Comparative Analysis of Final-Effect Secondary Steam Cooling Methods in Evaporation Stations of Alumina Plants

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Abstract

This paper conducts an in-depth study on the cooling methods for the final effect secondary steam in evaporation units of alumina refineries, detailing the process principles and technical characteristics of traditional direct cooling and the new indirect cooling using evaporative condensers. Taking a single-train evaporation unit with a water evaporation capacity of 500 t/h in an alumina project as an example, a systematic comparative analysis is performed from multiple perspectives, including technical parameters, construction footprint, circulating water consumption, configuration methods, operational power consumption, investment, and economic benefits. The research shows that while the traditional direct cooling method offers advantages such as fast heat transfer, high vacuum, and lower investment, it suffers from large footprint requirements for the circulating water station and high operational power consumption. In contrast, the new evaporative condenser's indirect cooling method demonstrates significant advantages in saving fresh water, reducing footprint, lowering operational power consumption, and cutting production costs. However, it has drawbacks such as higher equipment investment, relatively lower vacuum, and difficulties in maintaining the heat exchange core. The findings of this study provide important reference for alumina refineries to rationally select the cooling method for the final effect secondary steam.

Keywords: Evaporation unit, Final-effect secondary steam, Direct cooling, Indirect cooling, Evaporative condenser.

1. Introduction

The integrated falling-film evaporators widely used in the alumina industry were initially introduced based on Kestner technology. After years of technological upgrades and improvements by domestic alumina refineries, the number of evaporation effects for sodium aluminate solution has now exceeded six (with most newly built alumina refineries adopting seven effects), and the steam-water ratio has dropped to below 0.2 t/t H_2O, achieving significant energy-saving effects. The 7-effect falling-film evaporator still utilizes new steam as the heat source, where new steam is introduced into the first effect, and the secondary steam from each effect heats the next effect's green liquor. The secondary steam from the final effect (7^{th} effect) is cooled using circulating cooling water, and non-condensable gases are vented to the atmosphere via vacuum pumps.

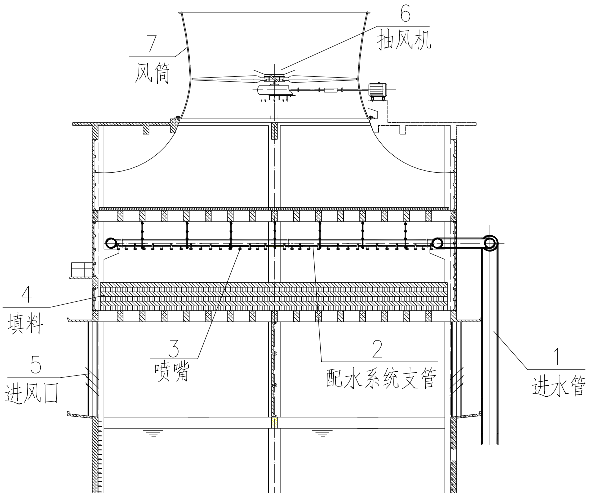
The traditional cooling method for the final-effect secondary steam is direct cooling, where the final-effect secondary steam directly exchanges heat with circulating water in a water cooler, and the condensed secondary steam water returns to the circulating water station along with the circulating water. A few alumina refineries (specialty alumina refineries) employ an improved indirect cooling method, where the final-effect secondary steam indirectly exchanges heat with circulating water in a novel evaporative condenser, and the condensed secondary steam water enters a condensate tank without mixing with the circulating water. Simultaneously, the cooling of the circulating water also occurs within the evaporative condenser, eliminating the need for a separate circulating water station. Given the current production and operation status in domestic alumina refineries, both of the aforementioned cooling systems for the final-effect secondary steam have practical engineering applications. The following section provides an introduction and analysis of these two cooling methods.

2. Traditional Direct Cooling Method

2.1 Process Principle

The final-effect secondary steam from the evaporation unit enters the water cooler from the bottom and directly exchanges heat with the cooling water entering from the top. The cooling water absorbs heat and rises in temperature, while the secondary steam cools down and turns into condensate, which, along with the heated cooling water, flows into a downstream water seal tank. Utilizing the height of the water seal tank, the water self-flows back to an open counterflow cooling tower for cooling, where it is cooled and then pressurized by a circulating water pump to re-enter the water cooler, to continue cooling the secondary steam from the final effect of the evaporator train, thus forming a circulating system. Non-condensable gases are vented to the atmosphere using vacuum pumps.

An open counterflow cooling tower, also known as a mechanical draft counterflow wet cooling tower, refers to a tower where circulating hot water flows into the tower through Inlet Pipe 1, is uniformly distributed onto lower drenching Fillers 4 via Distribution System's Branch Pipe 2 and Nozzle 3. The hot water flows downward in the form of droplets or a water film, while cold air enters the tower from the lower Air Inlet 5. The hot water and cold air exchange heat and mass in the drenching fillers to reduce the water temperature. The heated moist air is drawn out of the tower by top-mounted Exhaust Fan 6 through Wind Tunnel 7. The cooled water flows into lower Collection Tank 8. A schematic diagram of the open counterflow cooling tower's structure is shown as Figure 1.



1 Inlet Pipe
2 Distribution System's Branch Pipe
3 Nozzle
4 Fillers
5 Air Inlet
6 Exhaust Fan
7 Wind Tunnel
8 Collection Tank

Figure 1. Schematic diagram of open counterflow cooling tower structure.

2.2 Technical Characteristics

The technical characteristics of this cooling method include: (1) The latent heat released during the condensation of the final-effect secondary steam is transferred to the atmosphere through two transfer area. Due to the difficulty in large-scale production of single heat exchangers, the corresponding evaporative condenser equipment quantity is larger, and all are located on the 21 m plane of the evaporation unit, increasing the floor load. Therefore, the construction investment is higher than that of the traditional final-effect secondary steam direct cooling technology. In terms of operating power consumption, in the novel final-effect secondary steam indirect cooling technology, the process of releasing latent heat from the final-effect secondary steam condensation into the atmosphere is completed entirely within the evaporative condenser, eliminating the need for circulating water to circulate back and forth between the evaporation process and the circulating water station in the traditional direct cooling technology. The operating power consumption is saved.

5. Conclusion

In summary, compared to the traditional direct cooling technology, the final-effect secondary steam indirect cooling technology in the evaporation system offers advantages in conserving freshwater, footprint, operating power consumption, and production costs. However, in terms of equipment configuration, the evaporative condenser requires a larger quantity, resulting in higher construction investment. Additionally, the uniform distribution of the final-effect secondary steam needs to be considered. During operation, it is essential to ensure that the spray water in the evaporative condenser is a clean soft water to prevent scaling on the heat exchange tubes. The material and processing quality of the heat exchange core must be reliable to prevent leaks and damage to the tubes, ensuring stable and reliable operation of the evaporative condenser.

6. References

1. Yuemin Zhao and Yaqun He, Alumina Production Technology, *Metallurgical Industry Press*, 2019 (in Chinese).
2. Hongtao Wang and Guanglong Liu, Application and Optimization of Falling Film Evaporator in Alumina Production, *Light Metals*, 2021(08): 34–38 (in Chinese).
3. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of China. Safety Regulations for Alumina Production: GB 28851–2012 [S], Beijing: Standards Press of China, 2012 (in Chinese).
4. Ming Zhou and Jianguo Wu, Research on Heat Transfer Performance of Evaporative Condensers, *Chemical Equipment Technology*, 2020(04): 18–22 (in Chinese).
5. Jianwei Li and Hongwei Zhang, Discussion on Energy-Saving Optimization Technology for Industrial Circulating Water Systems, *Water Saving Irrigation*, 2018(11): 89–93 (in Chinese).
6. Li Guo and Jun Yang, Analysis of Energy-Saving and Consumption-Reduction Measures for Alumina Evaporation Systems, *Design and Research of Nonferrous Metals Metallurgy*, 2022(03): 45–49 (in Chinese).
7. Zhenjiang Liu and Xindong Wang, Application Progress of Evaporative Condensers in the Chemical Industry, *Chemical Industry and Engineering Progress*, 2019, 38(06): 2473–2480 (in Chinese).
8. Baoqi Sun and Yan Zhao, Design and Practice of Evaporation Systems in Large-Scale Alumina Plants, *China Nonferrous Metallurgy*, 2020(05): 42–46 (in Chinese).