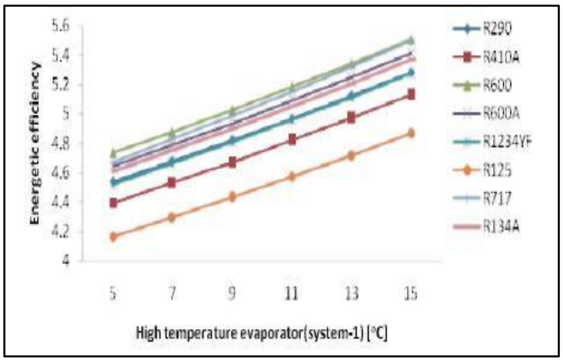


Fig 6: Variation of Low Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (System-2) with Variation of Energetic Efficiency (COP)

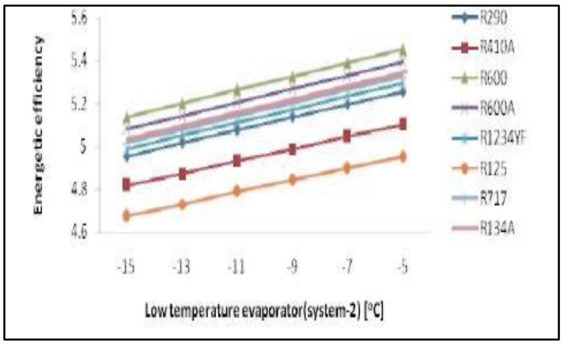


Fig 7: Variation of Intermediate Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (System-2) with Variation Energetic Efficiency (COP)

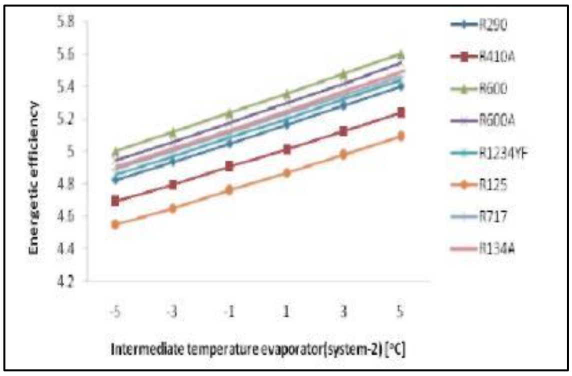


Fig 8: Variation of High Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (System-2) with Energetic Efficiency (COP)

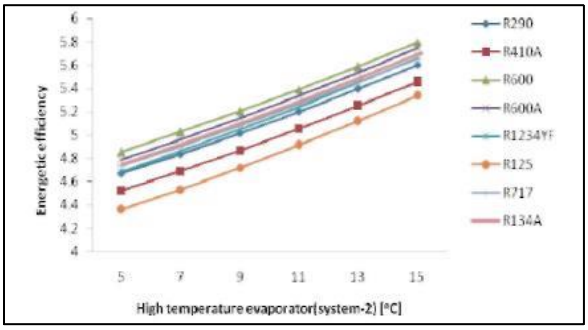


Fig 9: Variation of Low Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (System-1) With Variation of Exergetic Efficiency

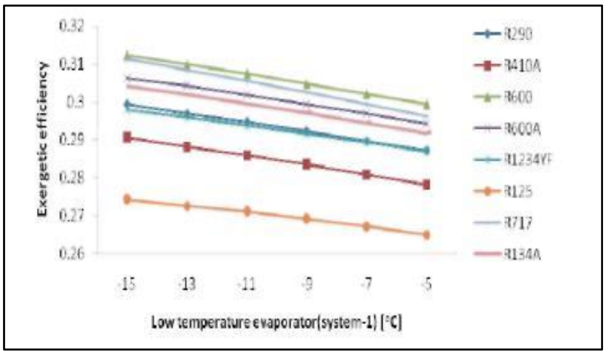


Fig 10: Variation of Intermediate Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (System-l) With Variation of Exergetic Efficiency

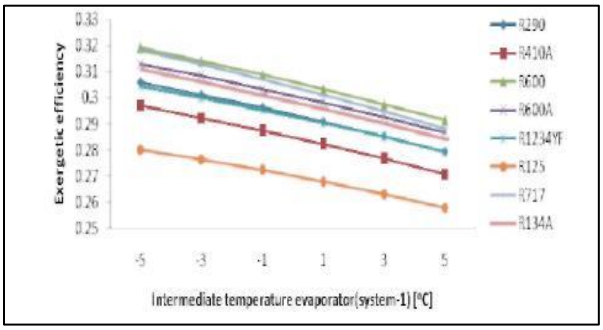


Fig 11: Variation of High Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (System-1) with Variation of Exergetic Efficiency

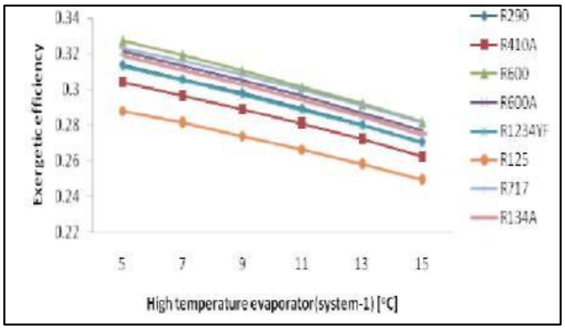


Fig 12: Variation of Low Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (System-2) with Variation of Exergetic Efficiency

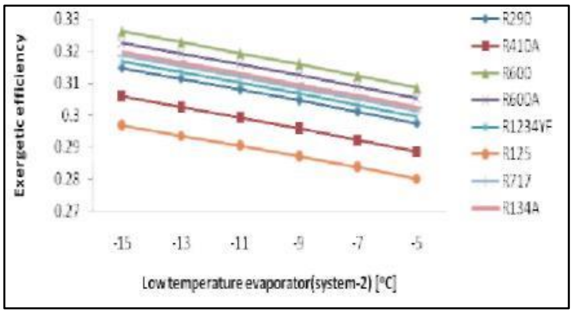


Fig 13: Variation of Intermediate Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (System-2) with Variation of Exergetic Efficiency

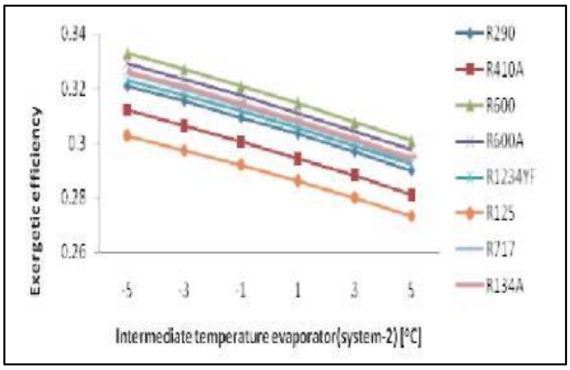


Fig 14: Variation of High Temperature Evaporator of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (System-2) with Variation of Exergetic Efficiency

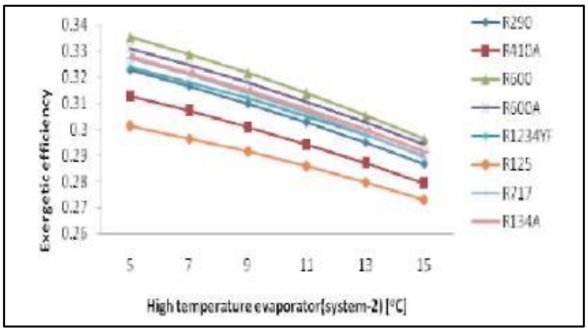


Fig 15: Variation of Low Temperature Evaporator with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (Sytem-1)

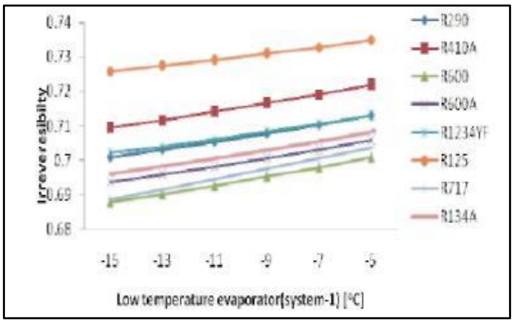


Fig 16: Variation of Intermediate Temperature Evaporator with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (Sytem-1)

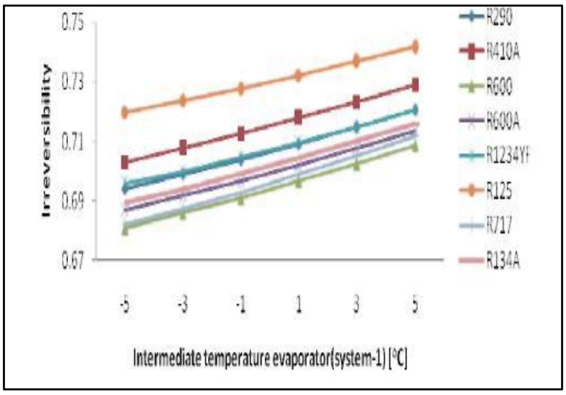


Fig 17: Variation of High Temperature Evaporator with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (Sytem-1)

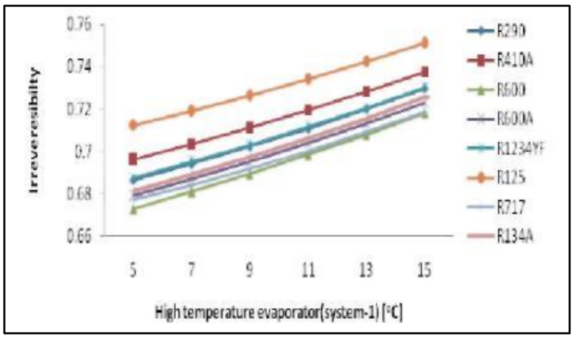


Fig 18: Variation of Low Temperature Evaporator with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (Sytem-2)

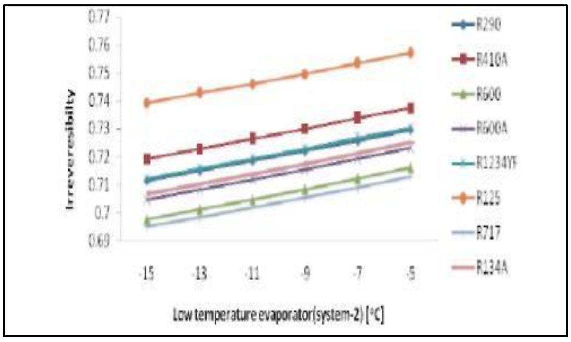


Fig 19: Variation of Intermediate Temperature Evaporator with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (Sytem-2)

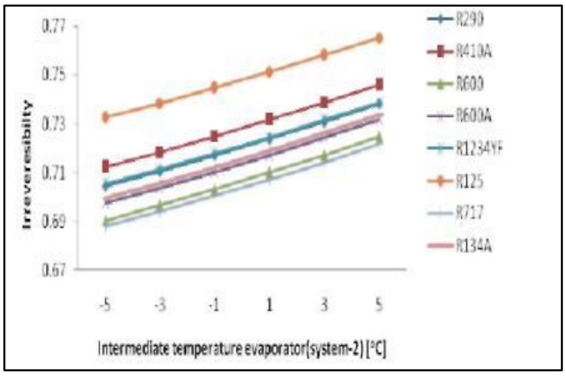


Fig 20: Variation of High Temperature Evaporator with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (Sytem-2)

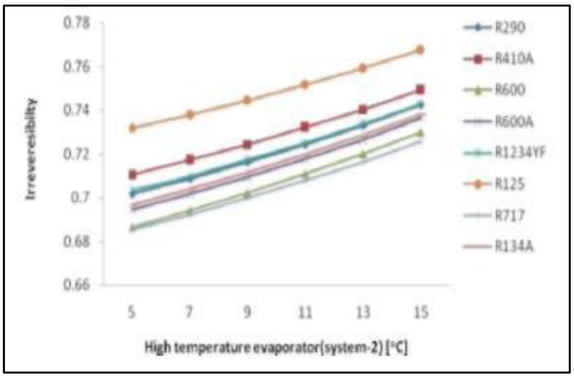


Fig 21: Variation of Condenser Temperature with Energetic Efficiency of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (Sytem-1)

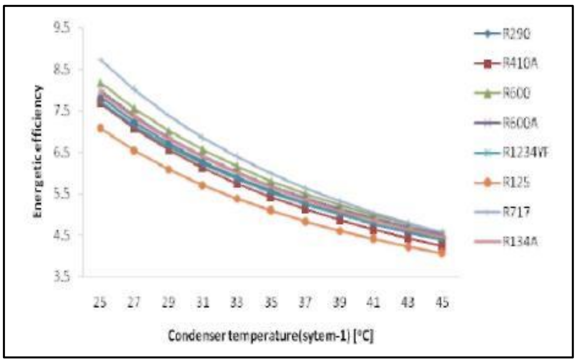


Fig 22: Variation of Condenser Temperature with Energetic Efficiency of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (Sytem-2)

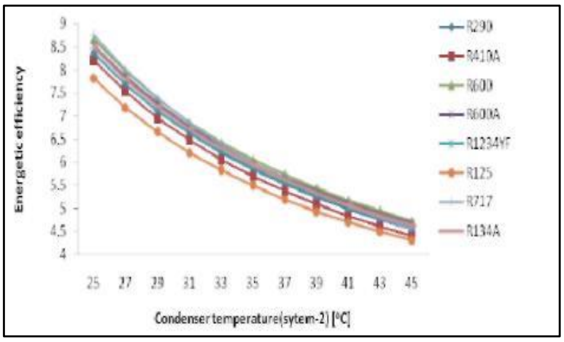


Fig 23: Variation of Condenser Temperature with Exergetic Efficiency of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (Sytem-1)

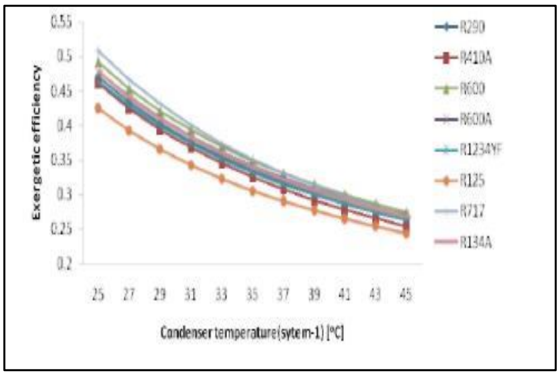


Fig 24: Variation of Condenser Temperature with Exergetic Efficiency of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (Sytem-2)

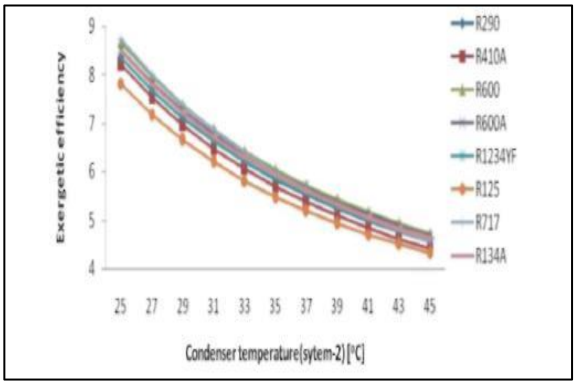


Fig 25: Variation of Condenser Temperature with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Individual Throttle Valves (Sytem-1)

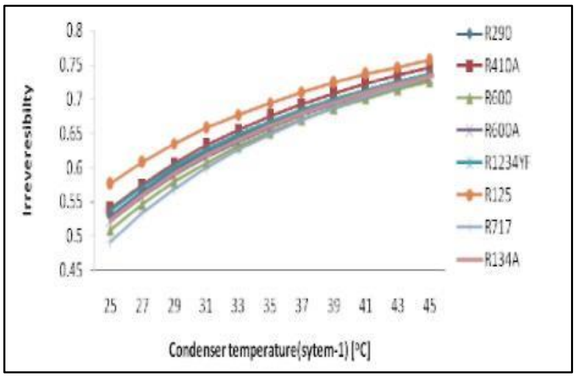
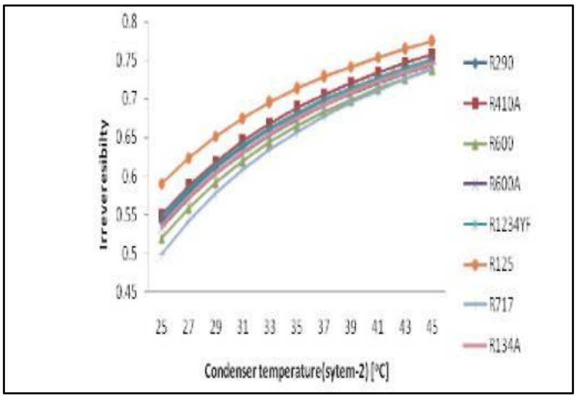


Fig 26: Variation of Condenser Temperature with Irreversibility of Multiple Stage Vapour Compression Refrigerator with Flash Intercooler and Multiple Throttle Valves (Sytem-2)



5.0 Conclusions and Recommendations

Thermodynamic nalysis of multi-stage vapour compression refrigerator and flash intercooler with individual or multiple throttle valves has been done in terms of COP, second law efficiency and irreversibility destruction using eight ecofriendly refrigerants for reducing global warmingand ozone depletion by replacing R12, the following conclusions were made:

1. Energetic and exergetic performance of and multiple stage vapour compression refrigerator with flash intercooler and multiple throttle valves (system-2) is higher than multiple stage vapour compression refrigerator with flash intercooler and individual throttle valves (system-1) for selected temperature range of condenser and evaporators with eight chosen ecofriendly refrigerants.
2. For both systems R125 shows minimum thermal performance in terms of COP, second law efficiency and maximum exergy destruction ratio for finding irreversibilities occurred in the system
3. Performances of R600 and R717 better in comparison of other selected ecofriendly refrigerants for system-1 and system-2. AS R717 is toxic and limited to industrial applications, therefore R600 is recommended for both systems by taking safety precautions. Performance of R134a is slighly lesser than R600, therefore R134a can also be used for practical applications without taking of any safety precautions.
4. The maximum percentage difference of COP between system-2 and system-1 is 9.59% for R125 at 15 oC , high temperature evaporator. Irreversibility in system-1 is 1.4-2.1%, 1.3-2.2% and 1.6-2.0% using R600 and 1.8-3%, 1.7-3.1%, 2.2-2.7% using R125 is lower than system-2 for low, intermediate and high temperature evaporator respectively. This marginal irreversibility differences between system-1 and system-2 can be neglected.

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Nomenclature

LTE	low temperature evaporator
ITE	intermediate temperature evaporatoı
THE	high temperature evaporator
TR	ton of refrigeration
P	power (kJ/s)
f	flash intercooler
$\dot{Q}$	rate of heat transfer (kW)
$\dot{W}$	work rate (kW)
T	temperature (oC)
TV	throttle valve
x	dryness fraction(non-dimensional)
Φ	specific enthalpy (kJ/kg)
$\dot{\Psi}$	irreversibility rate(kW)
C	Compressor
X	exergy rate of fluid (kW)
$\dot{m}$	mass flow rate (kg/s)
S	specific entropy (kJ/kgK)
$\dot{EP}$	exergy rate of product (kW)

Subscript

e	Evaporator
c	Compressor
o	dead state
f	flash intercooler
r	Refrigerant
tv	throttle valve
lsc	liquid subcooler
k	kth component
gen	Generation
cond	Condenser