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Adding a Bypass to Ensure the Chemical Plant Production

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Abstract

The chilling output of the chiller fluctuated according to the chilling load. When it dropped down below a certain value, the temperature of the supply chilled water flowing out of the chiller would drop down too much. And this would result the chiller being shut down abnormally, because of its low temperature protection. Any this shutdown of the chiller endangered the production continuity and security, and caused a certain economic losses. A bypass, which was from the outlet of the chiller's condenser to the chilled water filter inlet, was added to the chilling system. Through this bypass, some cooling water was introduced from the cooling water circulation into the chilled water circulation. Then the temperature of the supply chilled water flowing out of the chiller was promoted. With experiments, and by the aid of thermodynamics analysis, the amount of introduced cooling water, which could be introduced to promote the supply chilled water temperature for maintaining the chiller running normally, was researched. Ultimately, a certain amount of introduced cooling water, at which the chiller would no longer stop abnormally at any chilling load, was determined. And the energy lose caused by the introduced cooling water was less than 5 percent the rated output of the chiller. Compared with the chiller rated output, this energy lose was so small that it could be neglected.

Keywords: bypass, chemical plant, chilling load, chilling output, production continuity

1. Introduction

Chilling system was generally applied to many chemical plants for cooling their production processes, and their productions were often fluctuating. The chilling load (i.e., the required chilling load for production processes) varied much according to its production fluctuation. This caused the chilling output of the chiller varied much too. The chilling output could automatically adjust to fit the chilling load in an available range. But, when the chilling load was too small, the chiller could no longer adjust to fit it. The temperature of the supply chilled water flowing out of the chiller, which was monitored to prevent the chiller being frozen, dropped down and down, until to that of the chiller's low temperature protection. Then the chiller would be shut down abnormally, and restarted up in many minutes. Therefore, the security and continuity of the production were seriously affected, and the corresponding economic losses occurred at the same time. In a chemical plant, this case often occurred. In order to solve this problem, a bypass was added to the chilling system. This bypass was from the outlet of the chiller's condenser to the chilled water filter inlet. Through this bypass, some cooling water could be introduced to the chilled water circulation, to promote the supply chilled water temperature for maintaining the chiller running normally, even if the chilling load drop down below its available adjusting range.

This method of using bypass in the system was widely applied to engineering practice. In the refrigerating engineering field, Ma & Wang (2011) developed bypass check valve to enhance the overall system performance; Choi, B. Kim, Kang, & K. Kim (2011), and J. Kim, Choi, & K. Kim (2015) applied the bypass for defrosting in the heat pump; Tuo & Hrnjak (2012) showed that flash gas bypass method could improve refrigerant distribution and reduce pressure drop on refrigerant side in the mobile air conditioning system; Byun, Lee, & Jeon (2008) discovered that the hot gas bypass method was useful for retarding the formation and growth of frost at the outdoor coil and for improving the performance of the air source heat pump; Tso, Wong, Jolly, & Ng (2001) conducted simulation studies using a mathematical model to compare the performance of the hot-gas by-pass control and the suction modulation control in refrigerated shipping containers, their results showed that the suction modulation control strategy was the more energy efficient of the two; Elbel & Hrnjak (2004) found that the performance of transcritical R744 systems with direct expansion could be significantly improved by implementing a flash gas bypass; it was demonstrated by Wang, Han, Shi,

& Li (2012) that suction gas bypass was an effective regulating method of scroll compressor, and it could reduce the inner compression loss under over compression conditions and largely decrease the heating/cooling capacity of the refrigeration system; Tuo & Hrnjak (2014) used flash gas bypass for vapor-liquid separation in vapor compression systems; Huang, Li, & Yuan (2009) suggested that the hot-gas bypass defrosting could overcome the main disadvantages of the reverse-cycle defrosting method; Ding, Zhang, & Lu (2004) proved bypass two-circuit cycle freezers with one compressor were more efficient than two-evaporator in series cycle freezers in reducing the greenhouse gas emissions.

In the other engineering field, the bypass method also applied widely to the practice. For instance, W. Chen, H. Chen, Shi, Xue, Chong, & Yan (2016) installed a bypass in the low pressure district of the ejector to enhance its capacity; Zaccaria & Traverso (2016) regarded that the cold air bypass could be used for thermal management of the fuel cell. Luo, Xia, & Sun (2013) promised that bypass adjustment could improve operational efficiency and reduce heat exchanger network costs; W. Wang, X. Wang, & Liu (2011) used the bypass system for intermediate pressure start-up of a turbine unit; Yang, Pu, Wong, & Moore (2009) applied by-pass valve to reduce the overshoot and allow some exhaust compressed air to be reused in the pneumatic drive, they showed that a 12-28% saving in energy use could be acquired and meanwhile the position accuracy is maintained, compared with the traditional control of the motion of the asymmetric cylinder; research by Yoon, J. Lee, S. Lee, Tak, M. Kim, K. Kim, & Park (2013) supported that the bypass flow distribution was reduced throughout the entire core regions in block type very high temperature reactor (VHTR), and the bypass flow ratios at the inlet and the outlet were reduced by 36.19% and 14.66%, respectively; Ren & He (2009) designed a continuous circulating valve, in which a bypass was applied, to reduce oil drilling pipe accidents such as sticking and so on.

In this chemical plant, with experiments, and by the aid of thermodynamics analysis, the amount of introduced cooling water was researched. Ultimately, a certain amount of introduced cooling water, at which the chiller would no longer stop abnormally at any chilling load, was determined. And the energy lose caused by the introduced cooling water was less than 5 percent the rated output of the chiller at this introduced cooling water amount. Compared with the chiller rated output, this energy lose was so small that it could be neglected. At the same time, the security and continuity of its production were ensured, and the corresponding economic losses were avoided.

2. Case Study

The chilling system of this plant was composed of cooling water and chilled water circulations. The Cooling water circulation consisted of cooling tower, cooling water tank, filter, cooling water pump, and condenser of the chiller, etc. The chilled water circulation consisted of expansion tank, distributor, collector, filter, chilled water pump, evaporator of the chiller, as well as the production processes within which the chilling load was needed. In addition, the outflow and inflow of the chiller were called as the supply and return water, respectively. And the supply and return water pipes were shown with solid lines and dashed lines, respectively, as shown in figure 1.

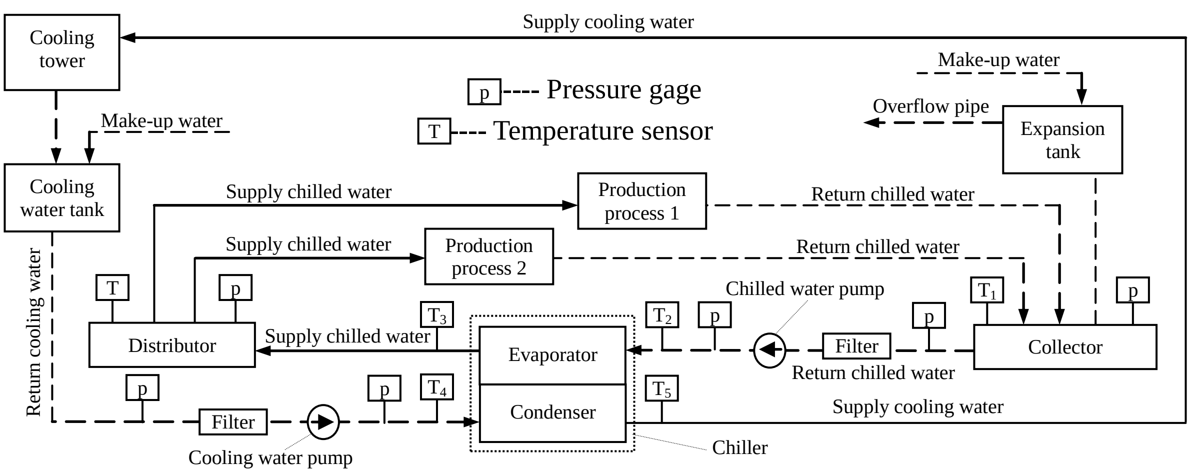

Figure1. Process of the chilling system

The design running data of the chilling system was shown in table 1. The chiller rated output was 220 kw. The temperature of the return chilled water t_1 was 10℃, that of the chiller condenser's inflow water t_2 was equal to t_1 in this system, and that of the supply chilled water t_3 was 5℃. They were measured by thermometers T_1, T_2 and T_3, respectively. The temperature of the return cooling water t_4 was 30℃, and that of the supply cooling water t_5 was 35℃. They were measured by thermometer T_4 and T_5, respectively.

Table 1. Design running data of the chilling system

Chilling output, O		Chilling load, L		Chilled water temperature		Cooling water temperature	
Rated, O_r, kw	Minimum, O_{min}, kw	Maximum, L_{max}, kw	Minimum, L_{min}, kw	Return, t_1, ℃	Supply, t_3, ℃	Return, t_4, ℃	Supply, t_5, ℃
220	66	175	30	10	5	30	35

Note: the return and supply mean the return and supply water temperatures, respectively.

The chilling output of the chiller could be automatically adjusted from 30% to 100% its rated output, i.e., from 66 kw to 220 kw; and the chilling load was fluctuating from 30 kw to 175 kw according to the production. Generally, the chilling output was nearly equal to the chilling load during production operations, because all the chilled water pipes and related equipments were thermally insulated. In fact, the chilling load often fluctuated to the value below 66 kw, even to 30 kw, while the chilling output could not drop down to that one. Then the chilling system would be running with 66 kw of the chilling output and with less than 66 kw of the chilling load, the supply chilled water temperature would be dropping down continuously, until to 3℃ and causing the chiller shutdown. This case often occurred. Any shutdown would make the chiller restart up in 20 minutes according to its procedural protection. The security and continuity of production were affected, and some economic losses occurred.

3. Research Method

In order to ensure the security and continuity of production, a bypass, which was from the outlet of the chiller's condenser to the chilled water filter inlet, was added to the chilling system, as shown with bold solid lines in figure 2. Through this bypass, some cooling water could be introduced into the chilled water circulation, to ensure the supply chilled water temperature not dropping down to 3℃, and maintain the chiller running continuously.

A modulating valve and a flow meter were installed on the bypass pipe, to modulate the introduced cooling water flow rates. With experiments, and by the aid of thermodynamics analysis, the amount of the introduced cooling water for maintaining the chiller running normally was researched.

When the supply chilled water temperature t_3 dropped down to 3℃, the chiller would shut down because of its procedural protection. During any experiment, when it dropped down to 3.5℃, it was regarded that this experiment failed.

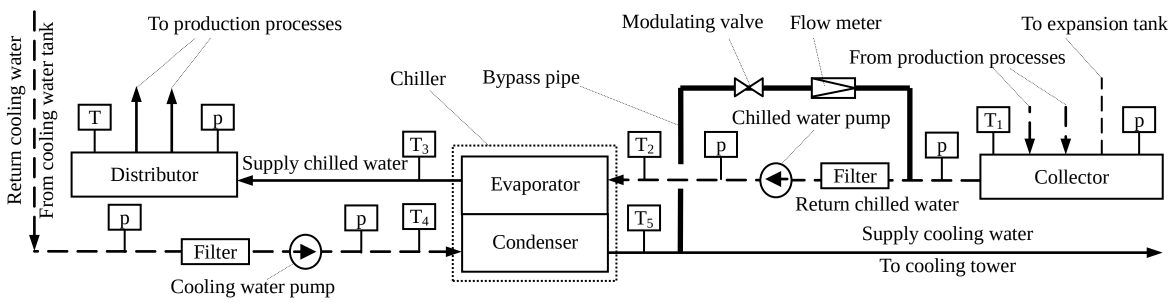

Figure 2. Process of the chilling system with bypass

On the other hand, when the supply chilled water temperature t_3 was beyond 8℃, it would dissatisfy production operation. During any experiment, when it rose up to 7.5℃, it was regarded that this experiment failed.

4. Results and Discussion

4.1 Thermodynamics Analysis

Because all the pipes and equipments, through which chilled water ran, were covered with thermal insulation layers, the heat lose could be neglected. Based on principle of energy balance according to the heat transfer edited by Yang & Tao (2006), the chilling output of the chiller with introduced cooling water can be expressed as:

$$O = \rho c \delta Q (t_5 - t_1) + \rho c (Q + \delta Q)(t_1 - t_3) \quad (1)$$

Here: O means the chilling output of the chiller, kw; ρ means the density of water, kg/L; c means the heat capacity of the water, kJ/(kg·℃); δQ means the introduced cooling water amount, L/s; t_5 means the supply cooling water temperature, ℃; t_1 means the return chilled water temperature, ℃; t_3 means the supply chilled water temperature, ℃; Q means the amount of chilled circulating water, L/s.

In the right side of equation (1), the first item denotes the load for chilling the introduced cooling water from temperature t_5 to t_1, the second item denotes the load for chilling both the introduced cooling water and chilled circulating water from temperature t_1 to t_3. At the same time, the corresponding chilling load for the production operation was required as below:

$$L = \rho c Q(t_1 - t_3) \tag{2}$$

Here: L means the chilling load for the production operation, kw. Solving equations (1) and (2), the introduced cooling water amount can be obtained as below:

$$\delta Q = \frac{O - L}{\rho c(t_5 - t_3)} \tag{3}$$

Define the chilling load ratio as:

$$\alpha = \frac{L}{O_r} \tag{4}$$

Here: α means the chilling load ratio; O_r means the chiller rated output, kw. And name the chilling output ratio as:

$$\beta = \frac{O}{O_r} \tag{5}$$

Here: β means the chilling output ratio. Then the introduced cooling water amount δQ can be expressed as:

$$\delta Q = \frac{O_r}{\rho c(t_5 - t_3)}(\beta - \alpha) \tag{6}$$

According to equation (6), the chilling output ratio β might be written as follow:

$$\beta = \frac{\rho c(t_5 - t_3)\delta Q}{O_r} + \alpha \tag{7}$$

Because ρ, c and O_r are almost constant values, the chilling output ratio β relates to t_3, t_5 and α.

4.2 Experiment Results

Experiment results were shown in figure 3 and figure 4, the chilling output ratio β were obtained according equation (7). And all those experiment results could ensure non-stop of the chiller and continuity of the production.

At the chilling load of 30 kw, i.e., α = 0.14, it was shown in figure 3 that:

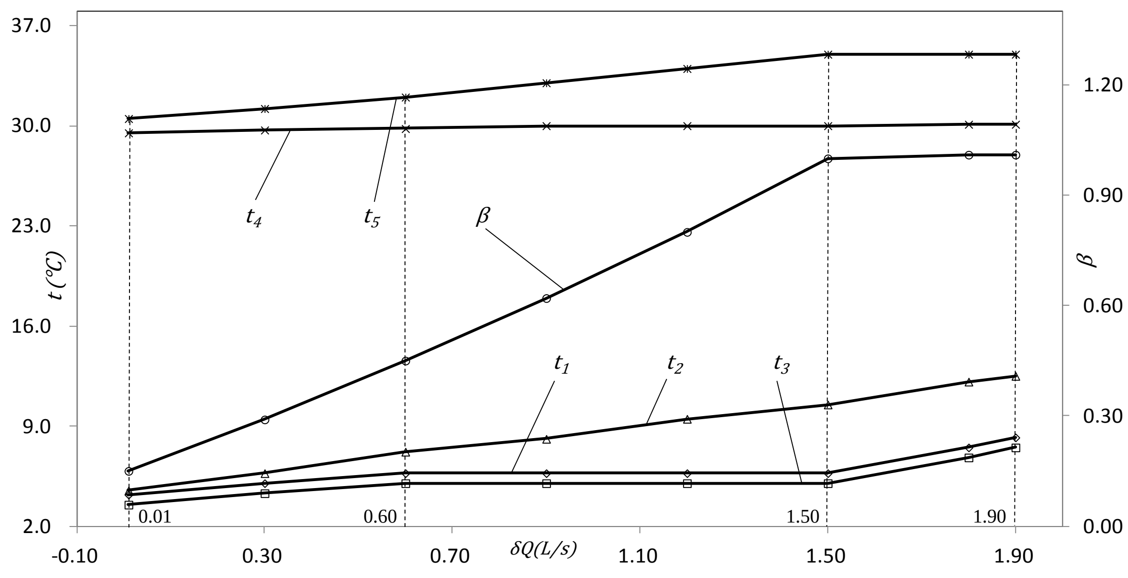

Figure 3. Experiment results while α = 0.14

The minimum introduced cooling water amount was 0.01L/s, while the t_3 = 3.5℃ and the β = 0.15; and the maximum amount was 1.90L/s, while the t_3 = 7.5℃ and the β =1.00.

In the range between 0.6L/s and 1.5L/s of the δQ, the t_3 stayed the same with the δQ increasing, because the chiller could automatic adjust its output to maintain t_3 at 5℃; in the other ranges, the t_3 was rising with the δQ. The change trend of the t_1 was the same as the t_3, because the chilling load was not changed, i.e., α = 0.14. The t_2 was always rising with the δQ.

The t_4 came nearer to 30℃, because it was determined by its environment wet bulb temperature; the t_5 and β were rising before 1.50L/s of the δQ. After 1.5L/s of the δQ, the t_5 and β rose up to 35℃ and 1.00, and stayed the sames, respectively.

At the chilling load of 175 kw, i.e., α = 0.80, it was shown in figure 4 that:

The minimum introduced cooling water amount was 0.00L/s, i.e., no cooling water introduced, while the t_3 = 5.0℃ and the β = 0.80; and the maximum amount was 0.42L/s, while the t_3 = 7.5℃ and the β =1.00.

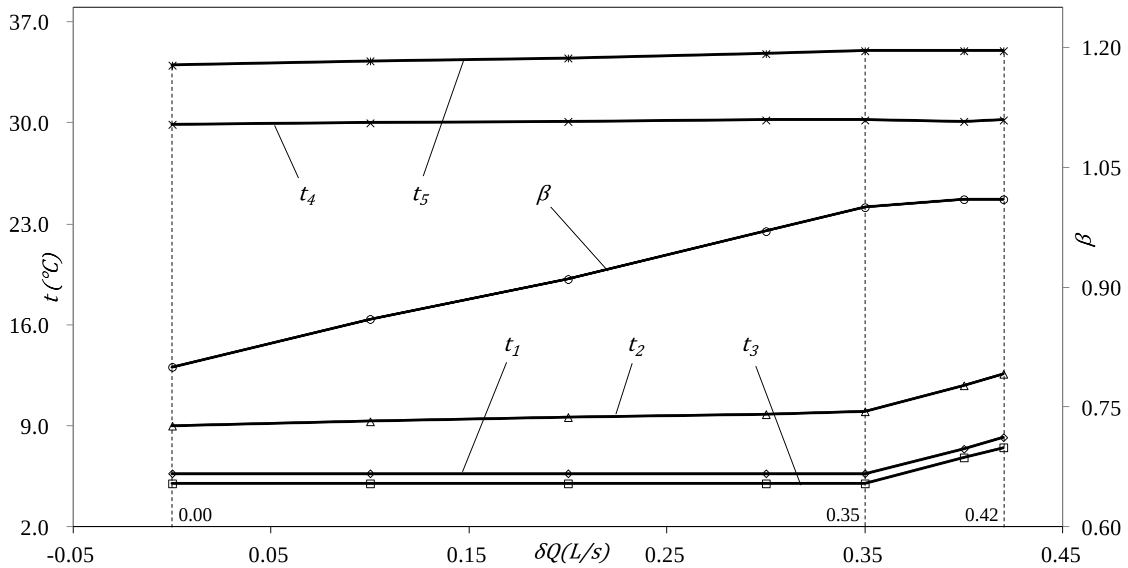

Figure 4. Experiment results while α = 0.80

The t_3 stayed the same because the chiller could automatic adjust its output to keep it at 5℃, until it began to rise after 0.35L/s of the δQ. The change trend of the t_1 was the same as the t_3, because the chilling load was not changed, i.e., α = 0.80. The t_2 was rising with the δQ, yet it was rising more sharply after 0.35L/s of the δQ.

The t_4 came nearer to 30℃, because it was determined by its environment wet bulb temperature. The t_5 and β were rising, until they rose up to 35℃ and 1.00 and stayed the sames after 0.35L/s of the δQ, respectively.

From figure 3 and figure 4, it could be obtained that the δQ between 0.01L/s and 0.42L/s could satisfy any chilling load. Considering the parameter fluctuation and energy conservation, the δQ was controlled at 0.10L/s. At this amount, the energy lose caused by the introduced cooling water was nearly 10kw, which was less than 5% the rated output of the chiller. Compared with the chiller rated output, this energy lose was so small that it could be neglected.

At the same time, because the chiller would no longer shut down abnormally, the security and continuity of the production were ensured, and the corresponding economic losses were avoided.

5. Conclusion

In some chemical plants, the production often fluctuated much, caused the chiller stopped abnormally. This seriously endangered the production. In order to keep the chiller running normally, bypass was applied to introduce some cooling water into chilled water circulation. Thermodynamics analysis and experiment study were conducted to determine the introduced amount. The chilled and cooling water temperatures and the chilling output ratio, which changed with the introduced cooling water amount, were obtained. Ultimately, a certain amount of introduced cooling water, at which the chiller would no longer stop abnormally at any chilling load, was determined. And the energy lose caused by the introduced cooling water was less than 5% the rated output of the chiller at this amount.

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