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Experimental performance evaluation of vapour compression refrigeration system without nano particles

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Abstract

The computer model was developed for vapour compression refrigeration system using water cooled condenser evaporator and condenser for predicting its completely numerical values of system design parameters including its first law performance in terms of COP and Second law performance. The experimental facility was developed in the lab and experiment was conducted for several days on the system. It was observed that developed model predict experimental behavior well. The developed model was also applied on other ecofriendly refrigerants and found well predicting its thermal performance.

Keywords: Vapour compression Refrigeration system, Thermal Modelling, Ecofriendly refrigerants

1. Introduction

Refrigeration technology based on the principle of rejection of heat to the surrounding at higher temperature and absorption of heat at low temperature [1].evaporator, expansion valve, condenser and compressor are the main four components of single stage vapour compression system. Vapour compression refrigeration systems consume large amount of electricity. This difficulty can be removed by improve the performance parameters of system. Coefficient of performance and exergetic efficiency are main two parameters to calculate the performance of refrigeration systems. Coefficient of performance can be enhanced either by minimizing power consumption of compressor or increasing of refrigeration effect. Refrigeration effect can be increased by adoption of multi-stage throttling .On the other hand power consumption of compressor can be enhanced by incorporation of multi-stage compression and flash chamber. Collective effect of these two factors improves overall performance of vapour compression system.

It is presented that irreversibility in system components take place due to large temperature difference between system and surrounding. In order to improve the system performance Irreversibility should be measured in the cycle because Exergy losses are responsible for degradation of system performance .Coefficient of performance is commonly used to calculate the performance of vapour compression system but COP provides no information regarding thermodynamic losses in the system components. Using exergy analysis one can be quantify the exergy losses in vapour compression refrigeration systems. Exergy losses increase with increasing of temperature difference between systems and surrounding. Exergy is the available or useful energy and loss of energy means loss of exergy in the system. Exergy losses are useful to improve the performance of system and better utilization of energy input given to the system which is beneficial for environmental conditions and economics of energy technologies. Utilization of green energy can be increased by this method. [2-4]

In past decades, refrigerants such as R12,R02,R22 etc. used in vapour compression refrigeration system responsible for increasing of global warming and ozone depletion potential. An international society named Montreal protocol discussed and signed on the refrigerants having higher global warming and ozone depletion potential values for all countries. In order to control the emission of greenhouse gases one more committee was formed named as Kyto protocol [5].After

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90's a program was ran to phase out the higher GWP and ODP refrigerants(CFC and HCFC) for the purpose of environmental problems.

To replace "old" refrigerants with "new" refrigerants lots of researches has been b lots of researches has been carried out [6-11]. Selladurai and Saravana kumar [12] evaluated thermal performance parameters such as COP and exergetic efficiency with R290/R600 hydrocarbon mixture on a domestic refrigerator designed to work with R134a and observed that performance of same system is higher with R290/R600a hydrocarbon mixture compared to R134a. In their analysis condenser, expansion valve and evaporator showing lower exergy destruction compared to compressor. Reddy et al [13] presented a theoretical analysis of R134a, R143a, R152a, R404A, R410A, R502 and R507A in vapour compression refrigeration system and effect on coefficient of performance and second law efficiency with variation of superheating of evaporator outlet, evaporator temperature and degree of sub-cooling at condenser outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature was discussed. They reported that COP and exergetic efficiency significantly affected with change of evaporator and condenser temperatures and also observed that R134a and R407C show highest and lowest performance in all respect. Kumar et al [14] carried out energy and exergy analysis of single stage vapour compression refrigeration system using R11 and R12 as working fluids.

Thermal performance evaluation in terms of COP, exergetic efficiency and exergy losses in different components (compressor, evaporator, expansion valve and condenser) was done. Cornelissen [15] proposed that non-renewable energy sources are useful for minimizing the irreversibility of the system for sustainable development of systems. He also observed that emissions of gases put adverse effect on environmental conditions. Nikolaidis and Probert [16] considered the effect of condenser and evaporator temperatures on two-stage vapour compression refrigeration system using R22 was studied and suggested that there is requirement to optimize the condenser and evaporator conditions.

Many researchers carried out researches on different proportion of hydrocarbons as working fluid in vapour compression refrigeration systems. Fatouh and Kafafy [17] suggested to replace R134a with hydrocarbon mixtures such as propane, propane/isobutane/n-butane mixtures, butane, and various propane mass fractions in domestic refrigerator. Pure butane showed high operating pressures and low coefficient of performance among considered refrigerants. Wongwises et al [18] did experimental investigation on automotive air-conditioners with isobutene, propane, butane and suggested to replace R134a with these hydrocarbon mixtures. They observed that mixture of propane 50%, butane 40%, and isobutane 10% was best hydrocarbon mixture to replace R134a.Jung et al [19], Arcaklioglu [20] , and Arcaklioglu et. al [21] suggested to use of pure hydrocarbon instead of their mixtures due variation in condenser and evaporator temperature during phase changing at constant pressure. These Changes in condenser and evaporator temperature cause for problem in vapour compression refrigeration cycle. Liedenfrost et al [22] investigated Freon as refrigerant on the performance of a refrigeration cycle

Through above literature, it was found that energy, exergy and sustainable analysis of single stage vapour compression refrigeration systems have been done. But no literature contributed for energy and exergy analysis of two-stage vapour compression refrigeration system. Present works analyze the system in terms of energy and exergy efficiencies and explain the effect of exergy losses on two-stage vapour compression refrigeration system with hydrocarbons and R134a.

2. Result and Discussion

The most widely used fluorocarbon refrigerants in the world in the vapour compression refrigeration systems includes environmentally friendly hydrocarbon (HFC) refrigerants (i.e. R134a, R404A, R407C and R290) have been considered for computing first law performance of vapour compression refrigeration system because vapour compression refrigeration system simulate thermal performance of actual system as closely as possible, has been used to compare the characteristics of various eco-friendly refrigerants (i.e.R134a, R404A, R407C and R290). The following input data have been used for modelling of vapour compression refrigeration system using ecofriendly R134a refrigerant and R718 in secondary circuit of evaporator and ecofriendly refrigerant in the primary circuit of evaporator using centrifugal compressor

Condenser and evaporator concentric tube type.

Condenser outer tube length is=1.2 m

Evaporator outer tube length is=0.8m

Condenser outer tube diameter is 5/8" and inside tube diameter is 3/8"

Evaporator outer tube diameter is 5/8" and inside tube diameter is 3/8"

2.1 Prediction in comparison with experimental Data

For the experiment we use refrigerant is R134a. In table-1 shows the initial input to for the computational model is given.

Table 1: Inputs of the design and experimental test rig

S. No	m_b (kg/s)	m_w (kg/s)	Tb_{in} (°C)	Tw_{in} (°C)	N (rpm)	Condenser size (m)	Evaporator size (m)
1.	0.006	0.008	25	25	2900	1.2	0.8
2	0.007	0.008	25	25	2900	1.2	0.8
3	0.008	0.008	25	25	2900	1.2	0.8

Table 2: Comparison between experimental and computed values of evaporator temperature and condenser temperature from model developed for vapour compression refrigeration system

S.No	Mass flow rate of brine in the secondary circuit of Evaporator (m_b) Kg/sec	Mass flow rate of water in the secondary circuit of Condenser (m_b) Kg/sec	Computed T_{Eva} (°C)	Experimental T_{eva} (°C)	Predicted T_{Cond} (°C)	Experimental T_{Cond} (°C)
1.	0.006	0.008	-1.501	-1.80	48.25	42.10
2.	0.007	0.008	0.277	-0.70	49.17	43.60
3.	0.008	0.008	-0.78	1.10	51.32	46.30

Table 3: Comparision between experimental and computed values of brine evaporator temperature out and water condenser temperature out from model developed for vapour compression refrigeration system for evaporator length (L_{eva} =0.80m), Condenser length (L_{Cond} = 1.2 m) along with inlet temperature of water and brine ($T_{wi}=T_{bi}=25^0C$)

S. No	Mass flow rate of brine in the secondary circuit of Evaporator (m_b) Kg/sec	Mass flow rate of water in the secondary circuit of Condenser (m_b) Kg/sec	Computed brine temperature out Tb_{out} (°C)	Experimental brine temperature out Tb_{out} (°C)	Predicted Tw_{out} (°C)	Experimental Tw_{out} (°C)
1.	0.006	0.008	12.9	13.1	37.01	34.70
2.	0.007	0.008	15.29	14.3	37.69	36.10
3.	0.008	0.008	13.19	16.4	40.82	35.20

Table 4: Comparison between Experimental and Computed values of evaporator pressure and condenser pressure from model developed for vapour compression refrigeration system for evaporator length (L_{eva} =0.80m), Condenser length (L_{Cond} = 1.2 m) along with inlet temperature of water and brine ($T_{wi}=T_{bi}=25^0C$)

S. No	Mass flow rate of brine in the secondary circuit of Evaporator (m_b) Kg/sec	Mass flow rate of water in the secondary circuit of Condenser (m_b) Kg/sec	P_{Eva} Computed (bar)	P_{Eva} Exp (bar)	P_{Cond} predicted (bar)	P_{Cond} exp(°C)
1.	0.006	0.008	2.774	2.86	12.90	12.90
2.	0.007	0.008	2.96	2.56	11.80	11.80
3.	0.008	0.008	2.847	2.80	12.64	12.64

Table 5: Comparision between Experimental and Computed values of first law efficiency (COP) from model developed for vapour compression refrigeration system for evaporator length (L_{eva} =0.80m), Condenser length (L_{Cond} = 1.2 m) along with inlet temperature of water and brine ($T_{wi}=T_{bi}=25^0C$)

S. No	m_b (kg/s)	m_w (kg/s)	$COP_{predicted}$ (bar)	COP exp (°C)
1.	0.006	0.008	2.973	2.67
2.	0.007	0.008	3.131	2.75
3.	0.008	0.008	2.827	2.84

Table 6: computed results from model for vapour compression refrigeration system for evaporator length (L_{eva} =0.80m), Condenser length (L_{Cond} = 1.2 m) along with inlet temperature of water and brine ($T_{wi}=T_{bi}=25^0C$)

S. No	T_e (°C)	T_k (°C)	Tb_{out} (°C)	Tw_{out} (°C)	P_e (bar)	P_k (bar)	COP
1.	-1.501	48.25	12.9	37.01	2.774	12.62	2.973
2.	0.277	49.17	15.29	37.69	2.96	12.91	3.131
3.	-0.78	51.32	13.19	40.82	2.847	13.63	2.827

Several refrigerants have emerged as substitutes to replace R22, the most widely used fluorocarbon refrigerants in the world. These include the environmentally friendly hydrocarbon (HFC) refrigerants R134a, R404A, R407C and R290.
Table 7 shows the physical and environmental characteristics of these refrigerants.
A comparison between the measured and predicted values for the parameters in three sets is presented. It has been observed that the predicted values of the parameters are within the 20% of the measured values
In reciprocating compressor vapour compression refrigeration system which can simulate the performance of actual system as closely as possible, has been used to compare the characteristics of various refrigerants R22, R134a, R404A, R407C and R290.

Table 7: Physical and environmental characteristics of selected refrigerants

Properties	R134a	R404a	R407c	R290
Molecular Wt (kg / Kmol)	102	97.6	86.20	44.1
Boiling Pt at 1.013 bar °C	-26.1	-51.4	-43.6	-42.2
Critical temperature (°C)	101.1	72.15	85.8	96.68
Critical Pressure (bar)	40.60	37.35	46.00	42.47
ODP	0	0	0	0
GWP_{100}	1300	3260	1800	3

Hydro Carbon refrigerant is R290. While R134a is a pure refrigerant, whereas R407C and 404A are blends of refrigerants. The advantages of blending refrigerants are that properties such as flammability, capacity, discharge temperature and efficiency can be tailored for specific applications. There are many considerations in selecting a refrigerant, and each has an impact on the overall performance, reliability, cost and market acceptance of a manufacturer's system. On the basis of above results, R134a, R404A, R407C and R290 are compared with R22 at the designed conditions Table 8.
R134a is a lower capacity and lower pressure refrigerant than R22. Because of these characteristics, a system with R134a of the same capacity requires a larger displacement compressor and larger evaporator, condenser, and tubing. The end result is a system which costs more to build and to operate than an equivalent R22 system.

Table 8: .Comparison of performance parameters for different refrigerants

Parameters	*R22*	*R134A*	*R404A*	*R407C*	*R290*
COP	2.629	2.978	2.638	2.574	2.959
Compressor work (W)	133.3	102	131.4	127.8	121.2
Refrigerating effect (W)	350.3	303.7	346.5	329	358.4
Mass flow rate (kg/s)	0.0027	0.00236	0.0047	0.0027	0.0015
Condenser pressure (bar)	23.49	12.62	27	23.27	17.16
Evaporator pressure (bar)	4.197	2.774	5.788	4.208	9.148
Condenser Temperature °C)	58.48	48.25	56.94	52.49	51.26
Evaporator Temperature °C)	5.155	-1.501	1.338	2.272	-4.326
Brine outlet temperature (°C)	11.04	12.9	11.19	11.89	10.72
Water outlet temperature (°C)	39.2	37.01	39.16	38.47	39.23

R407C is a potential HFC refrigerant replacement for R22 system such as new or existing residential and commercial air conditioners and heat pumps. A system with R407 C having similar capacity and pressures as R22 can be designed. Because of these features, it can be used as an alternative in R22 systems with a minimum of redesign. System efficiency is slightly lower as compared R22 system due to temperature glide. R407C exhibits a relatively high temperature glide compared to the other refrigerants, which have almost no glide. It also offer '0' ODP, low global warming potential. European market embraced R407C and currently offers a wide R407C AC product range. Further, a change to polyester lubricant is also required. R404A has been in the market place for more than 10 years and is the leading HFC refrigerant for replacing R22 in residential and light commercial air-conditions and heat pump systems. R404A is having a higher pressure refrigerant than R22. As a result of higher pressures and higher gas density, smaller displacement compressors can be used along with smaller diameter tubing and valves and therefore, R404A should only be used in new systems designed for this refrigerant and should not be substituted into existing R22 systems. Greater skill and attention to cleanliness is required during the installation of an R404A system to prevent moisture entering the system. Further, R404A has reduced environmental footprint versus an R22 unit that is comparable in size.

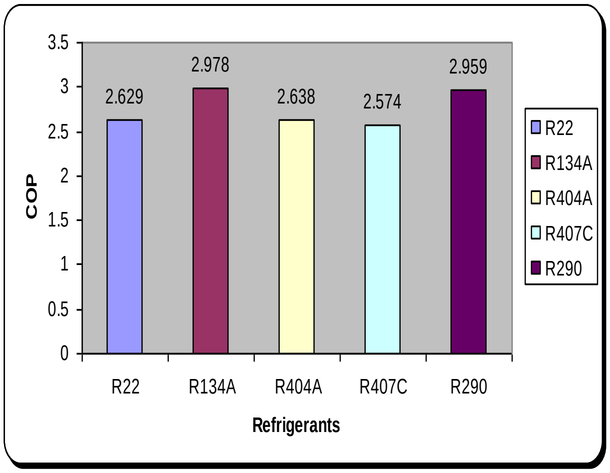

Figure 1: Comparison of COP of different ecofriendly refrigerants

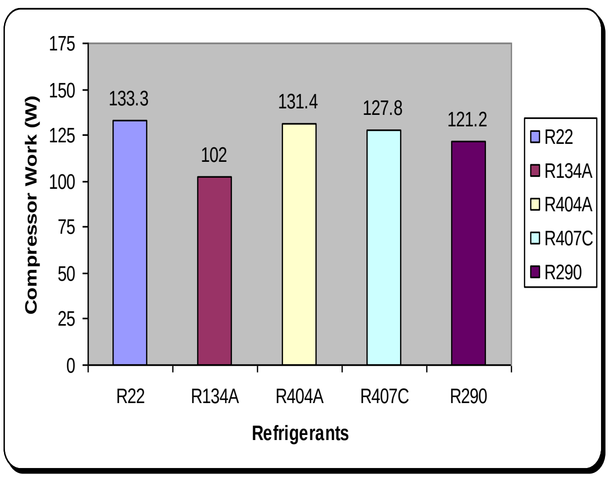

Figure 2: Comparison of compressor work of different ecofriendly refrigerants

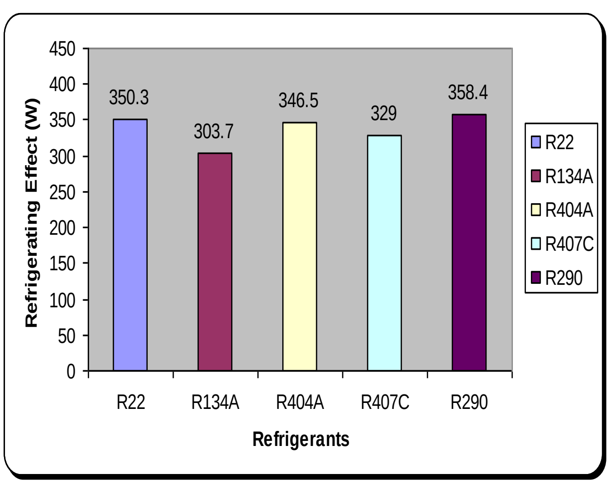

Figure 3: Comparison of refrigerating effect of different ecofriendly refrigerants

The characteristic performance curves of vapor-compression refrigeration systems are defined as a plot between the inputs of the system by using refrigerants R22, R134a, R404A, R407C and R290 to the coefficient of performance (COP) of the system.

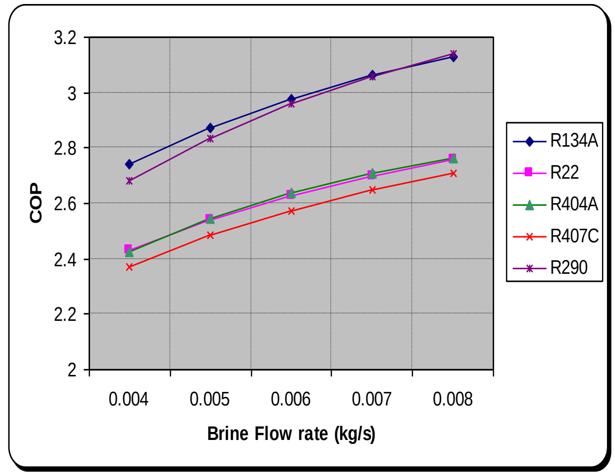

Figure 4: Variation of first law efficiency in terms of coefficient of performance (COP) vs. Brine flow rate of different ecofriendly refrigerants

In Fig 4 the performance curve is shown between COP and Brine flow rate of different refrigerants. When brine mass flow rate 0.004 to 0.008 kg/s (100%) then change in COP for R134a is 14.10 %, R22 is 13.59%, R404a is 13.94%, R407c is 14.39% and R290 is 17.06%.

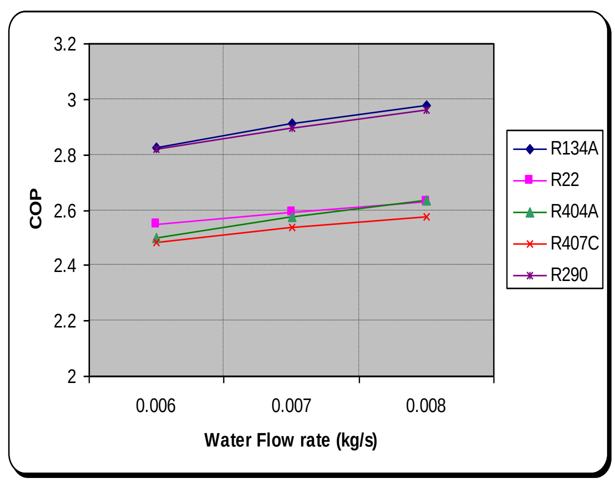

Figure 5: Variation of first law efficiency in terms of coefficient of performance (COP) vs. condensing water flow rate of different refrigerants

In Fig 5 the performance curve is shown between COP and Water flow rate of different refrigerants. When water mass flow rate 0.006 to 0.008 kg/s (33.3%) then change in COP for R134a is 5.54%, R22 is 3.26%, R404a is 5.65%, R407c is 3.58% and R290 is 5%.

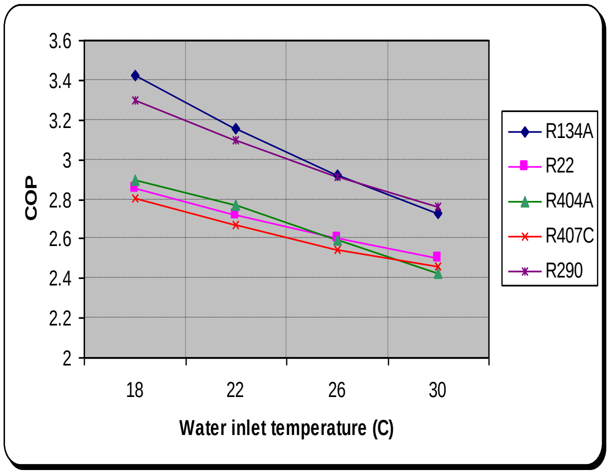

Figure 6: Variation of first law efficiency in terms of coefficient of performance (COP) vs. condensing water inlet temperature of different refrigerants

In Fig 6 the performance curve is shown between COP and condensing water inlet temperature of different refrigerants. When condensing water inlet temperature 18 to 30 °C (66.67%) then change in COP for R134a is 20.27%, R22 is 12.31%, R404a is 16.13%, R407c is 12.50% and R290 is 16.32%

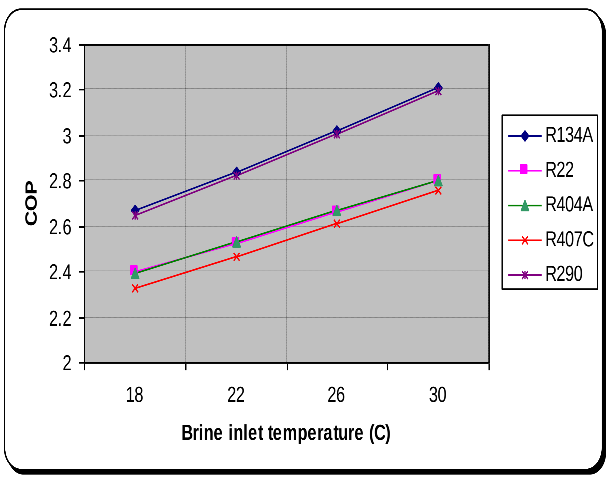

Figure 7: Variation of first law efficiency in terms of coefficient of performance (COP) vs. Brine inlet temperature of different ecofriendly refrigerants

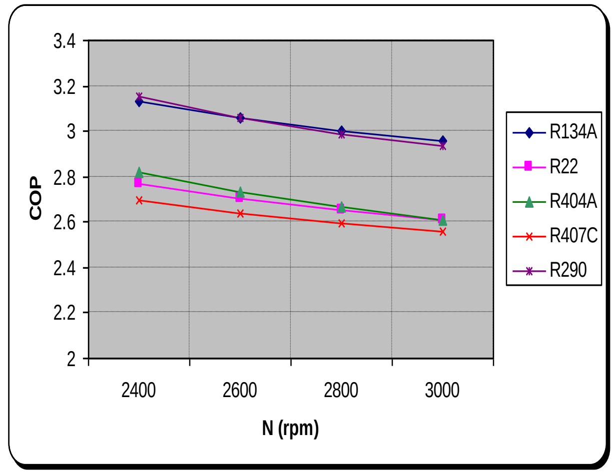

Figure 8: Variation of first law efficiency in terms of coefficient of performance (COP) with speed of compressor of different ecofriendly refrigerants

3. Conclusion

The computer model was developed for vapour compression refrigeration system using water cooled condenser evaporator and condenser for predicting its completely numerical values of system design parameters including its first law performance in terms of COP and Second law performance. The experimental facility was developed in the lab and experiment was conducted for several days on the system. It was observed that developed model predict experimental behavior well. The developed model was also applied on other ecofriendly refrigerants and found well predicting its thermal performance with slight modification and results shown in this paper. The following conclusions were made from present investigation.

- Developed thermal model predict the experimental behavior well in the range of deviation of 5% to 10% deviation.
- The refrigeration effect of R404A is higher than the R407C.
- R134a gives better thermal performance than R404a and R407c and is most commonly used in Refrigeration Systems, HVAC and automobile AC system

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