Studies on a Domestic Refrigerator Cabinet Temperature by Forced Convection Condensing Coil

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Abstract—This paper tells about an experimental investigation carried out to improve the performance of a domestic refrigerator by replacing its natural convection condenser by a forced convection condenser. The forced convection is achieved by blowing air on the condenser coil at various velocities. The surface temperature of the condensing coil, ambient temperature and the cabinet air temperatures are noted and compared with those available with natural convection condenser at constant loads. In this study R-134a has been selected as the suitable replacement for R-12. The experimental values of governing temperatures and pressures at different air velocities and cooling loads were recorded. Effect on the cooling of cabinet air is discussed on varying air velocity and cooling load. Effect on power consumption has also been discussed on varying air velocity and cooling load. It was found that the cabinet air temperature of the refrigerator goes down in comparison with that when it is operating with the natural convection condenser. This helps in longer preservation of food products in the refrigerator.

Keywords*-component;Refrigerator, Refrigerant,Natural & Forced Cooling.*

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I. Introduction

A refrigerator (colloquially fridge) is a popular household appliance that consists of a thermally insulated compartment and a heat pump (mechanical, electronic or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient temperature of the room.

There are two important parameters, which affect the performance of domestic refrigerator. First is the refrigerant used and second one is the heat transfer rate in domestic refrigerators. The heat transfer takes place primarily due to the natural convection. The theory of natural convection heat transfer has got applications in a variety of engineering problems. The theory has been usefully employed in the design of pipelines carrying hot gases for the heating of apartments arid commercial building or in the design of tubes carrying brines. In this work an experimental investigation has been carried out to improve the performance of a domestic refrigerator by replacing its natural convection condenser by a forced convection condenser.

The forced convection is achieved by blowing air on the condenser coil at various velocities. The surface temperature of the condensing coil, ambient temperature and the cabinet temperature are noted and compared with those available with natural convection condenser at constant loads. In this study R-134a has been summarized and selected as the suitable replacement for R-12 refrigerant. In this work this fact has been established that the cabinet temperature of the refrigerator goes down in comparison with that when it is operating with the natural convection condenser, when forced convection cooling by fan is provided. This helps in longer preservation of food products in the refrigerator.

A domestic refrigerator of 165 liters' capacity working on vapor compression cycle was used in this experiment. Cooling effect is achieved by flowing the air using two blowers, over condenser coil. For temperature measurement purposes SWG copper-constantan thermocouples were used. The unit consists of a compressor, a condenser, an expansion device for throttling, an evaporator, a drier and a flow-measuring device. The compressor used is of reciprocating, hermetically sealed type with displacement volume of 5.48 c. c. The compressor-delivery head, discharge line, condenser and liquid line form the high-pressure side of the system.

II. Modification

The principal modifications to the standard domestic refrigerators are the employing two blower fans, which are placed underneath the condenser coil to throw air in the plane perpendicular to the floor.

An anemometer was placed above the condenser coil to measure the air velocity in m/sec. To measure the temperature of upper and lower cabinets, freezer walls, three thermocouples are used inside the refrigerator, while four thermocouples were used to take the temperatures of compressor inlet and outlet, ambient and condenser liquid temperature.

Apart these four pressure gauges were added to measure Capillary Outlet Pressure, Capillary inlet pressure, Compressor outlet Pressure, Compressor inlet Pressure. All sides of the refrigerator are kept open to allow air circulation.

The velocity of the airin the vicinity of the refrigerator is less than 0.25 m/s. The windows in the test room are closed. A precision thermometer calibrated all the thermocouples with an accuracy of 0.1 ^{O}C. A digital temperature indicator is used to record the temperature signals continuously. Electric power consumption was measured with help of an energy meter with 0.01 KWh resolutions.

The starting conditions, both inside the refrigerator and the refrigeration equipment were not the same for all experiments; hence all the readings were taken for non-working conditions i.e. power-off state also.

Power consumption of compressor is measured by installing a KWH energy meter. A stopwatch was also used for accurate measurement of power consumption. The principal modifications to the standard domestic refrigerators are the employing two blower fans, which are placed underneath the condenser coil to throw air in the plane perpendicular to the floor. An anemometer was placed above the condenser coil to measure the air velocity in m/sec.

For performing the modifications in equipment, the refrigerant is pumped out of the system for temporary storage. For this, the liquid line shut off valve is closed and compressor is started. The compressor pumps the entire refrigerant into a receiver. At this stage equipment modification is made, such as capillary tube is pulled outside and thermocouples and pressure gauges are fixed at various points. After modifying the equipment as per the requirements, the charging of the refrigerating unit is done. It is necessary to remove the air (purging) from the refrigeration unit before charging. After removing the air, the compressor is stopped. Valves of the cylinder are opened and then the compressor is started. After taking the sufficient quantity (160-190 gm) of the refrigerant, using a spring balance, the compressor is stopped.

To identify any leakagessoap solution was applied with a spun to all the brazed joints and fasteners like flair nuts, gauge adapters, unions and hand shut off valves to check the leaks (if there is any leak a bubble is formed). Once the leak detection is made and the refrigerant R-134a was charged in the test refrigerator, it becomes ready for the experimental work.

For cooling load purpose various edible items like fruits, vegetables etc. were arranged in fresh condition. Before placing them inside the refrigerator cabinet, these were weighed properly as per the desired quantity in Kg. /Dozen. etc. Each time the experiment was performed, depending upon the cooling load, food items were placed inside the cabinet after properly weighing them.

III. METHODOLOGY

A. Natural Convection

For every cooling load, first set of readings was taken without blowing the Air on condenser coil i.e. natural or free convection cooling of condenser coil was set. In this case fans were kept off. Now before doing the electric power –on, readings of Energy meter, Ambient air temp. and all governing temperatures and pressures were noted-down. These readings were noted down under ‘Power-off condition’. After that power was ‘on’ and all the readings were taken at a gap of 5 minutes. After taking readings for 50 minutes of power-on, power was off. At this instant reading of Energy meter was once again noted. Thus for every run at a interval of 5-5 i.e. at time interval θ_1, θ_2, θ_3…. θ_{10}, all the temperatures and pressures were noted down.

B. Forced Convection

Thereafter, in the next run to provide Forced convection cooling of condenser, fans were run and Air Velocity was noted by Anemometer. Fan Speed (thereby Air Velocity) was regulated (using an electronic regulator) in such a way so that desired Air Velocity is displayed on the screen of Anemometer. i.e. 0.7, 0.8 etc. Now all the readings were taken in the same fashion as performed earlier in free convection cooling.

For each cooling load, total 6 runs of experiments were performed. Out of these 6 runs, the first run belonged to Free Convection cooling (at $V=V_0=0.0$) and remaining 5 are Forced convection cooling of condenser coil, with different Air Velocities i.e. (at $V=V_{i,}$ where i=1,2,3,4 and 5).

In this way, all the readings were taken for different cooling load conditions. A total of 30 runs of experiment were carried out for a range of cooling loads Q_1, Q_2, Q_3, Q_4 and Q_5. The following data were recorded:

i. Upper and lower cabinet air temperature, (T_{a1} and T_{a2})
ii. Freezer Wall temperature,T_w
iii. Compressor inlet Temp and Pressure,T_{C1}andP_{C1}
iv. Condenser Liquid temperature, T_{cf}
v. Capillary inlet and outlet Pressure,P_{X1} and P_{X2}
vi. Ambient temperature, T_∞
vii. KWH meter reading for energy consumed in 50 minutes
viii. Load wise details of quantity of items kept inside the cabinet to create different cooling loads

Cabinet air temperature Ta, i.e.

$$Ta = 1/2\ (Ta1 + Ta2) \quad \text{……………………. (1)}$$

Overall Average Cabinet air temperature T_m is calculated as:

$$T_m = (\Sigma\ T_a) / n \ ;\ n=10 \quad \text{……………………. (2)}$$

Average Freezer Wall Temperature, T_{wa} is calculated as:

$$T_{wa} = (\Sigma\ T_w) / n \ ;\ n=10 \quad \text{………………… (3)}$$

Once the values of T_a and T_m are calculated, value of ΔT_x is calculated as:

$$\Delta Tx = Ta - Twa \quad \text{…………………………… (4)}$$

Table III.1: Load wise details of quantity of items kept inside the cabinet to create different cooling loads.

	m(Quantity of items kept inside the cabinet to create different cooling loads)				
Food Items	**LOAD Q_1**	**LOAD Q_2**	**LOAD Q_3**	**LOAD Q_4**	**LOAD Q_5**
Apple	1.0 kg	1.5 kg	2.0 kg	2.5 kg	3.0 kg
Potato	2.0 kg	2.5 kg	3.0 kg	3.5 kg	4.0 kg

Water	1.0 liter	2.0 liter	3.0 liter	4.0 liter	5.0 liter
Butter	0.2 kg	0.4 kg	0.6 kg	0.8 kg	1.0 kg
Green Peas	1.0 kg	1.5 kg	2.0 kg	2.5 kg	3.0 kg
Banana	0.5 Dz.	0.75 Dz.	1.0 Dz.	1.25 Dz.	1.5 Dz.

Table III. 2: Calculations for LOAD Q_1

	(^{0}C)					Sp. heat (KJ/Kg ^{0}K)	m (kg)	(T_∞- T_m) (^{0}C)	Load for 50 minutes
	T_∞	T_m	(T_∞- T_m)						
V_0	17	4.98	12.02		Apple	0.42	1	14.5	2.0
V_1	16.5	-4.8	21.3		Potato	0.41	2	14.5	4.0
V_2	14	1.1	12.9		Water	4.19	1	14.5	20.3
V_3	18	1.3	16.6		Butter	0.34	0.2	14.5	0.3
V_4	17.5	5.7	11.7		Peas	3.31	1	14.5	16.0
V_5	16.5	3.8	12.6		Banana	0.4	0.5	14.5	1.0
Av. Value of (T_∞- T_m)			14.5						**43.7 Watt**

Table III. 3: Calculations for LOAD Q_2

	(^{0}C)					Sp. heat (KJ/Kg ^{0}K)	m (kg)	(T_∞- T_m) (^{0}C)	Load for 50 minutes
	T_∞	T_m	(T_∞- T_m)						
V_0	14	3.9	10.0		Apple	0.42	1.5	14.2	3.0
V_1	16	1.4	17.4		Potato	0.41	2.5	14.2	4.8
V_2	17	2.2	14.7		Water	4.19	2	14.2	39.5
V_3	16	1.9	14.0		Butter	0.34	0.4	14.2	0.6
V_4	16	1.8	14.1		Peas	3.31	1.5	14.2	23.4
V_5	15	0.5	14.4		Banana	0.4	0.75	14.2	1.4
Av. Value of (T_∞- T_m)			14.1						**72.8 Watts**

Table III. 4: Calculations for LOAD Q_3

	(^{0}C)					Sp. heat (KJ/Kg ^{0}K)	m (kg)	(T_∞- T_m) (^{0}C)	Load for 50 minutes
	T_∞	T_m	(T_∞- T_m)						
V_0	16	5.53	10.47		Apple	0.42	2	11.8	3.3
V_1	17	7.63	9.37		Potato	0.41	3	11.8	4.8
V_2	17	6	11		Water	4.19	3	11.8	49.5
V_3	16	3.44	12.56		Butter	0.34	0.6	11.8	0.8
V_4	15	0.56	14.44		Peas	3.31	2	11.8	26.0
V_5	18	5.02	12.98		Banana	0.4	1	11.8	1.6
Av. Value of (T_∞- T_m)			11.80						**86.0 Watts**

Table III. 5: Calculations for LOAD Q_4

	(^{0}C)					Sp. heat (KJ/Kg ^{0}K)	m (kg)	(T_∞- T_m) (^{0}C)	Load for 50 minutes
	T_∞	T_m	(T_∞- T_m)						
V_0	17.5	7.87	9.63		Apple	0.42	2.5	13.5	4.7
V_1	16.5	3.9	12.52		Potato	0.41	3.5	13.5	6.4
V_2	19	5.2	13.79		Water	4.19	4	13.5	75.3
V_3	18.5	4.3	14.15		Butter	0.34	0.8	13.5	1.2
V_4	19	4.3	14.62		Peas	3.31	2.5	13.5	37.2
V_5	19	2.8	16.18		Banana	0.4	1.25	13.5	2.2
Av. Value of (T_∞- T_m)			13.48						**127.1 Watts**

Table III. 6: Calculations for LOAD Q_5

	(^{0}C)					Sp. heat (KJ/Kg ^{0}K)	m (kg)	(T_∞- T_m) (^{0}C)	Load for 50 minutes
	T_∞	T_m	(T_∞- T_m)						
V_0	20.5	5.98	14.52		Apple	0.42	3	18.3	7.7
V_1	21	0.44	20.56		Potato	0.41	4	18.3	10.0
V_2	19.5	0.05	19.45		Water	4.19	5	18.3	127.7
V_3	20	2.56	17.44		Butter	0.34	1	18.3	2.1
V_4	19.5	1.23	18.27		Peas	3.31	3	18.3	60.5
V_5	18.5	-0.99	19.49		Banana	0.4	1.5	18.3	3.7
Av. Value of (T_∞- T_m)			18.29						**211.7 Watts**

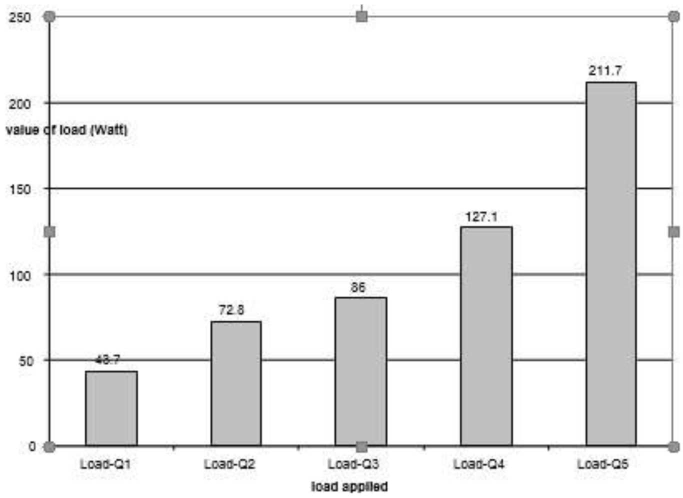

Fig III.1 Refrigeration Loads

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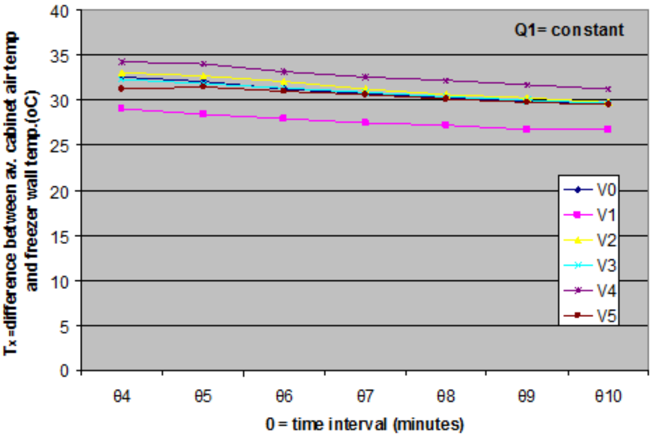

Fig. III.2 Effect of air velocity on the cooling of cabinet air at constant load Q_1

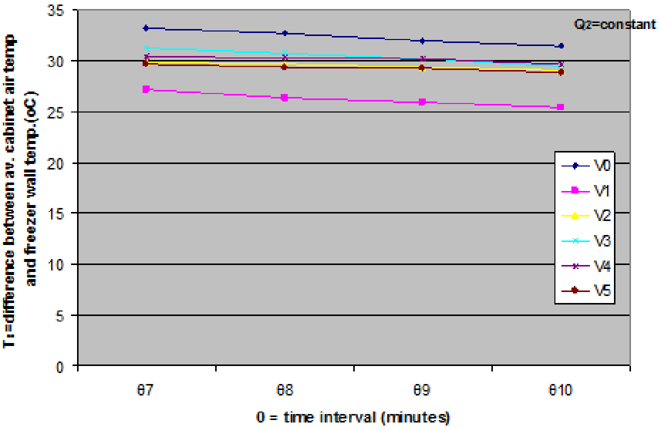

Fig III.3: Effect of air velocity on the cooling of cabinet air at constant load Q_2

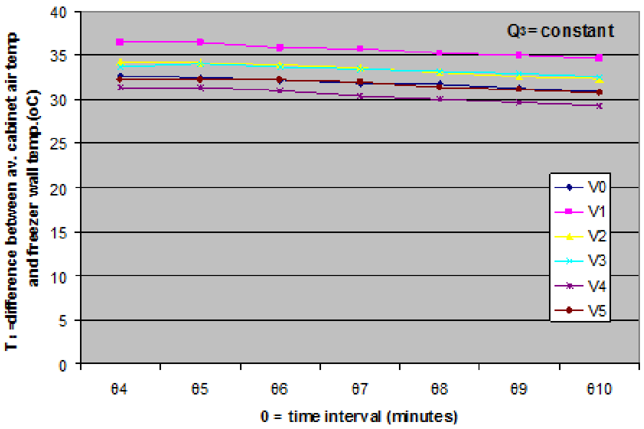

Fig III.4: Effect of air velocity on the cooling of cabinet air at constant load Q_3

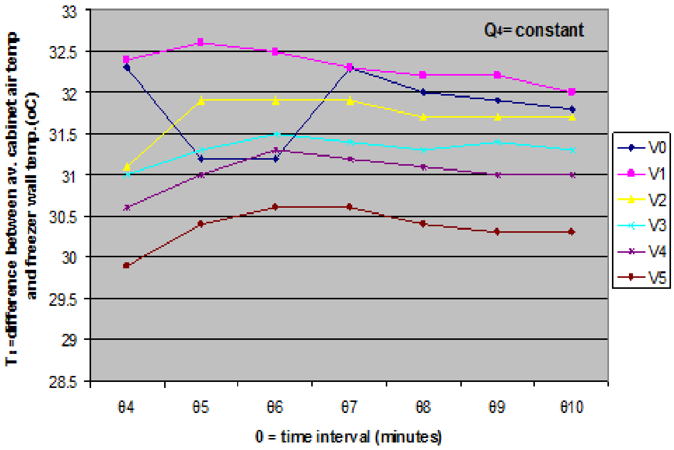

Fig III.5: Effect of air velocity on the cooling of cabinet air at constant load Q_4

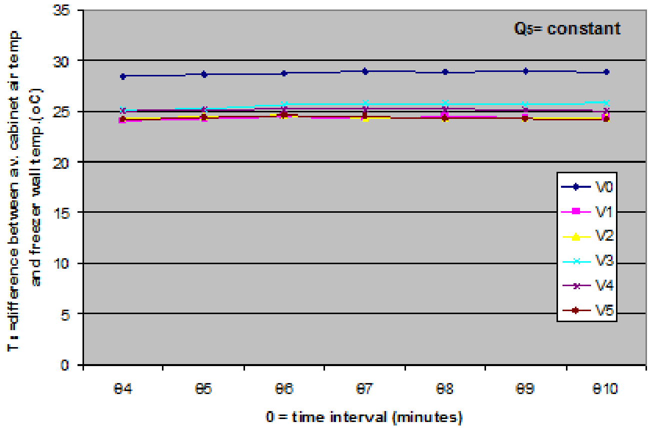

Fig III.6: Effect of air velocity on the cooling of cabinet air at constant load Q_5

EFFECT OF VARIATION OF LOAD ON POWER CONSUMPTION AT CONSTANT AIR VELOCITY

Table III.7: Effect of variation of load on energy consumption at constant air velocity.

	E (kWh)	T_{wa} (^{0}C)
Q_1	0.11	-24.79
Q_2	0.11	-25.07
Q_3	0.11	-23.83
Q_4	0.11	-20.88
Q_5	0.12	-19.5

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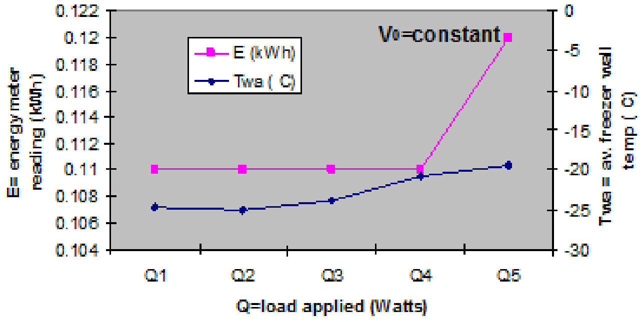

Fig III. 7: Effect of variation of load on energy consumption at constant air velocity.

EFFECT OF VARIATION OF AIR VELOCITY ON POWER CONSUMPTION AT CONSTANT LOAD

Table III. 8: Effect of air velocity on power consumption at constant load Q_1

	E (kWh)	T_{wa} (^{0}C)
V_0	0.11	-24.79
V_1	0.13	-28.25
V_2	0.14	-28.65
V_3	0.16	-28.85
V_4	0.17	-29.00
V_5	0.19	-29.35

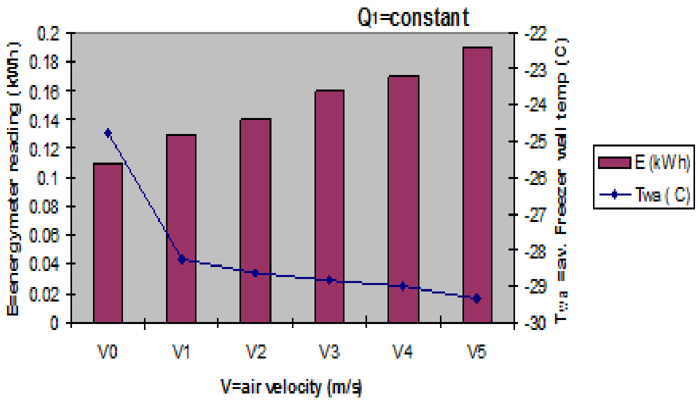

Fig III. 8: Effect of variation of air velocity on power consumption at constant load Q

IV. Conclusion

Based on the experimental results obtained for both type of convections various characteristics has been obtained at different cooling Loads and Air velocities. These results form the basis for comparing the various performance parameters for better cooling of the cabinet. Based on these results it can be concluded that:

- R-134 a can be used in domestic refrigerator working on R-12 directly as a drop in substitute. Major factors responsible for the selection of R-134a are its benign atmospheric behavior and thermodynamic properties that are similar to those of R-12.
- Power consumption increases with increase in air velocity and cooling load.
- COP of the system increases with the increase in load, at constant air velocity.
- COP goes down with increase in air velocity.
- With increase in air velocity the average Freezer wall temperature goes down; thereby cooling gets improved while more energy is being consumed.
- Average freezer wall temperature goes up with increase in load.
- Air velocities around 1.0 m/s will be ideal for cooling load of the range of 125 W and above. For loads lower than 100 W, lesser air velocity will be sufficient for the same cooling performance.
- Introduction of fans improves the performance of a domestic refrigerator. At free convection condition cooling performance does not get changed with increase in cooling load, while in forced convection condition study shows that at higher cooling loads, cooling is better than lower loads when fan speed is high (of the order of 1.0m/s).
- This study carried with forced fan heat transfer to the condenser shows that forced convection heat transfer from the condenser may be economical for large installation. This system is also recommended where more refrigerating effect is of prime importance.
- It was found that the cabinet temperature of the refrigerator goes down in comparison with that when it is operating with the natural convection condenser. It shows that forced convection condenser coil performs better than free convection condenser coil when fitted in a domestic refrigerator. This helps in longer preservation of food products in the refrigerator, such as perishable items of meat, dairy products, confectionary, general domestic medicines etc.

V. Scope for Future Work

.The use of CFC-12 can be replaced by retrofitting R -134a in the domestic refrigerator. This work may be extended for further studies in other cooling equipment's and refrigerating devices such as air conditioners, water coolers etc.

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References

[1] Akhavan- Behabadi, M.A.; Salimpoor, M.R.;Kumar, Ravi; Agrawal, K.N. (2005) Augmentation of Forced Convection Condensation Heat Transfer Inside a Horizontal Spiral

ISSN: 2321-8169
656 – 661

Spring Inserts, Journal of Enhanced Heat Transfer, Vol. 12, No.4,pp.373-384.

[2] Agrawal,K.N., Kumar,R., Lal,S.N., Varma,H.K.(2002),“Swirl Flow Heat Transfer During Forced Convection Condensation of R-22 in a Horizontal Tube Fitted With Segmented Tapes,” Fourth National Conference on Thermal Systems, BHU, Varanasi, pp. 152-157, Feb.22-23.

[3] Bilal A Akash, Said Salem A,(2003) "Assessment of LPG as a possible alternative to R-12 in domestic refrigerators". Energy Conversion and Management, Vol 44, issue-3, pp 381-388.

[4] Cleland A.C.,(1994), "Polynomial curve fits for refrigerant thermodynamic properties: extension to include R134a, Int. J. Ref Vol. 17, No.4.

[5] Devotta S. and S. Gopichand, (1992), “Comparative assessment of HFC-134a and Some refrigerants as alternatives Int.J .Refrigeration, vol. 15,No.2.

[6] Hammad M.A. and Alsaad M.A.(1998)," The application of propanelbutane mixture for domestic refrigerators." Applied Thermal Engg. V 0118 issues 9-10 pp 911-918.

[7] Hammad M.A. and Alsaad M.A.(1999), "The use of hydrocarbon mixtures as refrigerants in domestic refrigerators." Applied Thermal Engg. Vol19 issue-11, pp 1181-1189.

[8] Inan Cemil, Gonul Turgay, Tanes MY alcin,(2003),"X-ray investigation of a domestic refrigerator Observations at 25°C ambient temperature." Int.J.Refrig. Vol26 issue-2, pp-205-213.

[9] J.P. Holman,Edition 9th,(2004)," Heat transfer" , Tata mcgraw- Hill Publishing Company Limited, NEW DELHI., pp 358

[10] Jung,D. Song, K. Cho, Song Kilhong, Park. Byoungjin (2000) "Testing of propane/isobutene mixture in domestic refrigerators." Int.J.Refrig. Vol 23 issue-7 pp 517-527.

[11] Jung,D. Song, K. Cho, Y. And Kim, S. (2004) Flow condensation Heat transfer Coefficients of R22, R134, R 407 C and R410A Inside Plain and Microfin Tubes, lnt. J. Refiig., voi.26, No.l, pp4-11.

[12] Lavrenchenko O.K., Ruuvinskij G.Ya, Iljushenko S.V. and Kanaev V.V.,(1992),"Thermodynamic properties of refrigerant R134a, Int J.Ref Vol.1,S.No.6,

[13] Mclinden M.D.(1990),"Thermodynamic properties of CFC alternatives: A survey of available data," Int. J. Ref: vol. l3.

[14] M. A. Sattar, r. Saidur, and h. H. Masjuki (2007), “performance investigation of domestic refrigerator using pure hydrocarbons and blends of hydrocarbons as refrigerants”, international journal of mechanical systems science and engineering (volume 1 number 1).