Applied Thermal Engineering 59 (2013) 398–404

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Study on the operating performance of cross hot-gas bypass defrosting system for air-to-water screw heat pumps

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HIGHLIGHTS

- Principle of cross hot-gas bypass defrosting method was introduced.
- Thermal parameters' variation was experimentally studied.
- No problem was found for continuous defrosting of the reverse-cycle defrosting.
- Fluctuation of the pressure and temperature is less.

ARTICLE INFO

Article history:
Received 4 November 2012
Accepted 7 June 2013
Available online 19 June 2013

Keywords:
Cross hot-gas bypass defrosting
Air-to-water screw heat pump
Pressure
Temperature
COP

ABSTRACT

Large-scale air-to-water screw heat pumps often operate with substantial frost formation on the air side of evaporators in winter, and the frost layer has to be melted away periodically. This paper presents a defrosting method for air-to-water screw heat pumps, i.e. the cross hot-gas bypass defrosting method, which uses two air heat exchangers for hot air from one air heat exchanger to melt the frost and absorb heat from another heat exchanger through the corresponding four-way reversing valve. The principle and process of this method are illustrated. The dynamic characteristics are experimentally investigated on a 359 kW air-to-water screw heat pump. The discharge temperature of the unit is at the normal range and the pressure varies little. A higher suction pressure is needed to achieve low pressure protection. The time period needed for the combination of heating and defrosting processes is short and it is not necessary to shutdown the compressor for defrosting so that a longer heating time period is possible. The inlet & outlet water temperature can be kept at around 30 °C and high heating COP is obtained. The test results show that the units work as expected.

1. Introduction

Large scale air-to-water heat pumps usually employ screw compressors. There are two main problems with the air-to-water heat pumps: the heating capacity decreases as outdoor air temperature drops and when frost is formed on the outdoor heat exchanger (evaporator) surfaces in humid climate [1–4]. This research project in particular focuses on the latter issue as the frost on the air side of the heat exchanger surface degrades the thermal performance of the air-to-water heat pump by reducing airflow area as a result of the blockage caused by the frost layer. Frost as a thermal insulator is also built up over the evaporator coils, reducing their ability to absorb heat from the outdoor environment [5]. For heat pump applications, the frost needs to be removed periodically to improve the efficiency of the system, which further decreases the energy performance of the system.

Since 1990's, air-to-water heat pumps have been widely used for space heating and hot water production. Some researchers studied the frosting/defrosting problems of the air-to-water heat pumps. A scroll heat pump utilizes a solenoid by-pass valve for by-passing the thermal expansion valve (TEV) during the whole defrosting process to relieve the shutdown problem caused by the low-pressure protection and to decrease the defrosting time [6]. The fan pre-start method is used to prevent shutting down the heat pump on the reverse-cycle defrost operation of an air-to-water heat pump [7]. The dynamic characteristics of a medium air-to-water

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http://dx.doi.org/10.1016/j.applthermaleng.2013.06.007

heat pump with a multi-circuit evaporator controlled by the thermal expansion valve (TEV) under the frosting/defrosting conditions were investigated experimentally [8]. A simulation model of the frosting process in a water heater/chiller unit has been developed and the model has been validated using the experimental data available in open literature [9]. Compared with a medium air-to-water scroll heat pump, an air-to-water screw heat pump has greater capacity. The condenser for heating mode is a water-cooled shell and tube heat exchanger rather than a plate heat exchanger because a much larger air side heat exchanger has sufficient upper space. In a screw heat pump, oil is deliberately injected into the compression chamber to improve and to provide sealing and lubrication by the discharge & suction differential pressure. The discharge pressure falling on the defrosting initiation stage leads to the lack of lubrication and even damage of the compressor owing to lower differential pressure.

In this paper, a cross hot-gas bypass defrosting method is introduced. An air-to-water screw heat pump with a nominal 359 kW cooling capacity is investigated experimentally for verifying this method. Hot air is blown onto one evaporator's coils to melt the frost on the air side heat exchanger, which absorbs heat from another air side heat exchanger for cross hot-gas bypass defrosting. By using the four-way reversing valve, the normal heating operation is reversed. The whole unit can continue the heating process during defrosting. The amenity of the crossing defrosting method is better than the reverse-cycle defrosting (RCD) method due to smaller hot water temperature fluctuation. The cross hot-gas bypass defrosting could overcome the main disadvantages of the RCD method and deserves engineering application potential.

2. The heat pump unit with cross hot-gas bypass defrosting

2.1. Discussions and analysis of the cross hot-gas bypass defrosting process

At present, the air side heat exchanger of large air-to-water screw heat pumps often adopts V-type or inversing M-type coils. Fig. 1 shows the schematics of the prototype air-to-water screw heat pump unit where the original defrosting method is applied. While the unit works in cooling mode, the superheated refrigerant discharged by the screw compressor flows into two systems (multiple systems) to enter the air side heat exchangers separately with one four-way reversing valve, which then flows into each air side heat exchanger and the condenser, where the refrigerant transfers heat to ambient air and becomes a saturated or sub-cooled liquid. The refrigerant then goes through the air side check valve, accumulator, drier filter, water side solenoid valve and cooling thermal expansion valve (TEV), respectively, until flows into the water heat exchanger. While the refrigerant flows through the cooling TEV, the refrigerant expands and partly vaporizes. The chilled refrigerant then passes through the water side heat exchanger, the evaporator, which transfers produces chilled water. Finally, the refrigerant flows back to the compressor's suction port via the four-way reversing valve.

While the unit works in the heating mode, the superheated refrigerant discharged by the compressor flows through the water heat exchanger and the condenser, where refrigerant transfers energy to water and becomes a saturated or sub-cooled liquid. Then, the refrigerant as higher-pressure liquid consecutively flows through the water side check valve, accumulator, drier-filter, air side solenoid valve and heating thermal expansion valve (TEV), respectively. While the refrigerant flows through the heating TEV, the refrigerant expands and partly vaporizes, this chilled refrigerant then passes through the air side heat exchanger and the evaporator, which extracts heat from air to the refrigerant, reducing the temperature of the ambient air. Finally, the refrigerant flows back to the compressor's suction port via the four-way reversing valve.

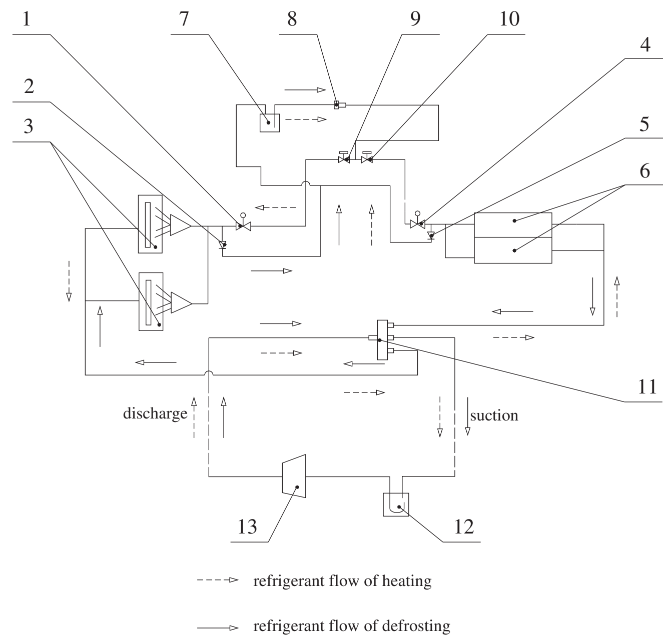

Fig. 1. Flow chart of the original air-to-water screw heat pump. 1 heating TEV, 2 air side check valve, 3 air side heat exchanger, 4 cooling TEV, 5 water side check valve, 6 water side heat exchanger, 7 accumulator, 8 drier filter, 9 air side solenoid valve, 10 water side solenoid valve, 11 four-way reversing valve, 12 receiver, 13 compressor.

The defrosting mode of the RCD is a reversing cycle defrosting process completed simultaneously. By using the four-way reversing valve during the reverse cycle defrosting, the normal heating operation is reversed and the refrigerant flow is reversed. The air side heat exchanger becomes the condenser and the water heat exchanger becomes the evaporator. During the defrosting process, hot gas is blown to the air side heat exchanger for melting the frost. The main feature is that no shutdown of the heat pumps is needed and any one system needs defrosting at the same time so long as its fan is shutdown. When the frost is melted and condensate is drained from the heat exchanger of one system which must wait for the others to complete defrosting and the heat pump switches back to the heating mode for resuming heating operation. The main disadvantage of this defrosting method is of less heating running time owing to the whole completeness of each system.

Fig. 2 shows the schematics of the prototype air-to-water screw heat pump unit where the cross hot-gas bypass defrosting method is applied. The cross hot-gas bypass defrosting unit includes compressor, receiver, accumulator, drier filter, air side solenoid valve, water side solenoid valve and water side heat exchanger as common parts, and at least two air side heat exchangers, two four-way reversing valves, two TEVs, two check valves and solenoid valves. The compressor discharge outlet is connected with both of the four-way reversing valve inlets. The first outlet of the four-way reversing valve is connected with the water heat exchanger refrigerant inlet. The water heat exchanger refrigerant outlet is connected with the accumulator through a check valve. The accumulator is connected with the corresponding air side heat exchanger inlet through drier filter, air side solenoid valve, and water side solenoid valve. The outlet of the air side heat exchanger is connected with the second four-way reversing valve outlet. The third outlet four-way reversing valve is connected with the receiver