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Research Paper

Investigation of air cooler fan start-up delay in liquid refrigerant defrosting system

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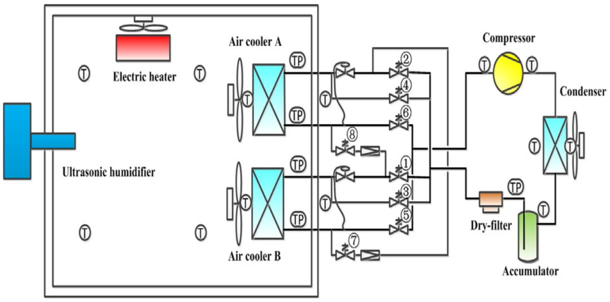
HIGHLIGHTS

- The liquid refrigerant defrosting system was introduced in detail.
- The fluctuation value of the cold storage temperature was controlled.
- The wet compression was prevented effectively.
- The gas return temperature of 10 °C was selected as the trigger signal of defrosting.

GRAPHICAL ABSTRACT

The liquid refrigerant defrosting system makes the liquid refrigerant in the high pressure reservoir to the frost evaporator. The air cooler fan start-up delay can reduce the temperature fluctuation and solve the problem of wet compression.



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ABSTRACT

To prevent problems concerning rapid rise in cold-storage temperature and severe frosting of the compressor inlet in liquid refrigerant defrosting systems (LRDS), a shutter has been installed upstream of the air cooler as well as the motor damper installed downstream. It is also proposed that the air-cooler fan is switched into operation delay after defrosting. Experimental results demonstrate that the best time to switch the fan into operation post defrosting is when the enclosed-space temperature of the air cooler falls in line with the cold-storage temperature. Time delays for the fan were set as 8.6 min, 8.8 min, and 8.9 min corresponding to frost-mass values of 1 kg, 2 kg, and 3 kg, respectively. Through use of the proposed technique, the observed increase in cold-storage temperature was controlled within 5 °C. In addition, gas return temperature of the compressor was observed to be greater compared to that of the air cooler; the compressor, therefore, utilized the available superheat to prevent the occurrence of wet compression.

1. Introduction

Fin-tube air coolers are often employed in miniature cold-storage systems. When its surface temperature falls below the dew-point temperature and 0 °C, the air cooler demonstrates frosting on its surface [1]. This surface-frosting phenomenon tends to increase fin thickness as well as reduce heat-transfer performance and evaporation temperature, thereby causing the cooling capacity will degrade significantly [2]. At

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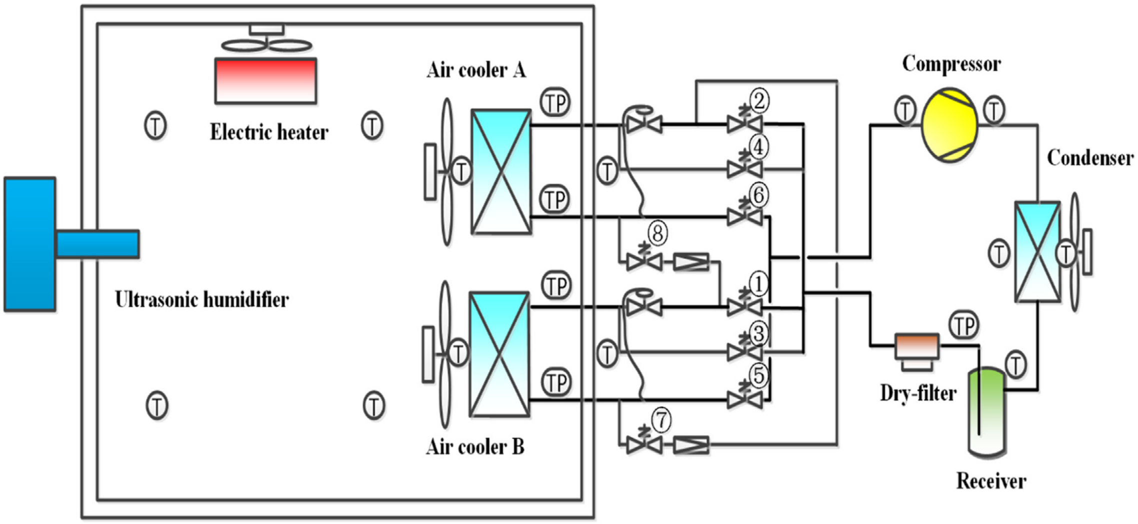

Fig. 1. Schematic of LRDS.

the same time, frost formation blocks the airflow, increases power consumption, and jeopardizes COP of the entire system [3]. Exploring a reasonable defrosting technique is, therefore, crucial in the context of researches performed concerning refrigeration systems. Extant studies concerning defrosting techniques have mostly focused on two aspects—passive defrosting and active defrosting [4].

Passive defrosting explores surface morphologies to delay and/or inhibit frost formation. Huang et al. investigated frosting and defrosting performance of three heat-exchanger structures comprising flat, wavy, and louver fins [3]. Liu et al. applied chemical coating on the heat-exchanger surface, to render the frost layer formed on the heat-exchanger loose and easy to remove [5]. Ning et al. compared different shapes of freezing water droplets and observed the defrosting process on hydrophilic and hydrophobic surfaces [6]. However, these passive defrosting methods are difficult for use in actual production applications owing mainly to poor durability and difficulties involved with use over long periods of time.

Active defrosting requires additional power input, which could be provided in one of the following methods.

(1) Hot-gas defrosting is the most widely used defrosting technique. The discharge pressure is reduced to 0.6–0.8 MPa by means of a regulating valve. Subsequently, the refrigerant is made to flow through the defrosting air cooler [7–9]. When employing air-source heat pumps, the method is often referred to as reversed cycle hot-gas defrosting [10–12]. Qiao et al. [13] proposed a five-stage hot-gas defrosting model to provide a solution to complex system dynamics of air-source heat pumps over the frosting/defrosting cycles. Their method was characterized by uniform heating and fast defrosting. However, the refrigerant had to be stored in a liquid receiver for a long time after defrosting. Consequently, optimum utilization of the subcooling process was not realized, and the compressor was observed to be prone to perform wet compression.
(2) Electric-heat defrosting involves the tube is heated outside the tube by mean of an external resistance wire [14,15]. The method offers advantages, such as fast defrosting, simple pipeline designs, and easy to realize automatic control. However, the overall power consumption is rather large, and temperature rise within the cold storage is also high. Additionally, heating of the evaporator is uneven and local temperature rise is high. Further, owing to differences between thermal-expansion coefficients of aluminum fins and copper tube, the fins tend to easily become loose, thereby reducing their overall efficiency.
(3) Saline water defrosting technique serves to defrost the outer surface of an evaporator by means of a pump or sprinkler. It is considered to be a rather fast and low-cost defrosting technique. However, the meltwater drainage in this technique is not in time. This increases the rating of frosting for second time.
(4) On–off defrosting (or air defrosting) involves installation of an air cooler within a closed space, and the operates via opening and closing of an electrically operated door to achieve refrigeration and defrosting. The defrosting method utilizes heat from the natural environment to save energy. However, it is only useful for application in regions that observe high temperatures throughout the year. Further, use of this technique requires large initial investment.
(5) In addition, there exist a few uncommon defrosting methods, such as ultrasonic defrosting [16,17], electro-hydrodynamic defrosting [18], and others [19,20], wherein the effect of continuous defrosting is poor. As such, these methods can only be utilized in conjunction with other defrosting techniques.

Liquid refrigeration defrosting systems (LRDS) offer such advantages as continuous refrigeration, small temperature fluctuations within cold-storage, and effective recovery of frost-cooling energy. LRDS, however, has not yet been widely employed owing to the inherent rapid rise in cold-storage temperature post completion of the defrosting process in addition to the severe frosting observed at the compressor inlet. Extant studies have reported no effective solution to the above problems. This study proposes the method of introducing air-cooler fan start-up delay upon completion of the defrosting process, thereby determining the optimum delay duration. In addition, the study also suggests improvements in the air-cooler structure to facilitate effective control over rising cold-storage temperatures, thereby causing optimization of the entire system.

2. LRDS description

Fig. 1 depicts an LRDS schematic, wherein the system comprises two air coolers, two thermal expansion valves (TEVs), two check valves (CVs), eight solenoid valves (SVs) and a compression condensing unit. It must be noted that the compressor continues to operate when switching between the refrigeration and defrosting modes. The switching operation is realized by changing refrigerant-flow direction in the system via use of the eight SVs. In the refrigeration mode, the two air coolers are connected in parallel to perform simultaneous refrigeration. By opening the ①, ②, ⑤, and ⑥ SVs, compressor discharge can successively be made to pass through the condenser, high-pressure reservoir, and filter drier. Refrigerant flow is divided into two streams—one stream flows back to