IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

2nd International Conference on Advances in Mechanical Engineering (ICAME-2016)

Amrutvahini College of Engineering, Sangamner

Vol. 3, Special Issue 1, March 2016

Performance Evaluation of Vapour Compression System with R22 and Environment-Friendly Refrigerant

A.N. Korshetti[1], Dr.V.N.Raibhole[2], N.A. Kumbhar[3]

KJ's Trinity C.O.E., Pune, Maharashtra, India[1]

M.E.S. COE., Pune, Maharashtra,India[2]

PDEA COEM, Pune, Maharashtra, India[3]

Abstract: With increasing recognition of environmental protection, a great deal of attention has been devoted to the negative environmental effect of CFCs and HCFCs refrigerant. Based on scientific findings, regulatory requirements and market pressure, the governing selection criteria for the new alternative refrigerants are changing. New long term alternative refrigerant should have not only zero ODP but it should have low GWP value As per the research and scientific study of environmental pollution extensively, there is an noteworthy need to phase out R22 earlier than that prescribed by Montreal protocol. Any alternative to R22 has to possess all desirable properties of refrigerants like thermodynamic efficiency, non-flammable and non-toxic, thermal and chemical stability, compatibility and low cost. There are other concerns such as Ozone Depletion Potential (ODP) & Global Warming Potential (GWP) of a refrigerant. Vapour compression refrigeration system is used for many applications such as cooling the food items in the refrigerator like vegetables (potato, tomato, etc), fruits (banana, palms, apples, etc) & Medicines, Pharmaticules, beverages, pickles and chutneys, processed mushrooms etc are required to be stored in the cold storages to meet the market demand basically those refrigeration system used refrigerant like R134a, R22, R410, R700C in various countries of the world however it is always tied out we use environment-friendly refrigerants the refrigerantsR134a, R22, R410, R700 facilities in As per the scientific study of environmental pollution extensively, there is an significant need to phase out R22 earlier than that prescribed by Montreal protocol. Any alternative to R22 has to possess all desirable properties of refrigerants like thermodynamic efficiency, non-flammable and non-toxic, thermal and chemical stability, compatibility and low cost. There are other concerns such as Ozone Depletion Potential (ODP) & Global Warming Potential (GWP) of a refrigerant. Worldwide many research activities are carried out to mitigate the till effects of Global Warming, Ozone layer depletion and climate changes. For the past 20 years efforts are made to phase out the production and consumption of Hydro Chloro-Fluorocarbon (HCFCs) and Chloro-Fluorocarbon (CFCs), as these chemicals are responsible for the depletion of the stratospheric ozone layer and used in refrigeration and air-conditioning industry. The Current literature review has indicated that to satisfy the objectives of International protocols, many research works are in finding out a suitable alternative refrigerant with low Global Warming Potential (GWP) compared with R22, minimizing the mass of refrigerant charge used in the system, enhance and ensure energy efficient system operation by adding intelligence to components and enhance the energy efficiency of the system. In that glance, retrofitting of existing R22 vapour compression system with Eco friendly refrigerant R290 is attempted in the present research work.

Keywords: COP- Coefficient of Performance CFC-Chlorofluorocarbon ODP-Ozone Depletion Potential GWP-Global Warming Potentia, HCFC-Hidrochlorofluorocarbon R-Refrigerant.

VAPOUR COMPRESSION REFRIGERATION SYSTEM

The development of refrigeration and air conditioning industry depended to a large extent on the development of refrigerants to suite various applications and the development of various system components. At present the industry is dominated by the vapour compression refrigeration systems. The success of vapour compression refrigeration systems owes a lot to the development of suitable refrigerants and compressors. The theoretical thermodynamic efficiency of a vapour compression system depends mainly on the operating temperatures. Fig. shows the basic components of a vapour compression refrigeration system. The basic system consists of an evaporator, compressor, condenser and an expansion valve (valve or capillary tube). The refrigeration effect is obtained in the cold region as heat is extracted by the vaporization of refrigerant in the evaporator.

The refrigerant vapour from the evaporator is compressed in the compressor to a high pressure at which its saturation temperature is greater than the ambient or any other heat sink. Hence when the high pressure, high temperature

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refrigerant flows through the condenser, condensation of the vapour into liquid takes place by heat rejection to the heat sink. To complete the cycle, the high pressure liquid is made to flow through an expansion valve. In the expansion valve the pressure and temperature of the refrigerant decrease. This low pressure and low temperature refrigerant vapour evaporates in the evaporator taking heat from the cold region. It should be observed that the system operates on a closed cycle. The system requires input in the form of mechanical work. It extracts heat from a cold space and rejects heat to a high temperature heat sink.

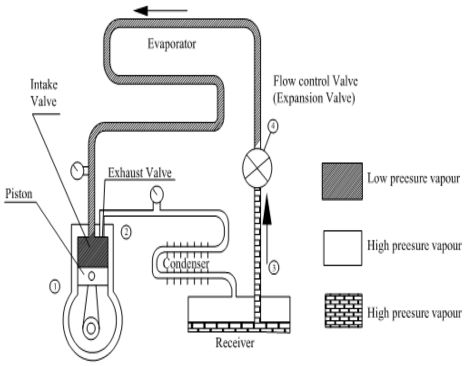

Fig. No-1 : Vapour compression system with components

Here one can see the existence of refrigerant in different phases at different cycle conditions. The high pressure side consists of outlets of compressor, condenser, receiver and up to the inlet of evaporator. The remaining part, i.e., from point 4 through the evaporator and up to inlet of compressor is the low pressure side. The cycle can be represented on T-s, p-v and p-h diagrams as shown below. The condition of refrigerant vapour leaving the evaporator can be assumed to be dry saturated and enters the compressor. The suction to the compressor is indicated by point 1. Some of the assumptions made in theoretical vapour compression cycle are all the processes involved are reversible, there is no internal and external friction between the refrigerant and the surface of heat exchangers neglecting the pressure drop and there is no heat gain or loss except in evaporator and condenser.

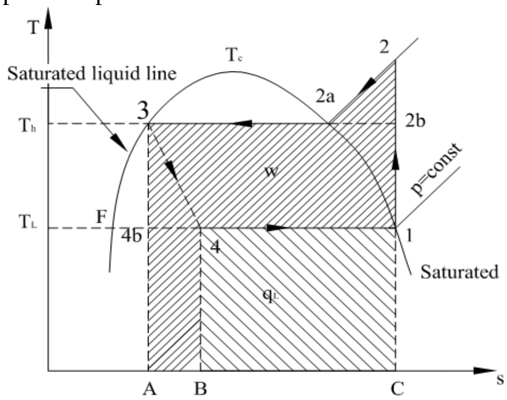

Fig. No-2 : Vapour compression cycle on T-s diagram

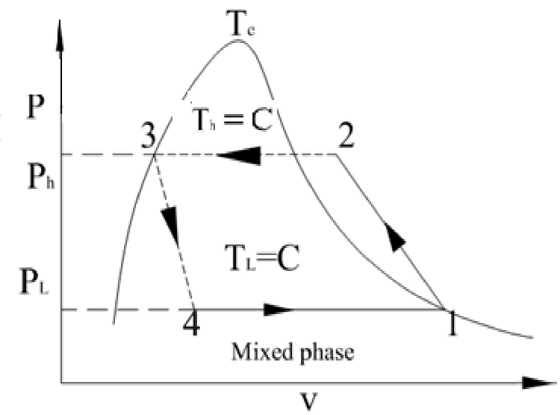

Fig. No-3 : Vapour compression cycle on p-v diagram

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The various processes in the cycle can be explained in brief as follows.
Compression process (1-2): The compressor takes the dry saturated refrigerant vapour during the suction stroke at pressure p_1 and is compressed to pressure $p_2$isentropically. The vapour at pressure p_2 and temperature T_2 enters the condenser and is condensed.

Condensation process (2-3): The function of the condenser is to remove heat from vapour refrigerant so that it changes to liquid phase. The superheated vapour from the state point 2 is first cooled so that it reaches the dry saturated state (point 2a), where the vapour starts condensing and further removal of heat would result in a liquid refrigerant at state point 3. The condenser may be air or water cooled.

Expansion process (3-4): The high pressure liquid from the The state point 3 is expanded through an expansion valve during which the enthalpy remains constant. This process is represented by line 3-4. At the end of this process (point 4), the refrigerant is again a mixture of liquid and vapour phases.

Evaporation process (4-1): Evaporation of liquid refrigerant takes place in a heat exchanger called the evaporator. Its function is to transfer heat from its space to the refrigerant. The refrigerant at start point 4 enters the evaporator slowly changes to saturated vapour as it flows towards the exit (poin1).

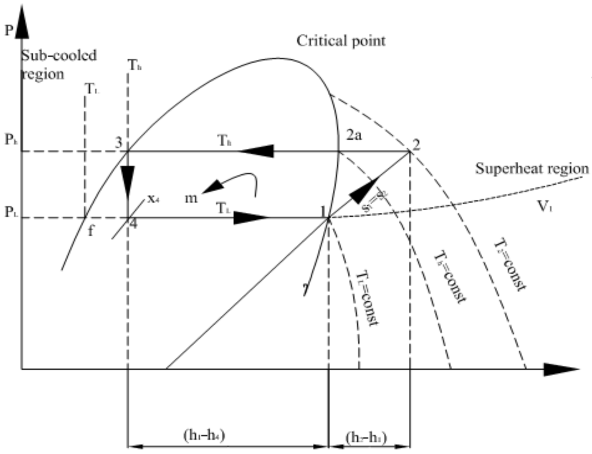

Fig. No-4: Vapour compression cycle on *p-h* diagram

In the above cycle the condition of vapour at the end of compression is super-heated. Similarly the condition of the vapour at the end of compression may be either dry saturated or wet, and accordingly the cycles can be drawn.

CALCULATION METHOD

for cycle analysis the following parameters of vapour compression cycle are used.

1. Pressure ratio is calculated by using

$$\text{Pressure ratio} = {P_{Cond}}/{P_{evap}}$$

2. Compressor work is calculated by using

$$Wc = P = {\gamma}/{(\gamma - 1)}\, P_1 V_1 \left\{ \left({P_2}/{P_1}\right)^{{\gamma-1}/{\gamma}} - 1 \right\}$$

3. Refrigerating effect is calculated by using

$$R.E. = h_1 - h_4$$

4. Volumetric refrigeration Capacity is calculated by using

$$V.R.C. = \rho 1.RE$$

5. Coefficient of Performance is calculated by using

$$C.O.P. = RE / P$$

EXPERIMENTATION

The refrigeration system used for the experimentation is first evacuated to a pressure the order of 10 mm of Hg. Then it is tested for leakages by pressurizing the whole system by N_2 gas. The pressure of N_2 gas was kept in order of 20 bars. The various temperatures at various locations are noted down during the experimentation, once it reached that steady

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state condition then the pressure at the outlet of the compressor is noted, energy meter reading is also noted & the cooling capacity, COP and other parameters are calculated.

This chapter describes the experimental test facility for obtaining experimental data. The System is designed such that various tests can be conducted. Domestic refrigerator with a modified evaporator is used for the study.

The Internal volume of the cabinet design was 60 liters and insulated with 33mm PUF walls and a layer of polyethylene from outside.

The details about working of the apparatus, instrumentation used and measurements taken are described. The experimental procedure adopted during the experimental campaign is explained.

EXPERIMENTAL FACILITY

This title describes the design of the experimental test facility or system for analyzing the effect Domestic refrigerator design is based on the cooling effect required during its service and its COP. The System comprises of components like compressor, condenser, evaporator, capillary tube, refrigerant. Selection and design of these components are described below.

COOLING LOAD CALCULATIONS

Calculating the cooling load is the first step in the design of a refrigeration system. Cooling load estimates the approximate heat to be removed from the goods kept inside the cabinet. It takes in consideration the heat each of the product has and sums the total cooling load on the system [5]. This calculation gives the total cooling capacity required for effective service life of the refrigerator. Total cooling load comprises of following loads.

1) Product Load
2) Load due to infiltration or door openings
3) Air change rate
4) Heat loss rate

For calculating the cooling load, average household needs of a rural family is considered. The specific heat and latent heat values of these products are taken from the ASHRAE handbook. These values are given in Appendix I. For calculation of cooling load from a single product following formula is used:

Product Load = Mass (m) × (Specific Heat (C_p) × Temp. Drop + Rate of Respiration)

Due to door openings, surrounding air adds heat to the refrigerated cabin. Number of door openings is considered as 20 openings per day. Air change rate & heat loss through walls is also considered for calculation of total cooling load on the system.

EXPERIMENTAL FACILITY OPERATION

Experimentation is carried out with load conditions and without load conditions in the refrigerator. Care to be taken while operating the test facility and procedure is as follow:

- Select the capillary tube to be used by opening the flow control valve.
- Ensure that at least one of the flow control valves is open at a time.
- Connect all the thermocouples to the points specified.
- Connect other ends of thermocouples to the data logger with polarities indicated on it.
- Check thermostat setting.
- Start the data logger.
- Start the compressor.
- Note down the Energy Meter reading.
- Set time interval on data logger.
- Turn on printer of the data logger.
- Make sure there is paper in the data logger.
- After the test is done switch off compressor first and then the data logger.

EXPERIMENTAL APPARATUS

The test setup, as shown schematically consists of Components like Compressor, Condenser, Capillary Tube, Evaporator, Filter and Drier, Flow Control Valves and Data Logger.

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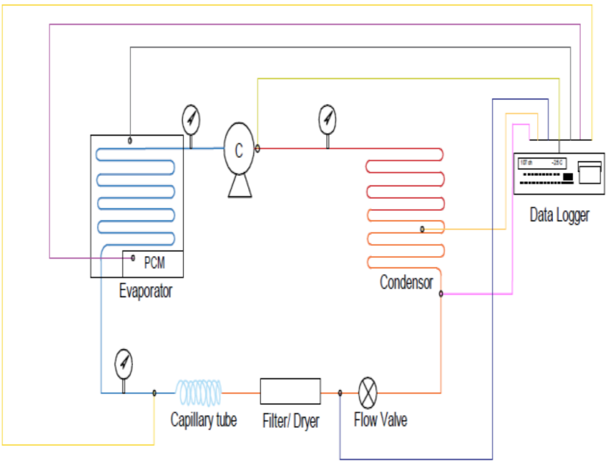
Fig no. 1 Actual Photograph of Test set up



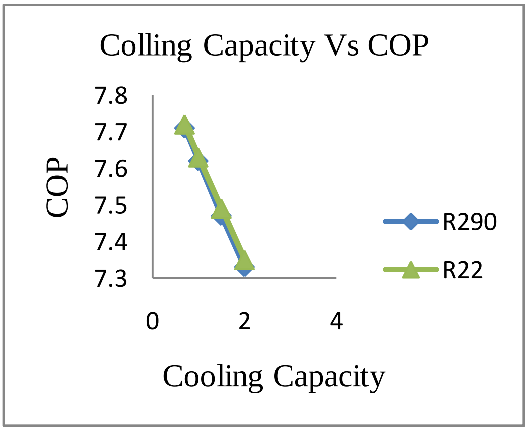
Block Diagram of Actual Test set up

RESULT AND DISCUSSION

COOLING CAPACITY VS COP

Experimental tests have been carried out at different loads to investigate the performance improvement of a domestic refrigerator with and without load. The following conclusions were drawn based on the simulation and experimental results.

Graph : Cooling Capacity Vs



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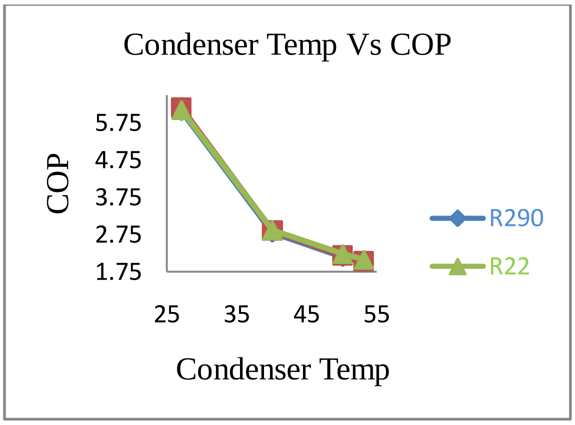
The above graphs show variation of coefficient of performance with respect to cooling capacity. As cooling capacity increases coefficient of performance decreases for all refrigerant.R22 a having more coefficient of performance of performance as compare to R290.

CONDENSER TEMPERATURE Vs COP

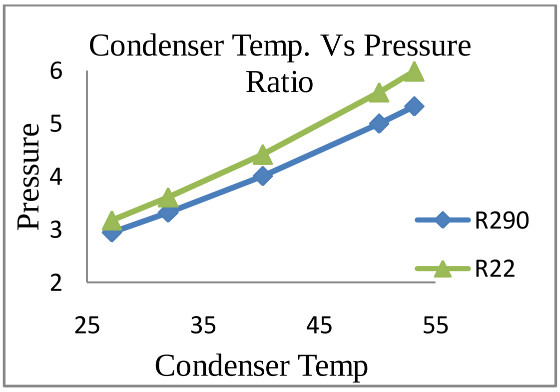
Graph No-1: Condenser Temperature Vs COP



The above graphs show variation of coefficient of performance with condenser temperature. From the above graphs it seems that condenser temperature affect dominantly on performance of domestic refrigerator for all refrigerants that is for R290, R22.

CONDENSER TEMPERATURE Vs PRESSURE RATIO

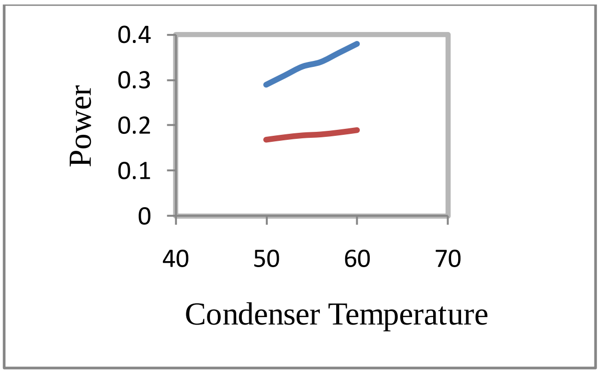
Graph : Condenser Temperature Vs Pressure ratio



The above graphs show variation condenser temperature variation with respect to pressure ratio. R22 having more pressure ration as compared to other refrigerant. But for R290,R22 the pressure ration increases as condenser temperature increases.R290 having minimum pressure ration as compared with other refrigerant.

CONDENSER TEMPERATURE VS POWER

Graph No-4 : Condenser temperature Vs Power



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The above graphs show variation in power consumption of domestic refrigerator for various condenser temperatures for R-290 & R-22. As condenser temperature increase from 50 to 60^0C power consumption increased by 26.42% for R-290 & 21.87% for R-22. as condenser temperature increase dryness fraction after expansion reduced by 23.68% for R-290 & 21.87% for R-22.

CONCLUSION

Based on the theoretical analysis (using coolpack software) and experimental analysis of refrigeration system using R22 and R20 refrigerants the following conclusions are drawn. The refrigerant R22 can be suitably replaced by R290, without much difficulty. The cooling capacity of the system using R290 is higher than that refrigerant produced using R22 for the same operating conditions.

ACKNOWLEDGEMENT

Authors would like to thank Dr. V. N. Raibhole, Dr. S. N. Sapali, Dr. M.A. Makasure, Dr. P.S. Dabeer, Dr. K.D. Sapate, Prof .M. M. Dange & Prof. M. R. Jagdale for the needful support and guidance.

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- Refrigeration & Air Conditioning, Dr. S.N. Sapali,PHI Publications.

SOFTWARES

- Aspen Plus Software manual (10.2 Version)
- REFPROP refrigerant simulation software
- Coolpack software
- Dancap software

BIOGRAPHY

Ashok N. Korshetti, Born on 25th October 1985. DME., B. E. (Mechanical), Assistant Professor in Mech. Engg., KJ's Trinity College of Engg & Research, Pune-48, Maharashtra, India, Member of ISTE. Member of ISHRAE, Pune Chapter. Area of interest: Energy conservation, Heat Transferm, Refrigeration and Air-conditioning, Cryogenics.