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Review on Hot Gas Bypass Defrosting of Evaporator Coil of Heat Pump when Subjected to Low Temperature

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Abstract - *Heat pump is used to transfer heat from source of heat to the heat sink by means of external power. When air source heat pump is operated in low temperature and high humidity atmosphere, problem of frosting of outdoor coil surface arises frequently. Frost accumulates on coil when surface temperature falls below zero-degree temperature, this accumulated frost degrades the performance of heat pump so this frost should be removed for efficient working of heat pump. In past many researchers are attracted towards the study of defrosting of outdoor coil, many of them used reverse cycle method of defrosting. This paper presents a review on defrosting of an outdoor coil of air source water heat pump by using hot gas bypass method. Compatibility of hot gas bypass method over reverse cycle defrosting method is described. Furthermore, effect of defrosting on performance of heat pump is also discussed.*

Key Words: Heat pump, Frost, Evaporator coil, Defrosting, Hot Gas Bypass defrosting, Reverse cycle defrosting

1. INTRODUCTION

Heat pump is a device which transfers heat from low temperature environment to the high temperature environment. Application of heat pump is vast. Major application nowadays used is water heating and space heating. This heat pump performs its operation normally when outdoor temperature is high but when outdoor temperature falls below condensation temperature, moisture present in an environment starts condensing on an evaporator coil. When outdoor temperature further falls below freezing temperature of water, this condensed moisture starts building frost layer around an outdoor/evaporator coil.

Moisture content of an atmosphere is one of the major factors that affects frost formation on an evaporator coil. This is because rate of condensate form from this moisture is directly proportional to humidity ratio difference between saturated frost surface and air vapor. When system works under same surrounding temperature but having higher relative humidity shows higher initial heating but it leads to faster frost formation. **[1]**

Moderate amount of frosting can improve system's performance as it increases surface roughness of coil but if it increases further it will start degrading performance of system as it acts as insulating layer. This increase frost amount starts creating resistance to air flow through coil results in poor heat transfer and hence degrades system performance. **[2]**

Defrosting performance is mainly dependent on density of an occulated frost. Evaporator which is having denser frost structure shows less defrosting time compared to lower density frost. This density of frost is dependent on supercooling degrees. **[3]**

1.1 Defrosting Stages

Defrosting can be done by various methods. Here in this paper we are going to study previous literature available on hot gas bypass defrosting. In this method, hot gas from compressor discharge is bypassed to the outdoor coil i.e. evaporator coil. This heat from hot gas is utilized to heat up the coil which then melts frost hence defrosting is done. This defrosting method is divided into six stages based on action performed. They are a. Preheating, b. Tube frost melting, c. fin frost melting, d. Air presence, e. Tube-Fin water film f. Dry heating.

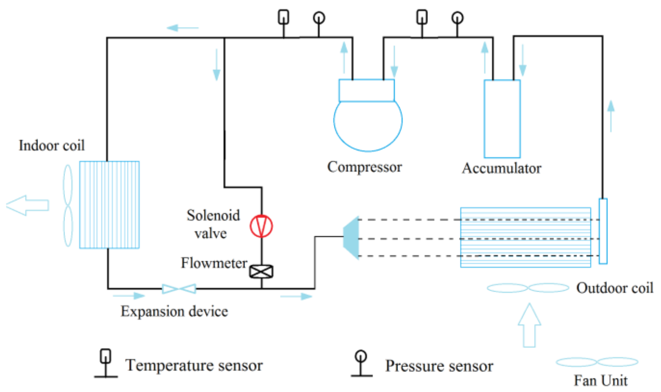

Fig - 1: Schematic diagram of HGBD cycle

Fig-1 shows the schematic diagram of hot gas bypass defrosting method. Setup include basic components of refrigeration cycle- compressor, indoor and outdoor coil, expansion valve and accumulator. In this figure we can see that discharge of hot gas stream is bypassed from compressor outlet and it is connected to outdoor coil inlet via solenoid valve, where it mixes in mixing chamber with cold gas stream coming out from indoor coil and this mixture gives its heat to outdoor coil and helps in defrosting.

2. LITURATURE

Bin hu et al performed experiment on defrosting of an Air source heat pump using Hot Gas Bypass Method. They tested system having operating conditions of 2^{0}C Dry bulb temperature and having relative humidity 80%. First heating cycle last till 81 minutes where air passage between coils almost blocks by accumulated frost. It is seen that most of the visible frost melted in 520sec from when defrosting process has been started. The whole defrosting period is around 600 sec i.e. 10 minutes. During this stage total frost collected is 8.16 kg. The normal operating discharge pressure of compressor is 9.8MPa and when defrosting starts the compressor discharge pressure drops to 7.25Mpa and then gradually returns to 8.72Mpa. The whole defrosting process was classifieds in 3 stages i.e. preheating, frost melting and evaporator heating. Duration of preheating stage is 120s in which most of the energy is used to increase the evaporator coil temperature from which very small amount of energy is used for frost melting. During this 120s in first 60s pressure rapidly increases and in next 60s pressure increases gradually. The system enters into second stage which is frost melting stage. This stage lasts about 400s. in this stage almost entire frost gets melted. All energy supplied during this stage is fully utilized in frost melting also all pressures are maintained at stable level. Then system enters into last stage called evaporator heating stage. In this stage all pressures are comes to its normal values and supplied energy is used for heating of an evaporator coil. Duration of this stage is around 80s. They found that when defrosting process starts, compressor power consumption drops immediately because of decrease in compression ratio. Defrosting efficiency of the HGBD method is ranged from 30 to 40% for the trans-critical CO_2 heat pump water heater. **[4]**

Ji Young Jang et al designed a new high temperature and low-pressure hot gas bypass method for continuous heating called Dual Spray Hot Gas method (DSHG). They found that the most effective flow rate was 50% in this case. They kept surrounding conditions around 2^{0}C DBT and 1^{0}C WBT. They used temperature sensors for initialization and termination of defrosting cycle. This cycle starts when temperature difference between outdoor and evaporator coil is became 8^{0}C and terminated when this difference becomes 5^{0}C. defrostation cycle time is around 10min. during this cycle indoor temperature drops from 43^{0}C to 33^{0}C. They suggested that during this stage reduction in speed of indoor fan is necessary. Found that when compared with reverse cycle defrosting method, the total heating capacity was increased by 17%. During 4 hour of operating duration there were around 4 DSHG and 2 RCD cycles in DSHG cycle the overall input power was increased by 7-8%. The overall energy efficiency was increases by 8% in DSHG compared to RCD. They also found that when outdoor temperature falls below 2^{0}C, the indoor heating supply in the defrosting range may drops below 50% **[5]**

Hwan Jang Choi et al adopted dual hot gas bypass method and compared with other methods. In dual hot gas bypass method bypassed gas from compressor is supplied to inlet and outlet of an evaporator coil. The outdoor conditions set up for this testing was 2^{0}C DBT and 1^{0}C WBT with relative humidity of 84%. They found that when HGBD and RCD method compared with each other, pressure variation in RCD method was higher hence prone to higher mechanical shocks. Duration of preheating stage was found to be 60sec and frost melting stage lasts for 920th sec. They dropped suction pressure to increase the circulation of mass of refrigerant. Defrostation cycles ends when evaporator coil temperature rose above 1^{0}C. At this time bypass solenoid valve was closed. Evaporator heating stage was about next 80sec. After terminating defrost cycle, suction and discharge pressure of compressor was decreased because of vaporization of liquid refrigerant in an accumulator. This takes around 60sec and then in next 20sec discharge pressure of compressor increased sharply. Found that defrosting and recovery time of Hot Gas Bypass method was 1.5 times higher than that of Reverse cycle defrosting method and compare with Dual Hot Gas Bypass it was around 4.88 times shorter than RCD method. COP of defrost cycle was highest for DHBD method then HGBD and then RCD method. It was 1.87 for DHBD,1.78 for HGBD and 1.763W/W for RCD respectively. DHBD method was 13% better energy efficient than RCD method.**[6]**

J. Alberto Dopazo et al performed modelling and experimental validation of hot gas defrost process if an air-cooled evaporator. They developed model and divided defrost process into six stages a. Preheating, b. Tube frost melting, c. fin frost melting, d. Air presence, e. Tube-Fin water film f. Dry heating. Finite difference approach was used to solve this model equation. By experiment they had found that after 3 min melting of frost starts. From 3 min to 9 min highest frost melting rate present. After 15 min evaporator was completely free from frost. From simulation they had found that total defrosting duration was about 14.03min that is 6.4% lower than experimental results. From total supplied energy 29% of energy was used for actual frost melting. From experiment they found that as we increase the mass flow rate of refrigerant the total energy supplied for defrosting increases hence results in decreasing of defrosting time.**[7]**

Bruce I. Nelson optimized hot gas defrosting. He suggested that drain pan and evaporator coil heating is unavoidable and this results in decrease in overall defrosting efficiency. Cole (1989) found that 15 to 20% of total energy was utilized to melt the frost and 80% of energy was lost to surrounding. Defrosting efficiency varies inversely with room temperature, hot gas temperature and duration of defrost. It is directly proportional to the frost thickness and evaporator coil material. Higher the hot gas temperature, higher will be the convective loss. Minimum hot gas temperature for effective defrosting process is around 10^{0}C. Pressure differential in an evaporator coil inlet and outlet to be maintained at 15 to 20psig. Reduction in defrosting time and increasing frost layer thickness can improve defrosting efficiency from 17% to 44%. **[8]**

Ju-Suk Byun et al studied hot gas bypass method for frost growth retardation. For this work they had used 1.5 hp capacity heat pump with R22 as a refrigerant. Ambient conditions set for testing was 2^{0}C DBT and 1^{0}C WBT. They conducted four cases of testing depends on bypassed gas amount. For this they used 0kg/min, 0.2kg/min, 0.3kg/min and 0.4kg/min bypassed gas amount. They carried test for 4 hours for each case. Hot refrigerant gas was directly injected at the inlet of the outdoor coil for 5 minutes at every 20 min interval. They found that when bypassed gas amount was 20% of total gas that is 0.2kg/min, highest value of heating capacity and COP has been achieved by system. In this case COP of system was 20% higher than that of no gas bypassed case. During entire cycle of four hours, the average COP and integrated heating capacity of system was improved by 8.5% and 5.7% respectively. **[9]**

Dang Huang et al compared hot gas bypass method and reverse gas cycle method on air source heat pump with capacity of 55KW. System includes evaporator of two air-cooled coils arranged in V shape. Test conditions used for system testing was 80% RH with maximum fluctuation of 5% and 2.0±0.4^{0}C DBT. When heating capacity of system reduced by 80%, defrosting cycle is started manually. During both defrosting cycles, evaporator fan turned off. When temperature at the outlet of an evaporator coil was rose above 10^{0}C, defrosting cycle turned off manually. During defrost initiation cycle, in RCD cycle pressure variation was 953.97kPa and 406.61kPa and that for Hot Gas Bypass method it was 502.92kPa and 105.74kPa. From this work they found some disadvantages of RCD cycle. In RCD cycle, while defrosting indoor coil acts as evaporator coil and it damages indoor air quality. While shifting from heating to defrosting cycle in RCD, high pressure fluctuations can be seen so system becomes noisy. **[10]**

Zhiyi Wang et al compared Reverse cycle defrosting with cross hot gas bypass defrosting method on system having screw heat pumps of capacity of 359kW. In this experiment they had used two evaporators for testing. While one evaporator is continuing its heating operation and the other one is undergoing defrosting process. From this work they found that suction and discharge pressures are in normal range while switching to defrosting cycle. Defrosting time for cross hot gas defrosting was about 4 min and that of reverse cycle defrosting process was 6 min. Suction and discharge pressure for cross hot gas defrosting process was range between 255 to 347kPa and 1286 to 1718kPa respectively and that for reverse cycle defrosting was 214 to 504kPa and 458 to 1823 kPa hence pressure fluctuations in cross hot gas defrosting was seen to be lower than reverse cycle defrosting. This shows that during defrosting, there was 9.24% of fluctuation in suction pressure and 26.34% of fluctuation in discharge pressure. **[11]**

3. CONCLUSIONS

Heating cycles of defrosting process mainly divided into 3 stages- preheating, frost melting, dry heating. When defrosting process starts, there is decrease in compressor power consumption. The overall defrosting efficiency ranges between 30% to 40%. Dual spray hot gas method is having 17% more heating capacity when compared to reverse cycle defrosting, also it is 8% higher energy efficient than RCD cycle. Defrosting and recovery cycle of hot gas bypass method was 1.5 times higher than RCD cycle and it was around 4.88times more than dual hot gas bypass method. COP of hot gas defrosting cycle is higher than reverse cycle defrosting. As mass flow rate increases, energy supplied for defrosting also increases results in lowering defrosting time. But this adversely effects heating performance of system during defrosting. Out of total supplied energy, around 29% is used for frost melting. Higher frost layer thickness can lead to lower defrosting duration and hence increase in defrosting efficiency up-to 44%. When bypassed gas amount was 20% of total gas flow, highest value of COP and heating capacity was observed. Reverse cycle defrosting shows more disadvantages than hot gas bypass method like system instability at the start of defrosting, noise and also damages indoor air quality. In cross hot gas defrosting, two evaporator coils were used. Alternately those coils undergone defrosting cycle with continuous heating. This reduces pressure fluctuations during start and end of defrosting cycle.

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