Performance of Vapour Compression Refrigeration System with Sub Cooling by Use of R134a and R600a Refrigerants

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Abstract— There are various obstacles faced in working of different refrigerants due to their environmental impact (R 11, R12), toxicity (NH3), Flammability (HC) and high pressure (CO2); which makes them more hazardous than other working fluids according to safety and environmental issues. Performance analysis on a vapour compression refrigeration system with eco-friendly refrigerant of HC600a were done and their results were compared with R134a as possible alternative replacement. In present work experimental setup is prepared for both existing and proposed system with R-134a and R-600a as refrigerants. In the proposed system suction line heat exchanger of 35cm length is used.
After conducting the experiment,

- In the proposed system the coefficient of performance is found to be greater than the coefficient of performance of existing system. The percentage of increase in COP using R-134a in no load condition is 3.27% and in loaded condition is 3.10%.
- In the proposed system the coefficient of performance is found to be greater than the coefficient of performance of existing system. The percentage of increase in COP using R-600a in no load condition is 4.09% and in loaded condition is 3.34%.
- From the above discussions, it can be concluded that the performance of vapour compression refrigeration system of domestic refrigerator can be increased by using 35cm length of a heat exchanger for different refrigerants.
- The retrofitting of R600a in all conditions showed better performance than R134a. And also that if care is taken in flammable of R600a retrofitting gives better performance with R600a in domestic R134a systems.

Key words: Compression refrigeration system, Refrigerant, COP, ODP, GWP

I. INTRODUCTION

Vapor compression Refrigeration system is an enhanced by air refrigeration system. The capacity of certain liquids to absorb giant quantities of heat as they vaporize is the basis of this system. Compared to melting solids (say ice) to find refrigeration effect, vaporizing liquid refrigerant has more advantages. To mention a few, the refrigerating effect can be started or stopped at will, the rate of cooling can be determined, the vaporizing temperatures can be governed by controlling the pressure at which the liquid vaporizes. Moreover, the vapor can be readily collected and condensed back into liquid state so that same liquid can be re-circulated over and over again to obtain refrigeration effect. Thus the vapor compression system employs a liquid refrigerant which evaporates and condenses readily. The system is a closed once the refrigerant never leaves the system. The coefficient of performance of a refrigeration system is the ratio of refrigerating effect to the compression work; therefore the coefficient of performance can be increased by increasing the refrigerating effect or by decreasing the compression work.

The vapor compression refrigeration system is now-a-days used for all purpose refrigeration. It is generally used for all industrial purposes from a small domestic refrigerator to a big air conditioning plant.

II. MATERIALS AND METHODS

A. Selection Of Environment-Friendly Refrigerants:

The range of possible alternative fluids is extensive; it includes Hydro-Fluorocarbons (HFCs), refrigerant mixtures, hydrocarbons, and natural fluids. Among these groups of alternatives, HFCs are the most useful. The possible environment-friendly refrigerants with zero ODP and lower Global Warming Potential (GWP) could be selected from derivatives of methane and ethane. In this work, full array of methane and ethane derivatives were considered and trade-off in flammability, toxicity and chemical stability concerning atmospheric lifetime with changes in molecular chlorine, fluorine and hydrogen content were carried out. Therefore, two promising alternative refrigerants (R134a and 600a) that contain no chlorine and that have short atmospheric lifetime were selected and investigated theoretically using sub-cooling coil.

1) Experimental Set Up:

In order to know the performance characteristics of the vapor compression refrigeration system the temperature and pressure gauges are installed at each entry and exit of the components. Experiments are conducted on a domestic refrigerator of 165 liters capacity, with R-134a and R-600a as refrigerants and using liquid line-suction line heat exchanger of 35cm length.

2) Domestic Refrigerator Selected For The Project Has The Following Specifications:

Refrigerant used: R-134a
Capacity of the refrigerator: 165 liters
Compressor capacity: 0.16 H.P

3) Condenser Sizes

Length	-	8.5m
Diameter	-	6.4mm

4) Evaporator

Length	-	7.62m
Diameter	-	6.4mm

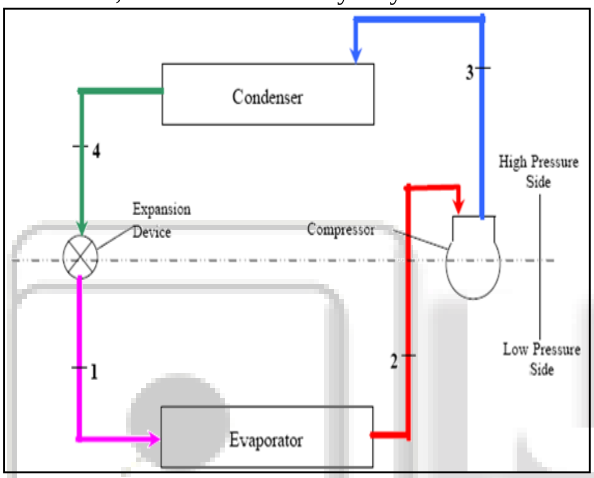
5) Capillary Tube

Length	-	2.428m
Diameter	-	0.8mm

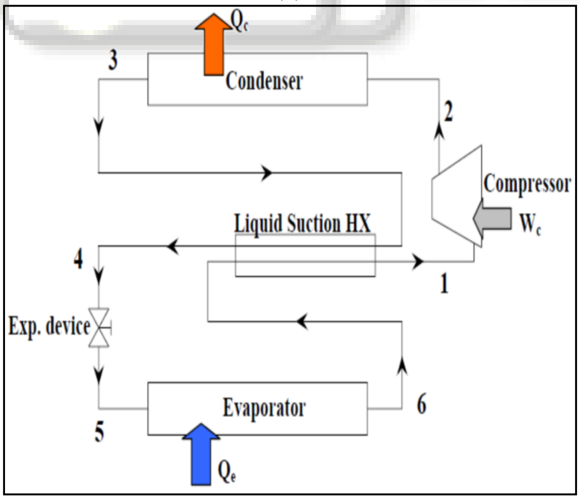
Among many possible variations of the basic refrigeration (vapor compression) cycle, the cycle with the liquid line/suction line heat exchanger (LLSL•HX) is probably used most often. As a result of employing this intra-cycle heat exchange, the high pressure refrigerant is sub cooled at the expense of superheating the vapor entering the compressor. Schematics of hardware arrangement for the basic cycle and cycle with the LLSL-HX are shown in Fig. 1.

The use of liquid line/suction line heat exchangers is widespread in commercial refrigeration. The heat exchangers are often employed as a means for protecting system components, by helping to ensure single-phase liquid to the expansion device and single-phase vapor to the compressor. In residential refrigerators, a capillary tube/suction line heat exchanger is used to heat the suction line above the dew-point temperature of ambient air, thus preventing condensation of the water vapor on the outside of suction line.

Employing an intra-cycle heat exchanger alters refrigerant thermodynamic states in the cycle, which may have significant, positive or negative, performance implications. For any fluid and system, a LLSL-HX increases refrigerant temperature at the compressor inlet and outlet, this is shortcoming. The Coefficient of Performance (COP) and volumetric capacity may increase for some fluid/application combinations, while for others they may decrease.\



(a)



(b)

Figure1 Schematic of hardware arrangements for a) The basic cycle and b) Cycle with the liquid line-suction line heat exchanger

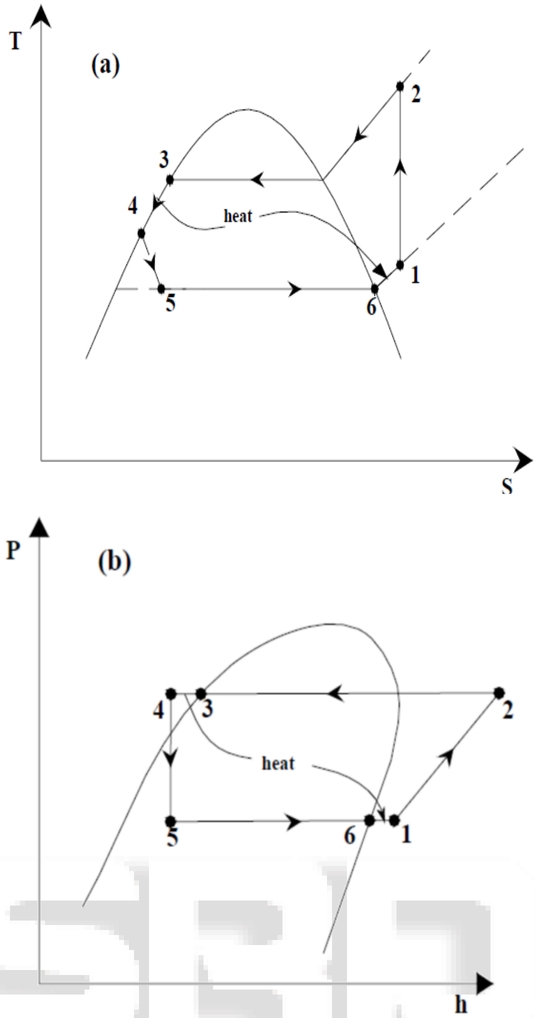


Fig. 2: VCRS cycle with LSHX (a) on T-S diagram (b) on P-h diagram

Fig. 3: a) Existing System and b) New system with 35cms length of heat exchanger

III. EXPERIMENTAL PROCEDURE

The vapour compression system is initially cleaned and the evacuation of the system is carried out with the help of a vacuum pump for nearly 30 min and then the refrigerant is charged into the system.

Initially the system is charged with refrigerant R-134a and then the following tests were carried out.

1) Pull–down characteristics
2) No load performance
3) Performance with load
4) Frosting

A. For Pull-Down Characteristic

The pull-down period is the time required to reduce the air temperature inside the refrigerator from ambient condition to the desired cabin air temperature (i.e., +70C average cabinet temperature) after switching on the unit.

Procedure:

- Initially the refrigerator door is kept open until the evaporator cabin attains the environment temperature and then it is closed and system is switched ON to run.
- System is kept for running condition until required temperature is attained.
- After attaining required temperature the system is switched OFF.
- Time taken by the system to get to required temperature is noted.
- Energy meter readings also noted from starting to off conditions.

B. No Load Performance"

In no load performance as the refrigerator is switched on and kept in running condition without placing any type of load inside the cabin until the steady state conditions are attained and then the readings are noted for calculating the COP of the system and system is switched off.

Procedure:

- Initially the system is switched ON.
- The system is kept in running condition continuously to obtain steady state conditions.
- After attaining steady state conditions the pressure gauge and temperature readings are noted.
- Energy meter readings also noted down as shown in table.8 and then system is switched OFF.
- COP calculations are made from the obtained values using p-h chart of the refrigerants.

C. Performance With Load"

In load performance as shown in figure 4 the refrigerator is loaded by arranging a bulb having capacity of 60 watts inside the evaporator cabin and the system is switched on and kept in running condition until the steady state conditions are attained and then the readings are noted for calculating the COP of the system and system is switched off.

Procedure:

- Initially the system is switched ON.
- After some time a 60W capacity incandescent bulb is placed inside the evaporator cabin and switched on for loading the system.
- The system is kept in running condition continuously for obtaining steady state conditions.
- After attaining steady state conditions the pressure gauge and temperature readings are noted and bulb is switched off.
- Energy meter readings also noted down as shown in table.8 and then system is switched OFF.
- COP calculations are made from the obtained values using p-h chart of the refrigerants.

Fig. 4: A view of refrigerator with bulb placed inside the cabin for load performance

D. Frosting And Defrosting

For occurrence of frosting the system is switched on with a load of water in open trough is placed in the evaporator cabin and kept in continuous running condition for 72 hours and then the system is switched off. The system is allowed to defrost for certain period and the quantity of water is collected.

Procedure:

- Initially the load of 3litres of water is placed inside the cabin as shown in figure 5 in an open trough and then the system is switched ON.
- The system is kept in continuous running condition for 72 hours to allow for frosting of freezer as shown in figure 5.
- Then the system is switched OFF and allowed to defrost for some period.
- The defrosted water is collected.
- The quantity of water collected is noted down.

Fig. 5: A view of refrigerator freezer box which is frosted

After that the vapour compression test rig is evacuated and retrofitted with refrigerant R-600a and the above tests were carried out following the same procedure.

E. Tabular Column 1:

Performance calculations of domestic refrigerator using refrigerant R-134a for both existing system and new system with suction line heat exchanger at different load conditions:

S.NO	PARAMETERS	EXISTING SYSTEM WITH NO LOAD	EXISTING SYSTEM WITH LOAD	NEW SYSTEM WITH NO LOAD	NEW SYSTEM WITH LOAD
1.	Net refrigerating effect kJ/kg	167	165	171	170
2.	Coefficient of Performance (COP)	6.1	5.15	6.3	5.31
3.	Mass flow rate to obtain one TR kg/min	1.25	1.27	1.228	1.23
4.	Work of Compression kJ/kg	27	32	27	32
5.	Heat Equivalent of work of compression per TR kJ/min	33.95	40.64	33.156	39.36
6.	Compressor Power KW	0.56	0.67	0.55	0.656
7.	Heat to be rejected in condenser kJ/kg	194	197	198	202
8.	Heat Rejection per TR kJ/min	243.95	250.19	243.144	248.46
9.	Heat Rejection Ratio	1.16	1.19	1.15	1.18
10.	Compression Pressure Ratio	8.90	9.11	8.06	8.6

F. Tabular Column 2:

Performance calculations of domestic refrigerator using refrigerant R-600a for both existing system and new system with suction line heat exchanger at different load conditions:

S.NO	PARAMETERS	EXISTING SYSTEM WITH NO LOAD	EXISTING SYSTEM WITH LOAD	NEW SYSTEM WITH NO LOAD	NEW SYSTEM WITH LOAD
1.	Net refrigerating effect kJ/kg	330	330	337	335
2.	Coefficient of Performance (COP)	6.6	5.68	6.87	5.87
3.	Mass flow rate to obtain one TR kg/min	0.636	0.636	0.623	0.623
4.	Work of Compression kJ/kg	50	58	49	57
5.	Heat Equivalent of work of compression per TR kJ/min	31.8	36.88	30.52	35.73
6.	Compressor Power KW	0.53	0.61	0.508	0.59
7.	Heat to be rejected in condenser kJ/kg	380	388	386	392
8.	Heat Rejection per TR kJ/min	241.68	246.768	240.478	245.392
9.	Heat Rejection Ratio	1.15	1.17	1.145	1.16
10.	Compression Pressure Ratio	4.76	4.77	4.95	4.96

IV. RESULTS AND DISCUSSIONS

A. *Graphs:*

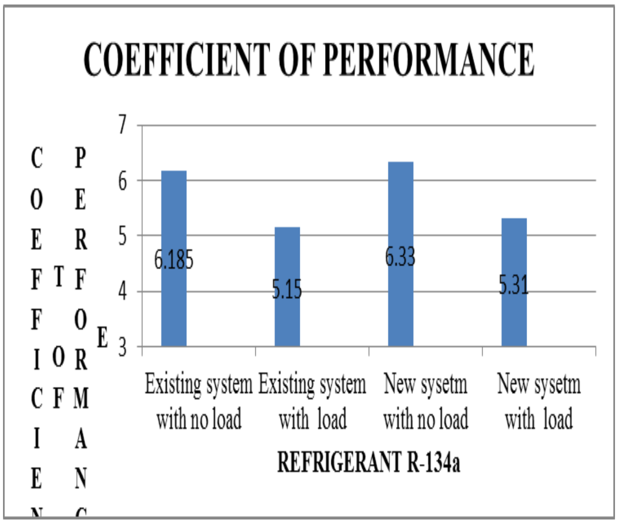


Fig. 6: Coefficient of performance for refrigerant R-134a

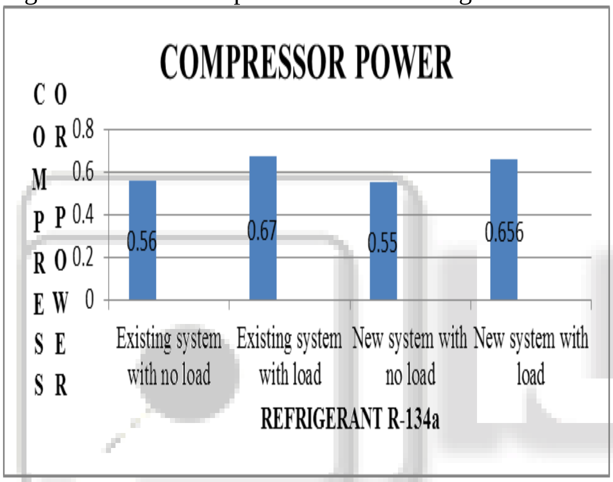


Fig. 7: Compressor power for refrigerant R-134a

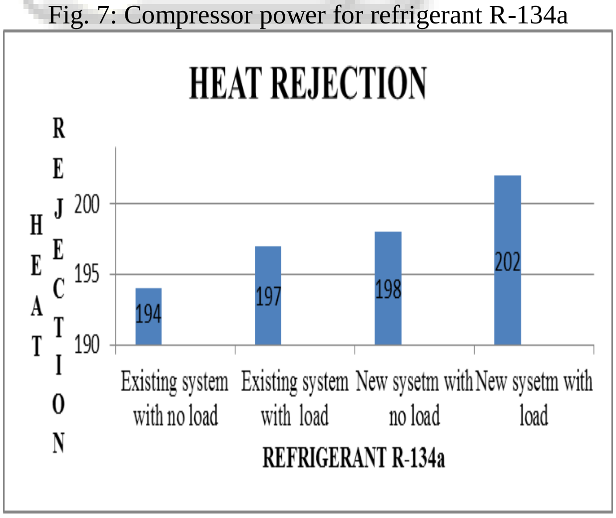


Fig. 8: Heat rejection for refrigerant R-134

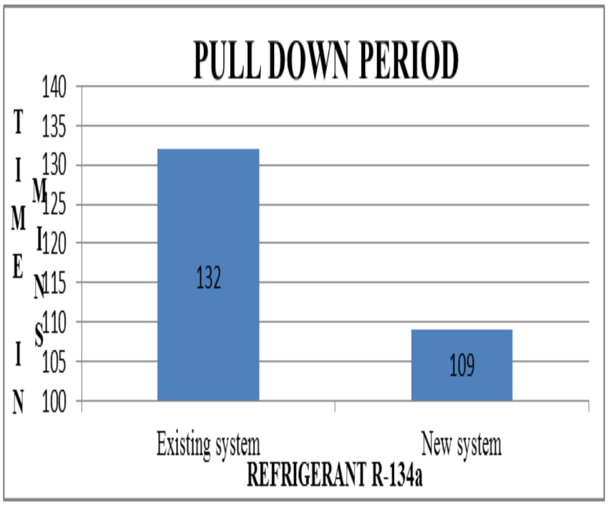


Fig. 9: Pull down period for refrigerant R-134a

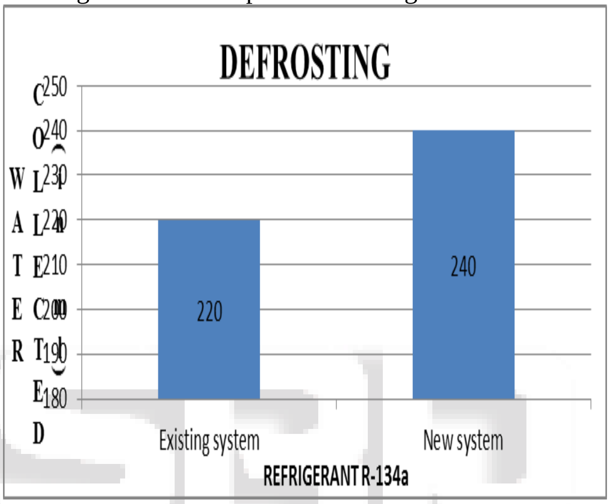


Fig. 10: Defrosting water collected for refrigerant R-134a

1) *Effect On Coefficient of the Performance Of The System By Adopting Suction Line Heat Exchanger Using Refrigerant R-134a:*

Graph 6 shows the coefficient of performance for refrigerant R-134a for both existing and new system with suction line heat exchanger at different load conditions.Net refrigeration effect is more with suction line heat exchanger so coefficient of performance is increased with proposed system.

2) *Effect On Compressor Power by Adopting Suction Line Heat Exchanger Using Refrigerant R-134a:*

Graph 7 shows the compressor power for refrigerant R-134a for both existing and new system with suction line heat exchanger at different load conditions.Mass flow rate is less with suction line heat exchanger so compressor power is decreased with proposed system.

3) *Effect On Heat Rejection by Adopting Suction Line Heat Exchanger Using Refrigerant R-134a:*

Graph 8 shows the heat rejection for refrigerant R-134a for both existing and new system with suction line heat exchanger at different load conditions.Subcooling is more with suction line heat exchanger so heat rejection is increased with proposed system.

4) *Effect On Pull Down Period by Adopting Suction Line Heat Exchanger Using Refrigerant R-134a*

Graph 9 shows that pull down period of domestic refrigerator by using suction line heat exchanger is higher as compared to that of existing system by about 17.4%

5) Effect On Defrosting By Adopting Suction Line Heat Exchanger Using Refrigerant R-134a:

Graph 10 shows that defrosting water collected in domestic refrigerator by using suction line heat exchanger is higher as compared to that of existing system by about 9.09% which shows that cooling is higher.

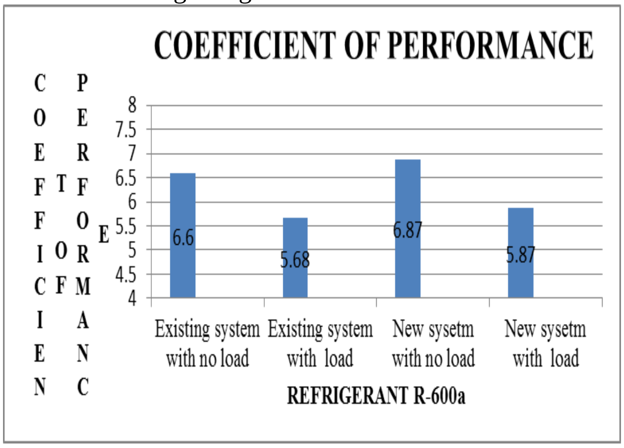


Fig. 11: Coefficient of performance for refrigerant R-600a

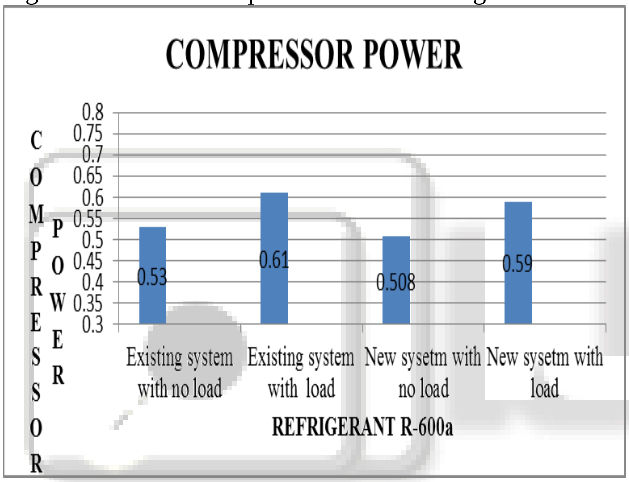


Fig. 12: Compressor power for refrigerant R-600a

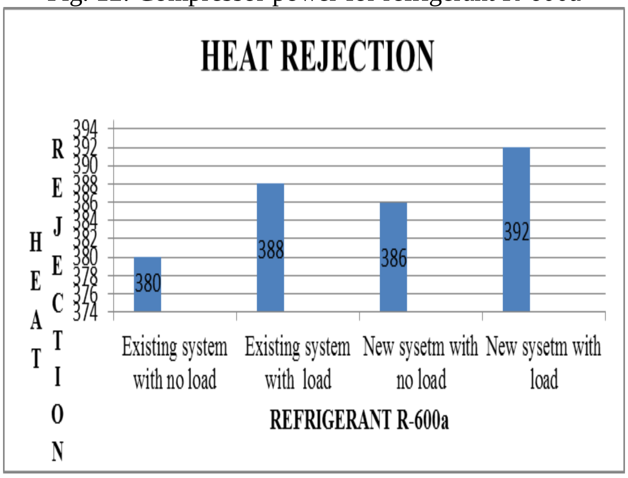


Fig. 13: Heat rejection for refrigerant R-600a

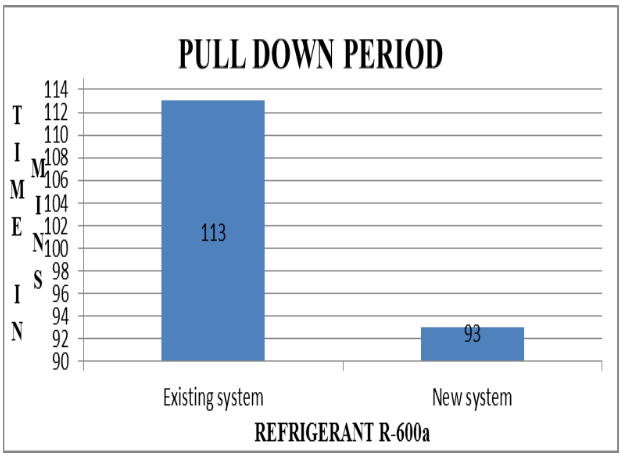


Fig. 14: Pull down period for refrigerant R-600a

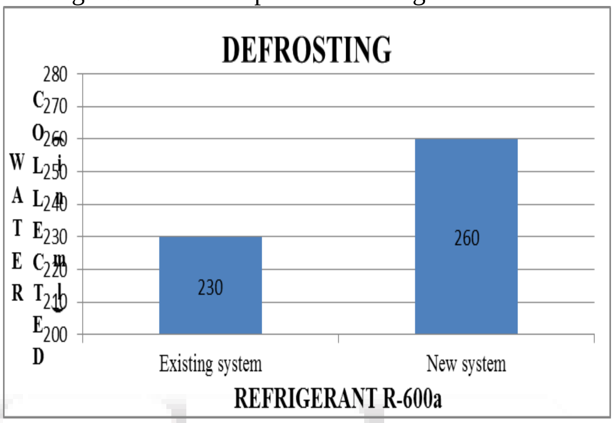


Fig. 15: Defrosting water collected for refrigerant R-600a

6) 6.Effect On Coefficient Of The Performance Of The System By Adopting Suction Line Heat Exchanger Using Refrigerant R-600a:

Graph 11 shows the coefficient of performance for refrigerant R-600a for both existing and new system with suction line heat exchanger at different load conditions.Net refrigeration effect is more with suction line heat exchanger so coefficient of performance is increased with proposed system.

7) Effect On Compressor Power By Adopting Suction Line Heat Exchanger Using Refrigerant R-600a

Graph 12 shows the compressor power for refrigerant R-600a for both existing and new system with suction line heat exchanger at different load conditions.Mass flow rate is less with suction line heat exchanger so compressor power is decreased with proposed system.

8) Effect On Heat Rejection By Adopting Suction Line Heat Exchanger Using Refrigerant R-600a:

Graph 13 shows the heat rejection for refrigerant R-600a for both existing and new system with suction line heat exchanger at different load conditions.Subcooling is more with suction line heat exchanger so heat rejection is increased with proposed system.

9) Effect On Pull Down Period By Adopting Suction Line Heat Exchanger Using Refrigerant R-600a:

Graph 14 shows that pull down period of domestic refrigerator by using suction line heat exchanger is higher as compared to that of existing system by about 17.6%

10) Effect On Defrosting By Adopting Suction Line Heat Exchanger Using Refrigerant R-600a

Graph 15 shows that defrosting water collected in domestic refrigerator by using suction line heat exchanger is higher as compared to that of existing system by about 13.4% which shows that cooling is higher.

V. CONCLUSIONS

In present work experimental setup is prepared for both existing and proposed system with R-134a and R-600a as refrigerants. In the proposed system suction line heat exchanger of 35cm length is used.
After conducting the experiment,

- In the proposed system with suction line heat exchanger the pull down period is found to be less than the pull down period of existing system. The percentage of decrease in pull down period using R-134a is 1.74%.
- In the proposed system with suction line heat exchanger the pull down period is found to be less than the pull down period of existing system. The percentage of decrease in pull down period using R-600a is 1.76%.
- In the proposed system the coefficient of performance is found to be greater than the coefficient of performance of existing system. The percentage of increase in COP using R-134a in no load condition is 3.27% and in loaded condition is 3.10%.
- In the proposed system the coefficient of performance is found to be greater than the coefficient of performance of existing system. The percentage of increase in COP using R-600a in no load condition is 4.09% and in loaded condition is 3.34%.
- In the proposed system the frost collection is found to be greater than the frost collection of existing system. The percentage of increase in frost collection using R-134a is 9.09%.
- In the proposed system the frost collection is found to be greater than the frost collection of existing system. The percentage of increase in frost collection using R-600a is 13.4%.
- From the above discussions, it can be concluded that the performance of vapour compression refrigeration system of domestic refrigerator can be increased by using 35cm length of a heat exchanger for different refrigerants.

The retrofitting of R600a in all conditions showed better performance than R134a. And also that if care is taken in flammable of R600a retrofitting gives better performance with R600a in domestic R134a systems.

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