# Optimum Refrigerant Charge of Refrigerator Working with Alternative Refrigerants for R12 (R134a, R600a and R290)

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***Abstract-* This study presents the impacts of suitable refrigerant charge to test the performance of laboratory refrigerator rig for using three refrigerants of (R134a, R600a and R290) instead of R12 .The coefficient of performance and maximum consumption amperes are taken as function to evaluate the optimum charge of these refrigerants. The results imply that the over refrigerant charge will reduce the system performance. Compared the optimum refrigerant charge of R600a is (45g), R290 is (70 g) and R134a is (60g), instead of R12. The results show that the refrigerator with R134a gives lowest capacity reduction with same performance to R12 from other alternative refrigerant, and can be taken as the best alternative refrigerant.**

**key word :- alternative refrigerant,refrigerator,R12,**

## 1. Introduction

A refrigerator is a major electrical energy consuming residential appliance .The most common household refrigerators are work with vapour compression cycle, which consist from compressor, condenser, capillary tube and evaporator with working fluid ‘refrigerant’. In Iraq, the most common refrigerant for household refrigerator is R12.This refrigerants contained on chlorine which found to diffuse up into the stratosphere. The chlorine is represent the major causes of ozone layer destruction, ozone layer that protects life on earth from excess ultraviolet light For this reason R12 is phase out by Montreal protocol, There for many refrigerant have been identified as alternatives to HCFC- 12, the current predominant refrigerant in Iraq refrigeration applications R-143a specifically designed to closely match R-12 performance with minimal design changes and for new equipment, Recently The European Union has proposed to ban the use of refrigerants with global warming potential (GWP)> 150 after 2011, effectively banning R134a in new mobile Air conditioner and refrigerator. so, the U.S. Congress proposed to phase down the production of HFCs based solely on their GWP value with production cap beginning at 90% in 2012 and ultimately at 15% in 2033[1].Therefore, the refrigerator should be charged with an optimum amount of proper alternative refrigerant in order to operate with high performance over its life time that will reduce the consumption power and the emission of Co2.

BOLAJI [2] studied the performance of domestic refrigeration system using R12 and alternative refrigerant R134a and R152a , he showed that the coefficient of performance (COP) of the domestic refrigeration system using R152a was very close to that of R12 with only 1.4% reduction, while that of R134a was significantly low with 18.2% reduction. Fernando et.al[3] presented the effect of refrigerant charge reduction on system using R290 ,in his study the charge will changed and conclude that the selection of compressor lubrication oil would further decrease the refrigerant charge of the heat pump, and the reduction of the tube lengths and exclusion of ball valves would give an optimum charge for the 5 kw propane heat pump with ground heat source or other liquid to liquid type applications of less than 200 g. Halimic et.al [4] showed The cooling capacity of R290 was the largest of the refrigerants tested, and higher than the original refrigerant R12.also showed that COP of system with R290 is very similar to that of R12 thus it can be said that it represents an attractive alternative to existing CFCs in small domestic refrigerators, also the original equipment it would require a smaller capacity compressor than would R12. The current study focused on three alternative refrigerants for R12 these are R134a, R290 and R600a.
Table (1) show a comparison between R12 and its alternative refrigerants.

## 2. System Analysis And Assumptions

The current study all vapor compression cycle components will analysis by using simple model on p-h diagram fig(1) with these assumptions.
A simple analysis of vapor compression refrigeration system can be carried out by assuming:-
**A)** Steady state steady flow cycle.
**B)** Negligible kinetic and potential energy changes across each component ($\Delta KE = 0, \Delta Z = 0$). and
**C)**No heat transfer (gain or losses) and no pressure drop in the connecting pipe lines. The steady flow energy equation is applied to each of the four components.

2. Compressor (Adiabatic Compression):-
The compressor is the major energy consuming component of the refrigeration system ,and its performance and reliability are significant to the overall performance of the refrigeration systems, The amount of specific work done by an ideal compressor work per unit mass of the refrigerant, can be expressed in terms of the change in enthalpy between State**1** and State **2**.

$$w_{scom} = h_2 - h_1 \qquad (1)$$

3. Condenser (Isobaric Heat Rejection)
All the heat removed at the evaporator together with all the energy provided by the compressor must be rejected from the system by condenser. The refrigerant leaves the compressor enters the condenser as superheated vapor and

leaves as sub cooled liquid .the condenser heat rejection is occurs at constant pressure. The specific heat rejected from condenser can be found by evaluating the refrigerant enthalpies at the inlet and outlet.

$$q_c = h_2 - h_3 \qquad (2)$$

where :-$q_c$:- heat transfer from condenser per unit mass of refrigerant.

4. Capillary Tube :
The capillary tubes are used to control the refrigerant flow through the system. The energy equation shows that the enthalpy is constant across the capillary tubes.

$$h_3 = h_4 \qquad (3)$$

5. The Evaporator:-
In the evaporator the heat is transfers from the air and food of the cabinet in order to remove the heat gain and moisture. Since the refrigerant enters the evaporator as a saturated mixture.

$$q_e = h_1 - h_4 \qquad (4)$$

where: -$q_e$heat transfer to evaporator per unit mass of refrigerant.

6. Coefficient Of Performance (Cop):-
COP is the ratio of refrigerating effect to the compressor work, which used to give an indicted about the vapour compression cycle performance.

$$COP = \frac{\text{Refrigerating Effect}}{\text{Compressor Work}}$$

$$COP = \frac{h1 - h4}{h2 - h1} \qquad (5)$$

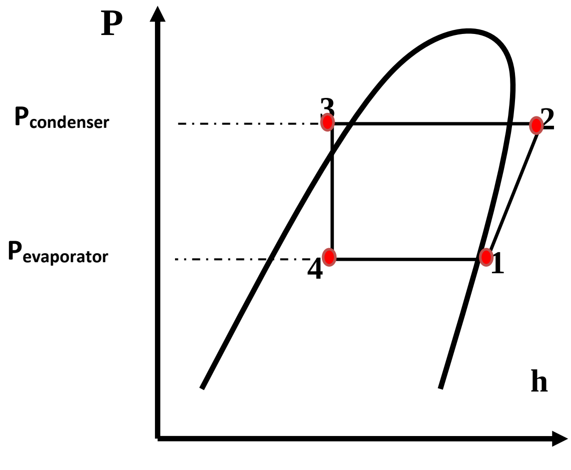



Fig (1) Refrigeration Cycle on P-h diagram

## 3. System modeling

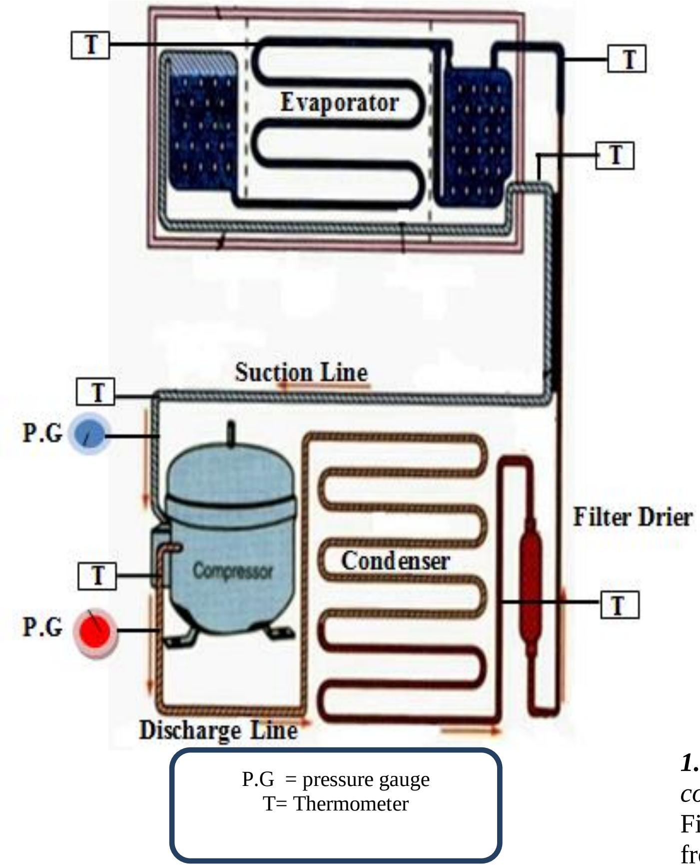
The refrigeration cycle model was programmed in Engineering Equation Solver; all modeling and simulations are performed using Engineering Equation Solver (EES). EES is a software package developed by Dr. Sanford Klein of the University of Wisconsin. EES incorporates the programming structures of C and FORTRAN with a built-in iterates, thermodynamic and transport property relations, graphical capabilities, numerical integration, and many other useful mathematical functions. By grouping equations that are to be solved simultaneously, EES is able to rapidly solve large numbers of transcendental equations [8]. EES can also be used to perform parametric studies. Most important for this study, EES has the ability to seamlessly incorporate fluid property calls. Thermodynamic transport properties for steam, air, and many different refrigerants including R12,R134a,R600a andR290 are built into EES.

## 4. Testing Refrigerator

In this study a training refrigerator that is manufactured by Prodit is used to perform all the study tests, which have pressure gauge connected in the suction side to measure the pressure of evaporator and another gauge is connected on the discharge side to measure the condenser pressure .and to measure the temperature of refrigerant ,there are many thermometers that attached on the inlets and outlets of the compressor , condenser and evaporator Fig (2).

## 5. Lubricant Oil Replacement

All refrigeration system requires lubrication. Oil seals compressed gas between the suction and discharge sides, acts a coolant .Good lubricating oil is that which has high miscibility and low solubility in the refrigerants. In this study the lubricants oil of compressor for R12 is a mineral oil and this type of lubricant oil is compatible with other refrigerants (R290 and R600a) but is not compatible with refrigerant R134a, so therefore the lubricant oil should be replaced when charging the refrigerator with R134a with the compatible oil of polyester[9][10].




Fig(2) Schematic of testing refrigerator

## 6. Refrigerant Charge Procedure

This study to indicate the charge of refrigerant an electronic refrigerant charging scale is used for this purpose, which consist from cylinder weight balance which take an electric signal by wire from digital programmable setting joystick Fig (3).In this study the first charge of refrigerator for any refrigerant is taken as 15 gram of refrigerant with increment of 15 grams from one charge to another ,these procedures are repeated to all addition quantity of Freon charge, the flow chart of the experimental test is shown in Fig (4)

Fig(3)Electronic Refrigerant Charging Scale connected with refrigerant cylinder and refrigerator

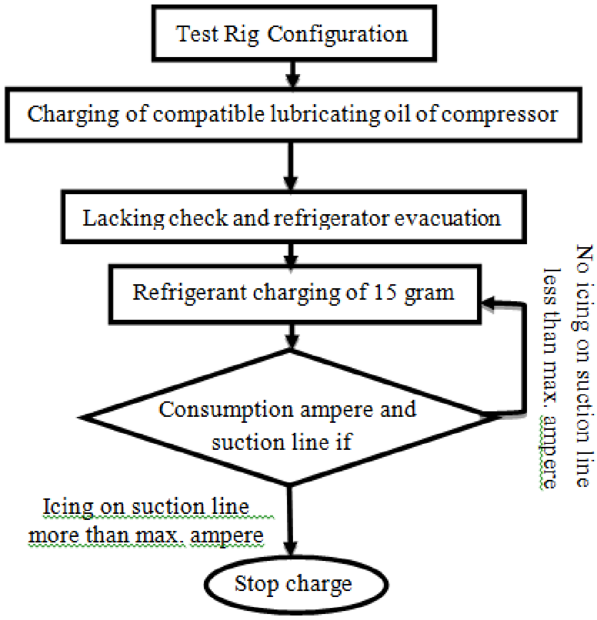



Fig.4 Flow Chart of charging procedure

## 7. Results and Discussion

***1.** Effect of refrigerant charge quantity on heat rejected by condenser ($q_c$):-*

Fig. (5) shows the relationship between the heat rejected from condenser with mass of refrigerants charge. The variation occurs due to many reasons :-

**A.** The condensing temperature is increased slightly with increasing in refrigerant charge, mainly due to the increased mass flow resulting more refrigerant occupation in condenser and this lead to increase the condenser pressure so as temperature, and this means more temperature difference between ambient air temperature and condenser refrigerant temperature that leads to more heat rejection.

**B.** The increasing in refrigerant mass flow rate will increase in the turbulence degree of flow (Reynolds number) which leads to heat transfer coefficient increasing, then more heat rejection.

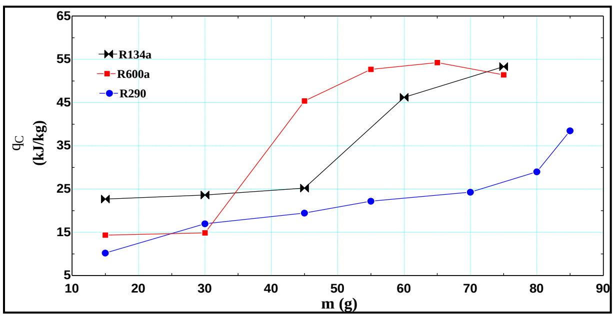



Fig.5 Effect of refrigerant Charge on heat rejected by condenser

***2.** Effect Of Refrigerant Charge Quantity on Refrigerating Effect):-*

Fig (6) shows the relationship between the mass refrigerant charge with refrigerating effects . At low refrigerant charge the system give low refrigerating effect, and as the refrigerant charge increased the refrigerating effect increased also until an optimum value of the refrigerant charge that mentioned above will be opposite is reached.

The decrease in refrigerating effect at lower amounts of refrigerant charge can be attributed to the flow of two-phase refrigerant from condenser to the capillary tube. Incomplete condensation (means less refrigerant charge) leads to lower heat transfer, and this will decrease the amount of in refrigerating effect due to the reduction in condensation area of the condenser.

*3)Effect of refrigerant charge quantity on compressor work:-*

Fig(7) show that when increasing the refrigerant charge the condenser pressure will be increased , this will increase pressure ratio which decrease the compressor volumetric efficiency Fig(8), so the compressor work is decreased as refrigerant charge decreased due to condenser pressure decreasing which leads to decrease in pressure ratio, so that the compressor volumetric efficiency tends to a maximum value .

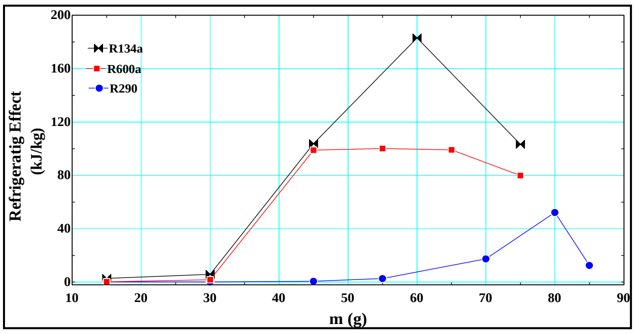



Fig.6 Effect of refrigerant Charge quantity on Refrigerating Effect

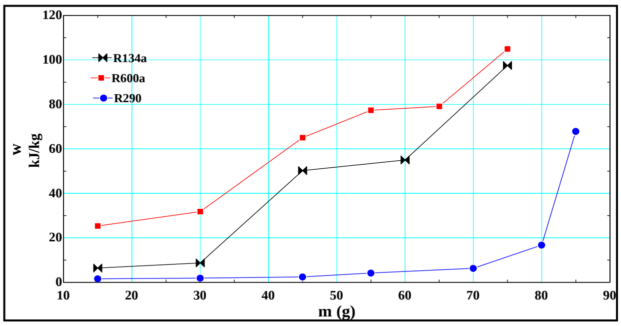



Fig.7 Effect of refrigerant charge quantity on compressor work

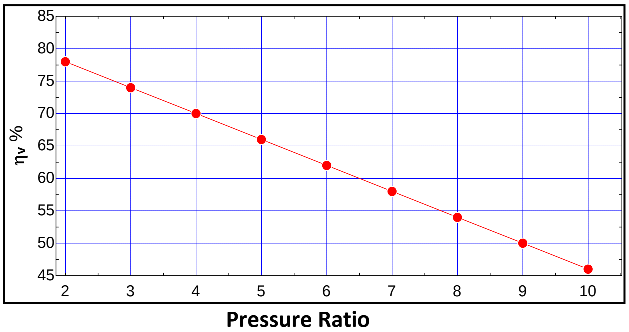



Fig.8 Effect of Pressure Ratio on Compressor Efficiency

*4) Effect of refrigerant cherge quantity on the coefficient of performance :-*

From preceding paragraph ,the refrigerant charge effects on both refrigerating effect and compressor work and these will effect on the coefficient of performance , so that the refrigerant charge that give refrigerating effect increase more than compressor work increase this will give the greatest COP for the system .

Fig. (9) there is one charge that give maximum value of COP ,and this charge can be taken as the optimum refrigerant charge ,so with optimum charge the refrigerant R290 give the highest Coefficient of performance Fig(10),but when comparing the refrigeration capacity the R134a give the highest value than other alternative refragerant , and this refrigerant can be be taken as the best alternative refrigerant to R12 in small domestic refrigerator Fig(11) (have highest COP than R12 with less reducation in capacity).

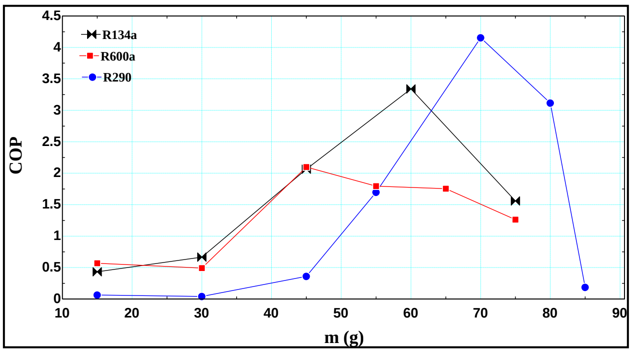



Fig.9 Effect of refrigerant charge quantity on COP of The System

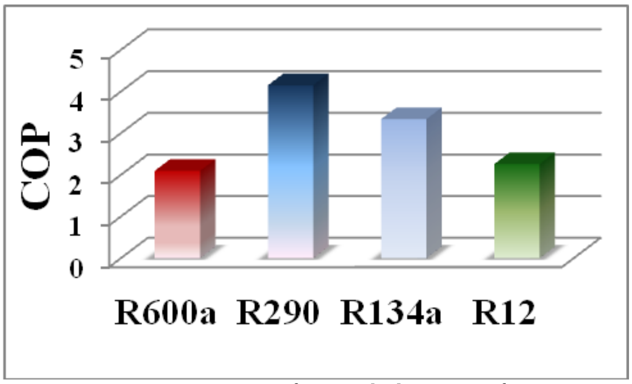



Fig.10 COP comparison of R12 with alternative refrigerants

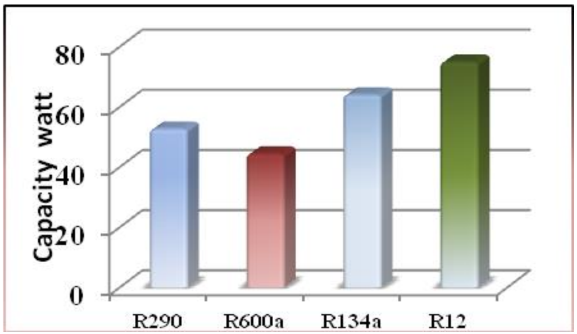



Fig.11 capacity comparison of R12 with alternative refrigerants

## 8. Conclusions

In the light of the preceding results, the following conclusions can be drawn:-

**1)** the overcharging of refrigerant will reduce the system performance ,this due to effect on condenser heat rejected by reducing area of condensing and compressor performance by increasing pressure ration and that's all effect on evaporator.

**2)** the refrigerant charge starving will reduce the system performance also ,this due to effecting on the condenser heat rejected by reducing heat transfer coefficient of condensing and reduce the amount of liquid refrigerant that enters to evaporator.

**3)** the optimum charge of R12 alternative refrigerant R600a (45g ) ,R290 (70 g) and R134a(60g)

**4)** with optimum charge the suction pressure of R134a is 1.6 bar (23 PSI) ,R290 is 0.8 bar (12 PSI ) and R600a is 0.9 bar (13 PSI)

**5)** The system with R134a gives highest performance from R12 with less reduction in capacity from other alternative refrigerant and can be taken as the best alternative refrigerant.

**6)** the system with R290 required modification for capillary tube size to get best performance.

## 9. References

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XI. BIOGRAPHIES

Ali Khalid Shaker Al-Sayyab received the B.Sc. degree in refrigeration and air conditioning engineering from Dept. of refrigeration and air conditioning technical Engineering, Basrah Engineering technical College, Basrah, Iraq in 2005. He received the M.Sc. degree in “thermal technical Engineering” from Baghdad engineering technical collage 2009. He worked as a technical in laboratory of thermal in the Dept. of refrigeration and air conditioning Engineering, Basrah engineering technical college, Southern technical university, Basrah, Iraq from 2005 to 2006. He rejoined the same department as a Asst. lecturer in 2009-until now. He has published three scientific and technical papers in the national journals and proceedings of conferences. His research interest includes, the use of solar energy, solar collector , Design of air cooled condenser and alternative refrigerant for R22 and other refrigerant.

**NOMENCLATURE**

| Symbols | Description | Unit |
|---|---|---|
| ODP | ozone depletion potential | |
| GWP | global worming potential | |
| COP | coefficient of performance | |
| $q_c$ | heat rejected by condenser | kJ/kg |
| $w_{scom}$ | compressor specific work | kJ/kg |
| $q_e$ | refrigerating effect | kJ/kg |
| h | enthalpy of refrigerant | kJ/kg |

| Refri. | R 290 | R 134a | R12 | R600a |
|---|---|---|---|---|
| Name | Propane | Tetra- flour ethane | DichloroDifluoro methane | Isobutane |
| Formula | $C_3H_8$ | $CF_3$ -$CH_2F$ | $CCl_2F_2$ | $(CH_3)$ 3 CH |
| Critical temperature °C | 96.7 | 101 | 112 | 135 |
| Critical pressure (bar) | 42.5 | 42.4 | 41.15 | 36.45 |
| Molecular weight in kg/kmol | 44.1 | 102 | 120.93 | 58.1 |
| boiling point in °C at 1.0135 bar | -42.1 | -26.5 | -29.8 | -11.6 |
| Vapor Specific volume $m^3$/kg | 0.4188 | 0.1925 | 0.1599 | 0.3561 |
| $h_{fg}$ at -25 °C in kJ/kg | 406 | 216 | 163 | 376 |
| Pressure at +20 °C bar (absolute) | 8.4 | 5.7 | 1.509 | 3 |
| GWP 100 years | 8 | 1300 | 8100 | 8 |
| ODP | 0 | 0 | 1 | 0 |

Table (1) Comparison Between R12 And Its Alternative Refrigerant[5] [6]