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Implementation of Hot Gas Bypass Defrost In Domestic Refrigerator And Its Comparison with Electrical Heater Defrost

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Abstract: **Frost formation on the evaporators reduces its effectiveness hence needs to be melted using external heat source in most of the frost free refrigerator, which contributes to its energy consumption. Currently electrical heaters are used for the defrost purpose. Alternative defrost technology i.e. Hot gas bypass defrost currently used in Industrial refrigeration is tried to be implemented in medium capacitydomestic refrigerator because of its higher Coefficient of Performance and reduced energy consumption. Performance of both electrical heater defrost and hot gas defrost are compared with the help of parameters such as defrost efficiency and heat distribution during defrost. Hot gas defrost has 62.4 % defrost efficiency compared to 38% defrost efficiency of electrical heater.**

***Index Terms*—Defrost, electrical heater defrost, Refrigeration, Hot gas defrost.**

I. INTRODUCTION

Frost formation effects the evaporator tubes heat transfer capacity by reducing external heat transfer coefficient linearly over time, reducing mass flow rate of air, increasing temperature drop of air but reducing net cooling capacity of evaporator due to reduction of mass flow rate by Horton [1], Alijuayel et al. [2].Hence periodic defrost is necessary for better performance of refrigerator.Some of the major defrosting techniques are electrical defrosting i.e. use of electrical heaters to defrost the evaporator. This is predominantly used in small cooling capacity equipment like domestic refrigerators because of the ease of implementation and lesser cost. Hot gas by pass defrost system , reverse cycle defrost system which uses compressed refrigerant from the compressor to defrost evaporator using 3 way solenoid valve and 4 way reversing valve respectively. These are predominantly used in large capacity system like heat pump, industrial refrigerators like chillers, cold storage because of lesser energy consumption compared to heater for the same capacity.

Hot gas bypass defrost is a technology used in industrial refrigerators. During hot gas bypass defrost, hot gas from the compressor is directly sent to the evaporator, bypassing condenser and capillary tube. The hot gas condenses inside the evaporator and melts the evaporator frost. Since the heat comes from within the evaporator tube its effectiveness in melting the frost is more compared to electrical heater defrost as the electrical heater is partially exposed to air. The problem however with hot gas defrost is that during defrost the hot gas condenses and this condensate may enter into compressor suction and harm the hermetically sealed reciprocating compressor.

Most of the work done in Hot gas bypass defrost system is in heat pumps and industrial refrigerators but very less work is present in case of small capacity cooling systems such as domestic refrigerators. Hoffenbecker ,Klein and Reindl [3] developed a hot gas defrosting model and validated it with experimental data of an industrial refrigeration system and showed that use of hot gas at lower temperature increases defrost time but is more efficient than using defrost gas at higher temperature and reduced defrost time. It implies that in case of domestic refrigerator the hot gas defrost should be initiated as soon as the compressor goes into off cycle since the discharge gas temperature is maximum at that instance.Huang, Li, and Yuan [4] compared hot gas bypass defrosting and reverse cycle defrosting methods on air to water heat pump. Hot gas bypass defrost was implemented without a suction heater and with an accumulator which prevented liquid slugging of compressor. Hence it suggests that with proper accumulator the problem of liquid slugging can be avoided.

Melo , Knabben and Pereira [5],have compared distributed, Cal rod and glass tube heaters defrost efficiencies under different operating modes such as integral mode with continuous power supply , pulsating mode with on-off cyclic pattern with nominal power and power step mode with gradual reduction of heater power during defrost and found that all three heaters have almost same defrost efficiencies within respective modes and pulsating mode gives the best defrost efficiency for cal rod heater as 48%.Distributed heater with integral mode used in the above work has 31-38% defrost efficiency is used in the current work. Hence from the literature review the maximum defrost efficiency of electrical heater can be 48 %. The main drawback of heaters is its tendency to increase air temperature during defrost because of high temperatures in case of cal rod heaters and higher surface exposure to air in case of distributed heater resulting in increased parasitic heat load leading to longer and higher energy consuming recovery cycles.

From the literature review it is inferred that most of the work on implementation of hot gas bypass defrost technology has been done with heat pumps and industrial refrigerator. Implementation of hot gas defrost in domestic refrigerator and its comparison with preexisting electrical defrost technology is not present. In the present work hot gas bypass defrost is implemented in domestic refrigerator and its energy consumption, defrost efficiency have been compared with baseline refrigerator with electrical heater with the help of experimentation.

II. EXPERIMENTAL SETUP

Experimental setup comprises of 360 L No frost domestic refrigerator with forced convection in evaporator. Refrigerant used is R600a of 55g quantity. Both hot gas defrost and electrical heater are installed within the same refrigerator. Preexisting electrical heater is of 170 W and defrost is initiated after 8 hours of compressor running time in case of electrical defrost. For hot gas defrost which is installed, defrost is initiated at the end of compressor off-cycle which comes after 8 hours of compressor run time. Electrical heater defrost and hot gas bypass defrost are terminated with the help of bimetal configured to stop defrost at 10ºC.

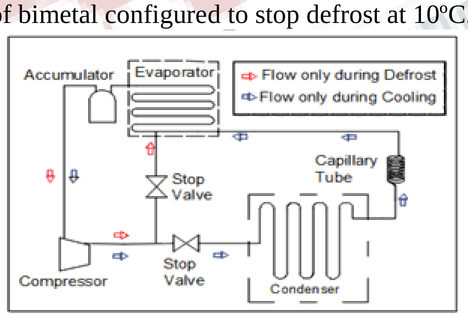

Figure 1: Schematic diagram of experimental setup

For estimation of defrost efficiency the test is conducted in ambient with 32ºC and 40% Relative humidity. Since frost formation is not enough with door closed in this ambient, two 1liter plastic containers with water are kept in the fresh food cabinet and door is kept opened by 5 cm for 6 hours. This ensures frost formation. Door is then closed and water containers are removed and defrost is executed after stable cycles are reached. Quantity of water collected and its temperature is measured. The stable cycle temperatures are kept same for both electrical heater defrost and hot gas bypass defrost.

Metal temperatures such as evaporator tube temperature and condenser tube temperature are measured with the help of T type point thermocouple. Thermocouple is placed at location of bimetal to measure initial and final evaporator temperatures during defrost. Mass thermocouples i.e. point thermocouple soldered into cu mass are used to measure air temperatures. Mass thermocouples are placed in freezer cabinet and fresh food cabinet to measure air temperatures. The power is measured by digital energy meter

Table (i) :Refrigerator and accessories specification

Made	Whirlpool
Volumetric Capacity	360L
Cooling Capacity	0.0425 Ton
Compressor	Hermetically Sealed (TX1113Y)
Condenser	Hot wall Condenser with Steel Tubes
Evaporator	Plate and Fin type (Al)
Refrigerant	R600a (0.055 kg)
Electrical Heater	Integrated Heater (170W)
Manual Stop Valve	Mini Ball Valve (6mm diameter)

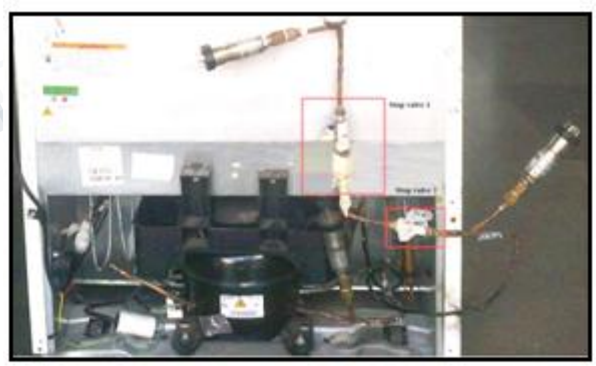

Fig. 2 Stop valve connections at compressor discharge

The readings of temperatures, power are fed into a real time tracking software and all the readings are extracted from the software directly.

The hot gas defrost is initiated manually by closing the stop valve connecting compressor discharge and condenser and by opening the stop valve connecting compressor discharge and the bypass tube leading to evaporator inlet. Fig. 2 depicts the connections near compressors. This is done at the end of that compressor off cycle which comes after 8 h of compressor run.

The heater operation is controlled by mechanical clock counter and bimetal. The mechanical clock counter initiates the heater operation by turning of compressor and turning on heater after 8 h of compressor run. When the bimetal temperature reaches the set temperature of 10ºC the heater is terminated and compressor is turned on after a small delay.

The electrical heater used is integrated heater of 170W. It is wound around the evaporator and also passes through drip tray where frost drops after melting from evaporator to ensure that water flows through drain pipe and frost does not choke the drain pipe hole. The evaporator is made of aluminum and weighs 800 g.

III. CALCULATIONS

Calculation for defrost efficiency, energy consumption and heat gained by air, frost and evaporator has been shown in the following section.

Ideal Defrost efficiency –D.E% $= \frac{Q_{Iceideal} x100}{W_s}$ (1)

W_s = Energy consumed by defrosting element.(kJ)

W_s is obtained from energy meter reading.

$Q_{Iceideal} = Q_{SHI} + Q_{LH} + Q_{SHWideal}$ (kJ)(2)

$Q_{Iceideal}$ =Ideal energy required to melt frost/ice. (kJ)

Q_{SHI} = Sensible heat required to melt the Frost from initial temperature to 0°C

Table ii. Evaporator parameters for heater, Hot gas by pass defrost efficiency test

Mass (g)	Mate rial	C_p (kJ/kg-K)	Starting Temp (°C)	Ending Temp (°C)	Eva Delta (°C)
800	Al	0.9	-18	15	33
800	Al	0.9	-10	10	20

$Q_{SHI} = m_f \times Cp_F \times (Ti - 0)$ (kJ) (3)

m_f = Mass of water collected at the end of defrost (kg).

Cp_F =Specific heat capacity of frost.

Ti= Initial temperature of frost (ºC)

$Q_{LH} = m_f \times S_{LH}$ (kJ) (4)

S_{LH} = Specific latent heat of ice = 335 kJ/kg (5)

$Q_{SHWideal}$ = Sensible heat required to heat the water from 0 ºC to 5°C to ensure frost melting.

Mass (g)	C_{pf} (kJ/kg/°C)	Frost Delta (°C)	LH kJ/Kg	C_{pw} (kJ/kg/°C)	Water Delta (°C)	Ideal Water Delta (°C)
160	2.03	18	335	4.18	31	5
280	2.03	10	335	4.18	21	5

$Q_{SHWideal} = m_f \times Cp_w \times (5-0)$ (kJ) (6)

Cp_w = Specific heat capacity of water.= 4.18 kJ/kg-K.

Q_{ice} = Sum of actual heat gained by frost and water.

$Q_{ice} = Q_{SHI} + Q_{LH} + Q_{SHW}$ (7)

Since in actual defrost the water gets heated up more than 5 ºC which is not required ideally.

Table iv. Parameters pertaining to air

Humidity RH	FC Delta (°C)	RC Delta (°C)	FC vel (L)	RC Vel (L)	Air Density	C_v (kJ/Kg-K)
0	6	2	93.1	236.9	1.35	0.72

$Q_{SHW} = m_f \times Cp_w \times (water_{delta})$ (kJ) (8)

Q_{SHW} = Actual sensible heat gained by water during defrost

$water_{delta}$ = Temperatures gained by water after 0ºC during defrost.

$Q_{eva} = m_{eva} \times Cp_{eva} \times Eva_{delta}$ (kJ) (9)

Q_{eva}= Heat gained by evaporator during defrost (kJ)

m_{eva} = mass of evaporator (kg)

Cp_{eva}= specific heat of evaporator (kJ/kg-K)

Eva_{delta} = Temperature change of evaporator during defrost

$Q_{air} = (m_{aFC} \times FC_{delta} + m_{aRC} \times RC_{delta}) \times Cp_{air}$ (10)

Q_{air}= Heat gained by air during defrost (kJ).

m_{afc} ,m_{arc}=mass of air in Freezer, Fresh food cabinet (g)

FC_{delta},RC_{delta} = Change in air temperature of FC, RC_{delta}

ρ_a = Density of air. (kg/m^3).

ρ_a is taken at average temperature of RC and FC .

$m_{afc} = \rho_a \times FC_{vol}$, $m_{arc} = \rho_a \times RC_{vol}$ (11)

FC_{vol} , RC_{vol} = Volume of freezer ,fresh food cabinet.

$Q_{total} = Q_{air} + Qi_{ce} + Q_{eva}$ (kJ) (12)

Q_{total}= Sum of heat gained by air, ice and evaporator.

Q_{uc} = Heat unaccounted or not measured.

$Q_{uc} = Ws_{supplied} - Q_{total}$ (kJ) (13)

For heat distribution

Percentage of total heat gained by individual things such as water, evaporator air is also calculated.

IV. RESULTS AND DISCUSSION

Defrost efficiency and Heatdistribution of electrical heater defrost.

Table ii shows the mass of evaporator, its material and the temperature change undergone by it during the defrost and table iii shows the same parameters for water or frost in order to calculate the total heat gained by water and evaporator during defrost.

Table iv shows the parameters pertaining to air and the assumption of 0 Relative humidity in the refrigerator as it is not measured since it does not have much effect on its heat gained. The air parameters are same in case of hot gas defrost and electrical heater defrost.

Table V.Heat Distribution and Defrost efficiency heater, hot gas bypass defrost

W_s	Q_{Ice}	Q_{air}	Q_{eva}	Q_{tota}	Q_{uc}	Q_{Ideal}	D.E
161.28	79.4	1.26	23.7	**104.4**	56.7	62.7	**38.8**
161.64	124.0	1.27	14.4	**139.67**	22.04	100.88	**62.4**

Table Vi. Percentage Heat Distribution for heater, hot gas bypass defrost

Water	49.2%	77%
Air	0.70%	0.8%
Evaporator	14.6%	8.9%
Plenum + Drip Tray + Cabinet +Other	35.5%	13.3%

From table V it can be seen that ideal defrost efficiency is 38.8 %. Actual defrost efficiency is however 50%. The water after melting is heated upto 31 ºC in the drip tray by electrical heater which is not necessary

Table v and Table vi show that the heat distribution in heater and hot gas bypass defrost cases. It can be seen that ideal defrost efficiency for hot gas bypass defrost is 62.4 % which is better than heater defrost efficiency of 38.8 %. This is attributed to the fact that unaccounted heat, excessive heat gained by water and heat gained by evaporator is more in case of heater defrost.

Table Vi. Shows the heat distribution during defrost. 50 % of total heat is gained by water and evaporator gains 13%. But around 36.20 % heat is unaccounted for which goes into heating the surrounding elements such as plastic plenum, drip tray and freezer cabinet walls which is the reason why defrost efficiency is less.

V. CONCLUSION

Hot gas bypass defrost if implemented in domestic refrigerator can improve the energy efficiency of refrigerator by reducing the energy consumption during defrost.77 % of heat provided goes into melting and heating up the water and very less heat is unaccounted for. The ideal defrost efficiency of hot gas bypass defrost is 64% which is a significant improvement compared to electrical heater defrost. This mainly due to less heating of the water beyond zero degree Celsius.

Future scope

In this setup hot gas bypass defrost has been conducted manually and not with the help of three way solenoid valve. By using the 3 way solenoid valve the execution of defrost can be kept more precise and more control can be achieved in execution of defrost.

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