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Analysis of Condensing Temperature Set Point of Air-Cooled Refrigeration System with an Electronic Expansion Valve

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Abstract. A method to determine the condensing temperature set point of air-cooled refrigeration system with an electronic expansion valve was discussed in this paper. This set point is fixed for a specific system and is based on the flow characteristic of the installed electronic expansion valve in variant opening and pressure drop. As common sense, at constant differential between condensing pressure and evaporating pressure, larger opening of expansion valve allows more refrigerant flowing through the expansion valve into evaporator. This feature offers an opportunity to lower the condensing temperature via increasing opening of expansion valve to enhance refrigeration efficiency and in the same time designed cooling capacity can be maintained at low ambient temperature. In this case it is supposed that the installed electronic expansion valve's capacity was larger than the evaporator's, and in fact that occurs frequently in refrigeration system designing. The benefits of this method could include: the capacity of electronic expansion valve is fully utilized, the refrigeration system will operate at a lower condensing pressure and the power consumption of compressor can decrease, hence the improvement of system efficiency is predictable.

Introduction

Industrial refrigeration systems are widely used for food processing, food preservation, chemical production, and numerous other special applications in the construction and manufacturing industries, many of which are air-cooled system. Because of the need for cooling year round industrial refrigeration systems are significantly different from air conditioning refrigeration equipments that only operate on summer days. Many air-cooled industrial refrigeration systems need to work in variant ambient temperature conditions, including the case of low outdoor temperature. In principle, for refrigeration systems lower condensing pressure means higher efficiency. Air-cooled condenser are usually designed with a 15℃ difference between condensing temperature and outdoor temperature. When the outdoor temperature drops, the condensing temperature will also decrease if the condensing fan's speed maintains the same. Some researchers have stated the opportunity to lower the condensing temperature to improve the operating efficiency of air-cooled refrigeration systems and made significant achievements[1][2]. While some researchers also stated that the condensing temperature should be above a minimum value in order to ensure that lubrication oil is properly returned to compressors and to ensure that thermostatic expansion valves work correctly at a high differential between the evaporating pressure and condensing pressure[2] [3]. However, this limit is inapplicable to chillers with electronic expansion valves, which still operate properly even when the condensing temperature drops to 10℃ for an evaporating temperature of 5℃ [4]. Yu FW and Chan KT also discussed the method of resetting the set point of condensing temperature which was related with the outdoor temperature when outdoor temperature and cool load condition changed [5].

However in fact, for a specific cooling load of a refrigeration system with electronic expansion valve, there also should be a limited minimum value of condensing temperature because the too low differential between the evaporating pressure and condensing pressure would prevent adequate refrigerant into evaporator even if the opening of electronic expansion valve exceed to the maximum.

For industrial refrigeration equipments the cooling load generally change little compared with air-conditioning refrigeration equipment. So as industrial refrigeration considered the method of determination the set point of condensing pressure (temperature) should be based on the flow characteristic of electronic expansion valve and the cooling load, which usually refers to the designed evaporator capacity, rather than the ambient temperature. Such a method is proposed in the following sections of this paper. How to achieve the set value of the condensing temperature will not be discussed here because for different condensers the methods to control condensing temperature are not unique and discussions on this problem can be found in many references.

Existing Methods to Determine Condensing Temperature Set Point

Many researchers have proposed several methods for determining the condensing temperature set point of air-cooled refrigeration system. Most of these methods can be divided into two categories:

Condensing Temperature Set Point Varies With the Changing of Outdoor Temperature. In this case, Yu FW and Chan KT's equation might be a typical example [5]. The algorithm was expressed by (1), where C is an adjustable parameter in a range of 5–10℃ according to a local outdoor temperature of 10–35℃. It was also stressed that the lowest T_{cdsp} should be set at 20℃ in order to meet the requirement of compressor lubrication.

$$T_{cdsp} = \begin{cases} T_{cdae} + C & for (20 - C) \le T_{cdae} \\ 20 & otherwise \end{cases} \tag{1}$$

- T_{cdsp}: set point of condensing temperature, ℃
- T_{cdae}: temperature of air entering the condenser or outdoor temperature, ℃

This algorithm was proved to be effective to improve chiller efficiency in that operating condition. However the flow characteristic and capacity of electronic expansion valve was not included in the discussion, while those two factors should be important for refrigeration systems' efficiency when condensing temperature changes.

Condensing Temperature Set Point is Determined "Simply" Based on Experiences. However, the word "simply" sometimes should be described as "in hasty". The set point of condensing temperature usually was an experience value from similar equipments. During operation, this setting generally does not lead to a device failure, but an inefficient system. Therefore, this method is wildly used just because of "simple" while it is not acceptable in consideration of energy efficiency.

Method Based on Flow Characteristic and Cooling Load

The use of electronic expansion valve has become increasingly popular because of its broad tuning range and precise control effect. This accurately controlling range is usually 10%–100% for electronic expansion valve [6] while 50%–120% for thermal expansion valve [7]. This method of determining condensing temperature set point is applicable for air-cooled refrigeration system with electronic expansion valve but not thermal expansion valve. In order to explain the principle of this method based on flow characteristic and load more clearly, a sample refrigeration system is introduced. Table I. summarizes the general information about the sample system. The maximum capacity of expansion valve refers to that when the expansion valve opening is 100%. The detail of the capacity range, or flow characteristic, at various condensing temperatures and openings about this valve refers to Fig. 1. It is necessary to point out that the data about electronic expansion valve's capacity at partly opening, which suppliers usually do not provide, was calculated from (2) [8] with some simplification that does not prejudice to the explanation of principle of the method.

$$q_m = C_d A \sqrt{2\rho(p_1 - p_2)} \tag{2}$$

- q_m: refrigerant mass flow, (kg/s)
- C_d: flow coefficient

- A: flow area, (m^2)
- ρ: density of refrigerant entering expansion valve (kg/m^3)
- p_1: inlet pressure of expansion valve (Pa)
- P_2: outlet pressure of expansion valve (Pa)

Table 1 Details of the sample system studied

Elements	Description
Refrigerant type	R404A
Evaporator	With a designed capacity of 2.3 kW when evaporating temperature is –15℃ and condensing temperature is 50℃.
Compressor	Supposed well match with the cooling load and can maintain a constant evaporating temperature of –15℃ via variable frequency drive.
Condenser	Direct air-cooled, finned coils with a speed variable fan.
Expansion valve	Electronic expansion valve with a maximum capacity of 4.6 kW at the condensing temperature of 50℃(without subcooled) and evaporating temperature of –15℃. e.g. type EX2-003 from Emerson.

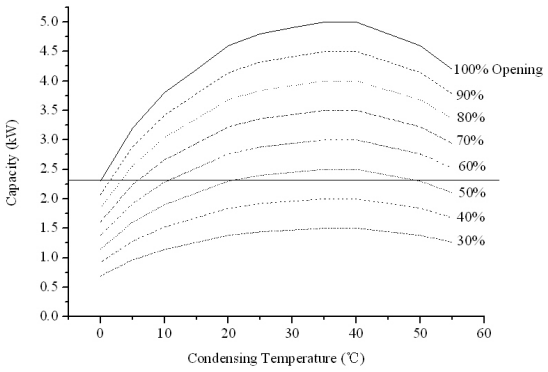

Fig.1 Capacity of electroinc expansion valve EX2-003 (at evaporating temperature of –15℃)

According to Fig. 1, drawing a horizontal line of 2.3 kW, the opening of expansion valve will be 50% if the evaporating load is 2.3 kW, evaporating temperature is –15℃ and condensing temperature is 50℃. When outdoor temperature drops there will be an opportunity to save power consumption of compressor via lower the condensing temperature. Supposing the evaporating load remains unchanged for industrial refrigeration process, the opening of expansion valve will first decrease and then increase with the dropping of condensing temperature. If the ambient temperature is low enough, the lowest set point of condensing temperature can be as low as 0℃ in theory when the opening of expansion valve is 100%. Therefore, in this case the lowest condensing temperature is only limited by the requirement of compressor lubrication.

If the electronic expansion valve is replaced by EX2-002, a smaller type of the same serious, with a capacity of 2.7 kW at condensing temperature of 50 and evaporating temperature is –15℃, the limit of lowest condensing temperature will change. Fig. 2 shows the capacity range of the smaller expansion valve EX2-002.

Similarly a horizontal line of 2.3 kW was drawn on Fig. 2. For the latter system, the lowest condensing temperature must be above 12℃ to maintain the cooling capacity for evaporating load because at this time the opening of electronic expansion valve has exceed the maximum 100%.

But if the cooling load of evaporator decreases to e.g. 1.8 kW, then the limit of condensing temperature will be decrease to about 5℃ without regard to requirement of compressor. So the condensing temperature set point in low outdoor temperature for air-cooled refrigeration system is limited by flow characteristic of expansion valve, cooling load of evaporator and lubrication requirement of compressor at the same time, and the final set point should be the highest of those.

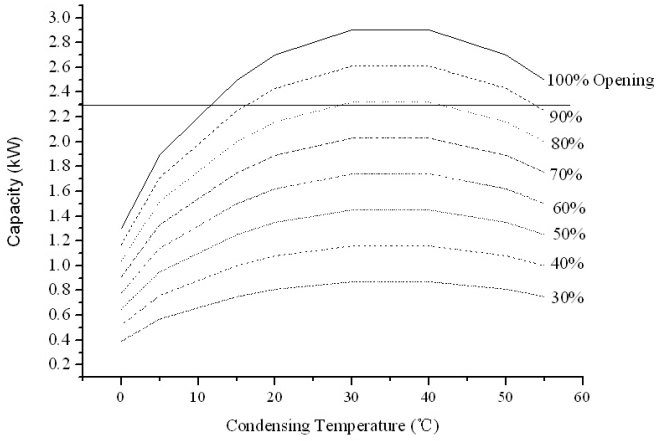

Fig. 2 Capacity of electroinc expansion valve EX2-002 (at evaporating temperature of –15℃)

Conclusion

This paper states that the flow characteristic of electronic expansion valve, the cooling load of evaporator should be considered as well as the requirement of compressor lubrication when determining condensing temperature set point of an air-cooled refrigeration system, while the local ambient temperature should be taken into account when the power consumption of condensing fan significantly impacts on system's efficiency.

Under the premise of lubricating oil properly returning to compressor, the use of electronic expansion valve allows a lower set point of condensing temperature because of the broader tuning range and more precise control effect of electronic expansion valve than thermal expansion valve. Determining the condensing temperature set point should be carried out after the system design has completed and the data of electronic expansion valve's flow characteristic is necessary. Use a larger electronic expansion valve may allow a lower condensing temperature setting. Further more studies are necessary to find whether the set point from this method was applicable in load variable conditions and whether resetting of the condensing temperature set point was necessary.

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