The International Journal of Engineering and Science (IJES)
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805
|| Pages || PP 51-57 || 2020 ||

Review on defrosting methods for heat pump when outdoor coil surface temperature falls below zero-degree temperature

Gurudas D. Awate[1], A.R. Acharya[1], Amit Kulkarni[2]
[1]*Mechanical Engineering Department Government college of Engineering, Karad 415124, Maharashtra, India*
[2]*Engineering Manager, Emerson Climate Technology India Pvt. Ltd, Karad,415110, Maharashtra, India*
Corresponding Author:Gurudas D. Awate

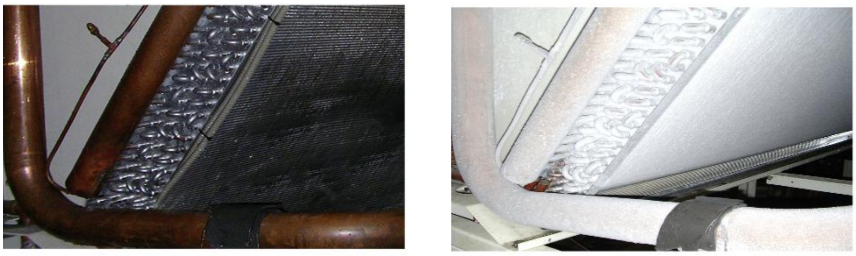
ABSTRACT
When outdoor coil of heat pump is subjected to low ambient temperature and high relative humidity, surface temperature of outdoor coil falls below dew point temperature and freezing temperature then frost starts accumulating on the outdoor coil surface. This accumulated frost reduces the heat transfer between coil and surrounding hence degrades system performance, so this frost needs to be removed to avoid this. Currently many methods are available for defrosting and lot of literature is available for each method. In this work detailed literature survey for various methods is carried out. Drawbacks of each method and modification to be done is also discussed here and finally most suitable method of defrosting for air source water heat pump is suggested.

KEYWORDS;-*Defrosting, Heat pump, Hot gas bypass defrosting, reverse cycle defrosting*

I. INTRODUCTION

Heat pump is a device which is used to transfer heat from source to the sink. This heat pump works on vapor compression cycle. In this refrigerant is used as a heat transfer medium. There are mainly two uses of heat pump heating and cooling. In heating operation evaporator takes heat from surrounding medium and condenser transfers this heat to the conditioned room. In cooling operation evaporator removes heat from conditioned room and condenser transfers it to the surrounding.

Depend on heating source there are various types of heat pump. A heat pump which takes heat from surrounding air is known as air source heat pump. When this taken heat is used for water heating purpose then it is known as Air Source Water Heat Pump. As in today's world, energy economics as well as environmental impact of any system is main concern. Because of this heat pump technology is rapidly growing as it is cost effective as well as non-harmful for environment [1] When ambient temperature falls below the dew point temperature of moisture, it starts condensing on the evaporator coil surface. When relative humidity of surrounding is higher the condensing rate of moisture is also higher. When ambient falls further below liquidous temperature of water, this condensed water starts freezing on it. This forms frost layer n coil surface. [2] This frost layer acts as a barrier for heat transfer and also blocks the air flow through evaporator coil hence reduces heat transfer from surrounding to evaporator hence this need to be removed for efficient working. [3] Below Figure 1. (a) & (b) shows coil before frosting and coil after frosting.



(a) (b)

Figure 1: (a) coil before frosting (b) coil after frosting

II. DISCUSSION

Literature review

There are lot of research is done in this area, here I am giving detailed literature review for each of the mentioned method of defrosting process. In this section, review on various defrosting methods are given

1. Compressor shutdown method

In this defrosting compressor is turned off for defrostation purpose. By using atmospheric heat frost is melted. [4] conducted an experiment in which they studied defrosting by utilizing outdoor heat for frost free domestic refrigerator. They called this method as "Defrosting system using outdoor heat air" (DSUOA). They found that for same defrosting time, there is need of high fan power in spring season as compared to summer season. When surrounding air temperature is less than 6^{o}C, fan power required is 79.8W for defrosting. For the same defrosting time when air temperature is more than 22^{o}C the smallest fan power 16.1W can be selected. They found that compared to electric defrosting, power consumption for defrosting is almost 77.6-98.2% less for same surrounding conditions. Hence it is clear that compressor shutdown defrosting method is totally depend on surrounding conditions. If surrounding is at lower temperature near to zero then this method is ineffective. For more effective defrostation by this method can be achieved by pre-starting evaporator fan and this was studied by [5]

2. Electric defrosting method

In an electric defrosting, electric heater inserted in an evaporator coil as seen in Figure 2. This defrosting is needed electric heater, this heater energized automatically by using sensors or manually. This heater gives it heat to the frosted coil and coil gets defrosted.[6] perform an experiment on defrosting of cold storage using electric heater and air bypass circulation. In most of the cold storage plants, electric defrosting is commonly used. Found that this method has very low defrosting efficiency. During defrosting operation high temperature variation was detected in cold storage this may affects products life stored in it as well as cabinet life. [7] studied this method for domestic frost-free refrigerator for improving its performance. In this work they install an additional heater of 60W in the middle height of the evaporator coil along with bottom mounted calord heater. By this move they found that there is reduction in defrosting time by 4.5 min. Also, they install cover on fan, this cover activated during defrost cycle hence stops entry of hot air in the freezing cabinet (FC). This causes reduction in rise FC temperature by 2.7^{o}C. From this work they found that there is 1.2% of reduction in total energy consumption of system. Similar study was carried out by [8] and reported that the temperature achieved by radiant heater is too higher for defrostation. This increases cabinet temperature and found this method as least efficient. From total energy, around 20% of energy is used in defrosting process [9]. In below figure we can see the heaters mounted on the evaporator coil for defrosting. [10] conducted an experiment with different types of heaters and found that all are having same defrosting efficiency.

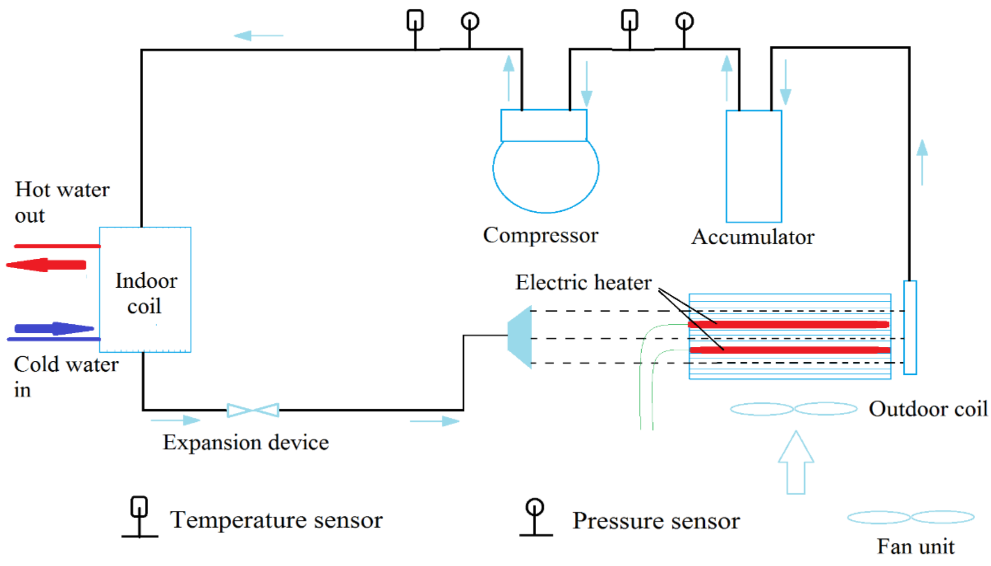


Figure 2: Schematic of electric defrosting method

3. Hot water spray defrosting

In hot water spray defrosting method latent heat of hot water is used for defrosting of coil. Hot water is sprayed on the frosted surface. For this we need extra storage for water and heating system to heat the water. For spraying also need some mechanism so this system increases overall cost of system. [12] found that thickness of frost layer on surface increases with time linearly. In water scarcity area this method cannot be used. Fig. 3. shows the schematic of hot water spray defrosting system. Nozzle are mounted on the top of the outdoor coil for spraying of water.

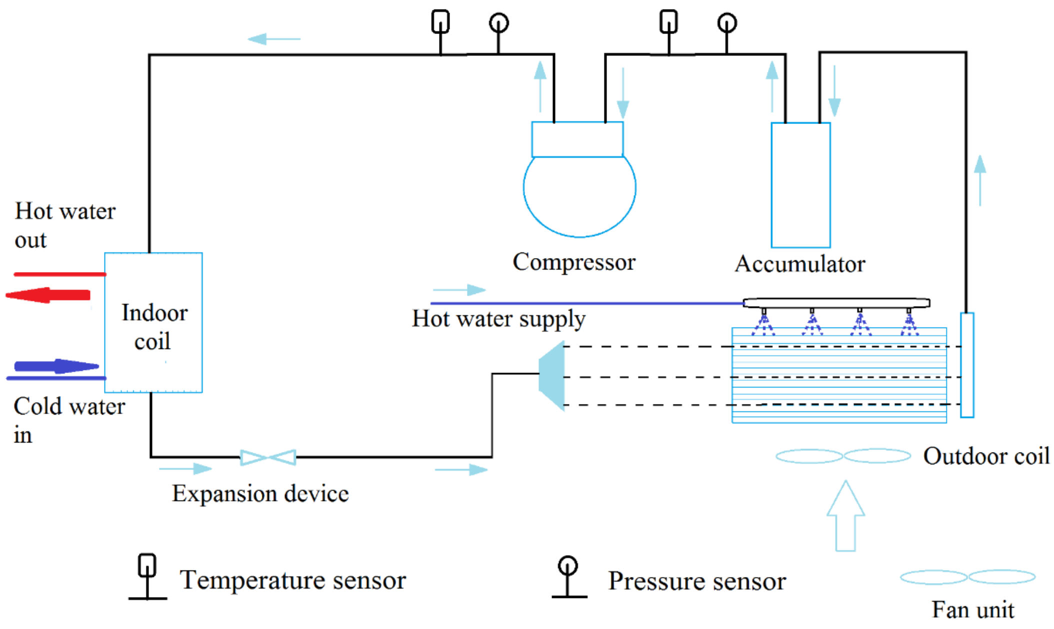


Figure 3: Schematic of hot water spray defrost method

4. Air jet defrosting

Air jet defrosting uses high pressure jet of air to remove frost from surface of coil by the erosion action. This high-pressure jet is directed to the evaporator coil of which frost is to be removed, this jet breaks the frost and removed it from surface. [12] worked on new defrosting method called jet impingement for defrosting of precooled turbojet engines. 10-50s of time interval was kept between two successive impingements, this jet last about only 0.1s. they found that at low coolant temperature of 83K and at low air flow speed (around 1.0m/s) system shows effective defrosting result for air jet defrosting. But when speed increases (3.0 m/s), defrosting performance gets degraded. When there no air jet defrosting, flow path gets blocked in just 250s by frost, but when air jet defrosting used time span for blocking of path was increases by doubles.

Similarly, in case of coolant temperature, if it is high, defrosting performance gets reduced and at 83K it shows best defrosting performance. [13] studied an air-particle jet method for heat exchanger defrosting. In this they used solid particles with 1mm & 2mm diameter. They impinged air-particle jet on evaporator at the interval of 50 to 300s. The air jet is having 20^{o}C temperature, 50% Relative Humidity (RH) and 3 m/s velocity. When air jet interval shortens, there is increase in total heat transfer. Their experiment shows that there is not much effect on defrosting performance by varying total number of particles.

5. Ultrasonic defrosting

This defrosting method uses ultrasonic vibrations to remove the frost from evaporator coil surface. [14] performed an ultrasonic defrosting experiment by spraying Ag_2O particles on rectangular and gives vibration to plate. Found that vibrations of an amplitude of 3.1 micron reduced the frost by 60%. They concluded that, frost accumulation can be suppressed by giving high ultrasonic vibrations to plate. [15] studied the effect on frost formation when rectangular plate was subjected to ultrasonic vibrations, for this study they used ultrasound of 20kHz sound frequency.

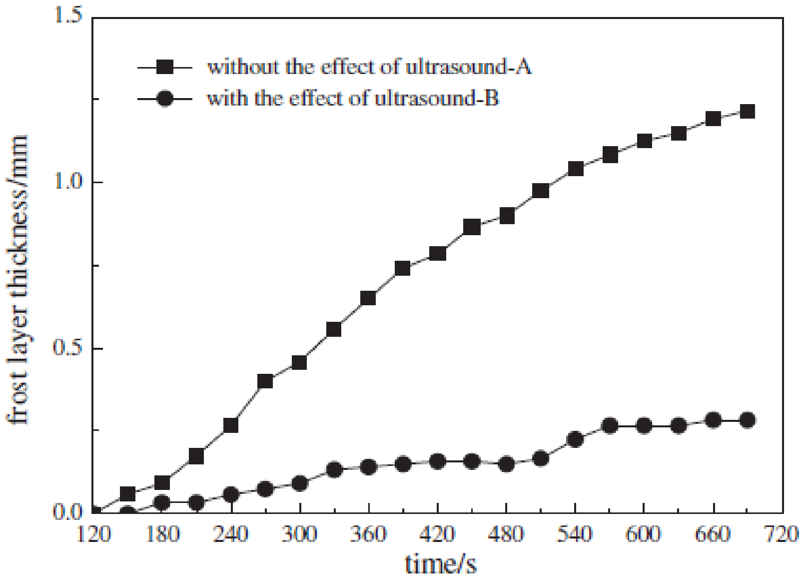


Figure 4: Variation of frost thickness with and without effect of ultrasound

They found that when system without ultrasonic vibration, frost covered almost 65% area of coil and with ultrasonic vibrations, it was around 52% for the same operating conditions. There is almost 75% of reduction in the frost layer thickness rate. Above Fig. 4. shows the variation of frost thickness with and without ultrasound.
When system works without ultrasonic vibration, fin spacing was completely blocked by frost in 32 min but when used ultrasonic vibrations up to 92 min, 2/3rd of the fin spacing was blocked by frost, this shows that ultrasonic vibrations reduces the frost growth. [16] Fig. 5. shows the growth of frost with and without ultrasound varying with respect to time.

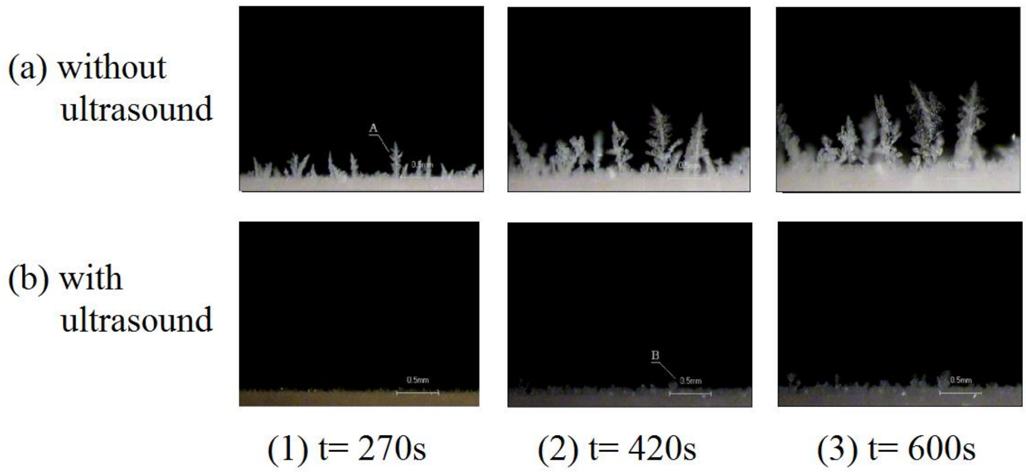


Figure 5: Frost growth [14]

6. Reverse cycle defrosting

In this method reverse valve is installed in a system which reverses the flow of refrigerant i.e. heating system is converted into cooling so indoor coil will now acts as an evaporator and outdoor coil becomes condenser. Heat for defrost is taken from two sources: heat generated by compression in compressor and heat removed from indoor area. While defrosting heating operation stops so this defrosting method is not feasible in applications where constant temperature conditions are required. During defrosting cycle high pressure fluctuations can be seen in system [17]. Below Fig. 6. shows schematic diagram of reverse cycle defrosting in which four-way valve is shows. This valve operates and reverses the flow of refrigerant. [18] conducted an experiment of defrosting ASHP using this method and found that around 60% of supplied energy is utilized in defrosting process.

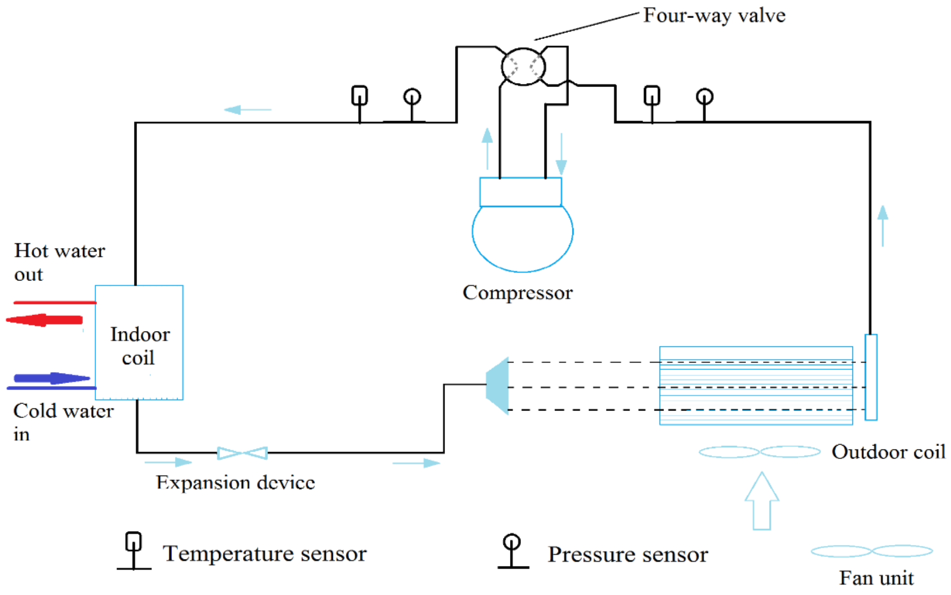


Figure 6: Schematic of RCD cycle

[19] performed an experiment to determine the transient response of the ASHP during RCD. The outdoor conditions for test are 35°F DBT and 30°F DPT. In this work they recorded frosting time 45 minute and defrosting last about 8.06 min. When defrost started suction pressure of compressor was increased from 30 Psia to 70 Psia and discharge pressure increased up to 130 Psia. The system's integrated COP was around 2.26. In below Fig. 7. we can see variation of suction and discharge pressure of compressor for total heating and defrost cycle. [20]used 3 circuit coil horizontal evaporator to avoid early frost formation by removing water retained in previous defrosting cycle effectively by using gravity action. They found that defrosting duration was significantly reduced.

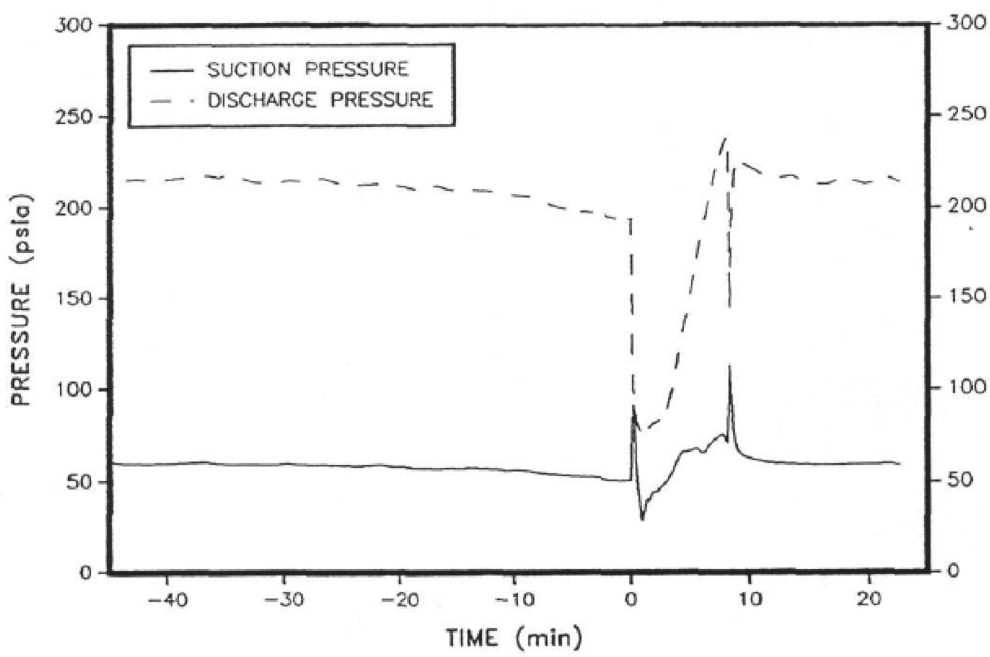


Figure 7: Pressure variation in RCD cycle [20]

7. Hot gas bypass defrosting

Hot gas bypass is the defrosting process in which hot gas from compressor discharge is bypassed into the evaporator inlet. The heat carried by this hot gas is utilized in melting of frost. This is continuous heating method because heating is continued while defrosting also, so this method of defrosting is used in many applications in which continuous heating is required without interruption. [21] found that when bypassed refrigerant mass flow rate increased, then there is a decrease in defrosting time as well as decrease in total energy transfer was observed. [22] designed a low-pressure bypass defrosting found that heating capacity of system increased by 17% as compared to RCD. When system runs for 4h with two defrost operations, the overall efficiency was found to be 8% higher that RCD cycle. Below Fig. 8. shows the schematic diagram of HGBD method for ASWHP. In this system we need solenoid valve for starting and stopping the defrost operation by opening and closing of bypass line. [23] conducted an experiment on ASHP with CO_2 as a refrigerant for HGBD method. The testing conditions are 2°C DBT and 80% RH. They found that at the start of defrosting cycle compressor discharge temperature drops from 105°C to 81°C sharply. Normal operating pressure of the system is 9.8 Mpa and when defrosting is started the pressure decreased slightly to 7.25 Mpa. When defrost ends this pressure rises gradually up to 8.72 Mpa. The found that efficiency if HGBD methods is in the range of 30-40%. Power consumption of compressor drops at the start of defrosting due to decrease in the compression ratio. [24]. Found that from total supply of defrosting heat, 75% to 85% heat goes to the surround as a waste heat.

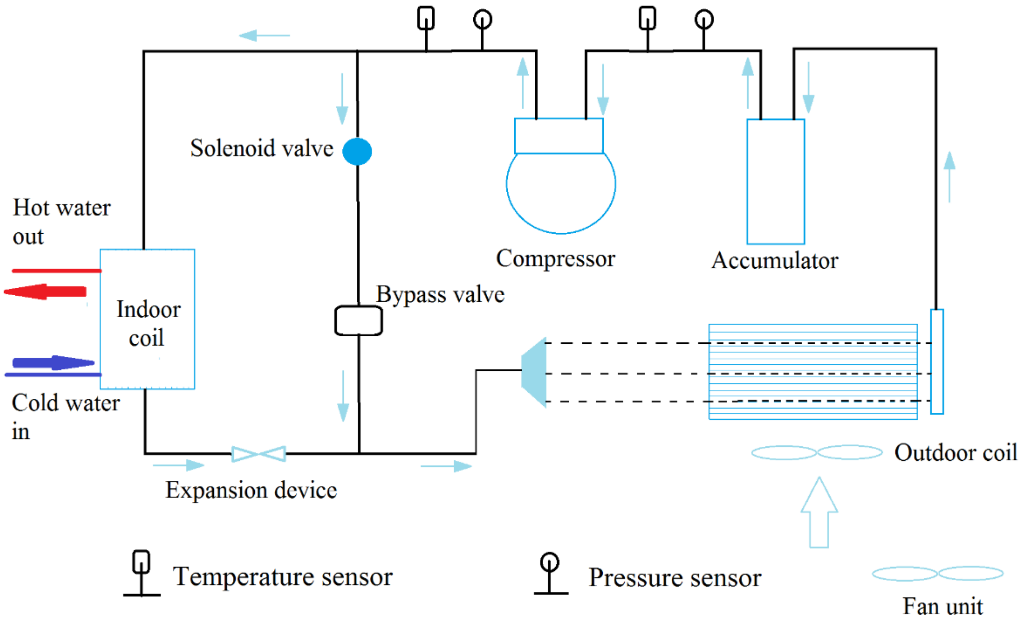


Figure 8: Schematic of HGBD method

Alternative method for HGBD is invented in which compressor discharge is given at inlet and outlet of the evaporator coil to avoid reduction in the discharge temperature of the compressor.

Discharge pressure variation is in the range of 1100 kPa and in suction side it was around 200 kPa. Defrosting time for HGBD method was almost two time the defrosting time of RCD cycle. [17]

III. CONCLUSION

Frost on the evaporator side significantly reduces systems performance. To remove this frost various methods are used and some of them are reviewed here. By studying those methods, conclusion has been drowned from it. When Compressor shutdown defrosting method is applied then for that defrosting period system stops its working and that is not desirable. Electric defrost method uses external energy for defrosting but electric heater will have maximum COP of 1 which is less than that of heat pump, so it will increase overall operating cost of a heat pump. In Reverse cycle defrosting method, refrigerant reverses the direction of flow hence condenser coil acts like evaporator and evaporator coil will acts like condenser in defrosting cycle. During this there is high pressure fluctuations detected in the system. Those pressure fluctuations are not desirable for system and may result in failure of system components. In hot water spraying defrost method there is chances of entry of water in critical parts of the system. This may damage the system in the form of corrosion or electric short-circuit. In air jet defrosting we need high pressure of air jet. For this we need device which will provide that, hence system will become bulky and set cost as well as operating cost will increase, also this method is prone to vibrations hence whole system should mount on vibration damping platform. Hot gas bypass method is continuous heating cycle also less pressure fluctuations can be seen during defrosting cycle so this defrosting method is most suitable for defrostation of an air source water heat pump.

REFERENCE

[1]. Nishimura T. "Heat pumps-status and trends", in Asia and the Pacific. International Journal ofRefrigeration, 25(4):405–13, 2002.
[2]. Lawrence J. M. W., Evans, J. A. "Refrigerant flow instability as a means to predict the need for defrosting the evaporator in a retail display freezer cabinet", International Journal of Refrigeration 31, no. 1: 107-112, 2008.
[3]. Tassou S. A., Datta D., Marriott D. "Frost formation and defrost control parameters for open multideck refrigerated food display cabinets", Proceedings of the Institution of Mechanical Engineers, Part A, Journal of Power and Energy, 215: 213-222, 2001.
[4]. Zhongbao Liu, Wenqi Gao, Huiwei Lang, Yuanying Chi "Experimental study on new type of defrosting system using outdoor air for frost-free household refrigerators", Applied Thermal Engineering, 134: 256-265, 2018.
[5]. Shang P. J., "Effect of pre-start fans on defrosting characteristics of air source heat pump". Refrigeration and Air Conditioning, 9(6):54–59, 2009.
[6]. Hai-Jiao Yin, Zhao Yang, Ai-Qiang Chen, Na Zhang, "Experimental research on a novel cold storage defrost method based on air bypass circulation and electric heater", Energy, Elsevier 37(1): 623-631, 2018.
[7]. Rijing Zhao, Dong Huang, Xueyuan Peng, Lin Qiao, "Comprehensive measures to enhance electric heater defrosting (EHD) performance for household frost-free refrigerators", International Journal of Refrigeration, 111: 1-11, 2019.
[8]. Bansal P., Fothergill D., Fernandes R., "Thermal analysis of the defrost cycle in a domestic freezer". International Journal of Refrigeration; 33:589–99, 2010.
[9]. Hussmann, 2011. http://www.hussmann.com
[10]. Melo C., Knabben F. T., Pereira P. V., "An experimental study on defrost heaters applied to frost-free household refrigerators". Appl ThermEng; 51:239–245, 2013.
[11]. Abdel-Wahed R. M., Hifni M. A., Sherif S. A., "Hot water defrosting of a horizontal flat plate cooling surface", International Journal of Refrigeration, Volume 6, Issue 3, 152-154, 1983.
[12]. KatsuyoshiFukiba, Shou Inoue, Hidetoshi Ohkubo, Tetsuya Sato, "New Defrosting Method Using Jet Impingement for Precooled Turbojet Engines", Journal of Thermo-physics And Heat Transfer, 23: 533-542, 2009.
[13]. NobukiSonobe, KatsuyoshiFukiba, Sota Sato, Yusuke Yoshimura,"Method for defrosting heat exchangers using an air-particle jet", international journal of refrigeration, 60: 261-269, 2015.
[14]. Kazunavi Adachi, Kazushi Saiki and Hiroki Sato, "Suppression of frosting on a metal surface using ultrasonic vibrations", IEEE Ultrasonic Symposium: 759-762, 1998.
[15]. Dong Li, Zhenqian Chen, Mingheng Shi, "Effect of ultrasound on frost formation on a cold flat surface in atmospheric air flow", Experimental Thermal and Fluid Science, 34: 1247-1252, 2010.
[16]. Dingyuan Wang, Tangfei Tao, Guanghua Xu, Ailing Luo, Shaoying Kang, "Experimental study on frosting suppression for a finned-tube evaporator using ultrasonic vibration", Experimental Thermal and Fluid Science, 36: 1-11, 2012.
[17]. Hwan-Jong Choi, Byung-Soon Kim, Donghoon Kang, Kyung Chun Kim, "Defrosting method adopting dual hot gas bypass for an air-to-air heat pump", Applied Energy, 88: 4544-4555, 2011.
[18]. Dong J., Deng S., Jiang Y., Xia L., Yao Y., "An experimental study on defrosting heat supplies and energy consumptions during a reverse cycle defrost operation for an air source heat pump", Applied Thermal Engineering, Volume 37: 380-387, 2012.
[19]. Dennis L. O'Neal N.K. Anand Kurt T. Peterson Steven Schleising, "Determination of the transient response characteristics of the air-source heat pump during the reverse cycle defrost", Energy systems laboratory, 1988.
[20]. Song Mengjie, Liu Shengchun, Deng Shiming, Sun Zhili, Yan Huaxia, "Experimental investigation on reverse cycle defrosting performance improvement for an ASHP unit by evenly adjusting the refrigerant distribution in its outdoor coil", Applied Thermal Engineering, 114: 611-620, 2017.
[21]. J. Alberto Dopazo, Jose Fernandez-Seara, Francisco J. Uhı, Ruben Diz, "Modelling and experimental validation of the hot-gas defrost process of an air-cooled evaporator", International journal of refrigeration, 33: 829-839, 2010.
[22]. Ji Young Jang, Heung Hee Bae, Seung Jun Lee, Man Yeong Ha, "Continuous heating of an air-source heat pump during defrosting and improvement of energy efficiency", Applied Energy, 110: 9-16, 2013.
[23]. Bin Hu, Xiaolin Wang, Feng Cao, Zhilong He, Ziwen Xing, "Experimental analysis of an air-source transcritical CO2 heat pump water heater using the hot gas bypass defrosting method", Applied Thermal Engineering, 71: 528-535, 2014.
[24]. Niederer D. H., "Frosting and Defrosting Effects on Coil Heat Transfer", ASHRAE Transaction 82, no. 1: 467-473, 1976.