AA08 - Performance of Wide-Channel Welded Plate Heat Exchanger for Bayer Precipitation Process

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Abstract

Based on the agglomeration, the hydromechanical and the thermodynamic mechanisms, the scaling characteristics of sodium aluminate solution on the heat transfer wall were explored. The performances of the wide-channel plate heat exchanger after scaling were investigated. With scaling on the surface, the heat transfer coefficient and the slurry flow rate would decrease, and the pump's power consumption and the pressure drop of the heat exchanger increase. The precipitation yield would also be impacted due to heat transfer deterioration. In addition, scaling on the heat transfer surface would also cause higher local flow rate and erosion acceleration, thereby shortening the equipment service life. Finally, the vertical wide-channel plate heat exchanger and the equipment quantitative management implemented by an intelligent IIot platform are proposed to improve the equipment performance.

Keywords: Sodium aluminate, scaling, wide-channel plate heat exchanger, maintenance.

1. Introduction

In the alumina production, the stability of sodium aluminate solution greatly restricts its precipitation yield. Because of the controllability, cooling system has become the most effective means to regulate the precipitation process and improve the precipitation yield while maintaining the alumina quality at the desired levels. However, due to a number of operating and technical reasons of Bayer process, precipitation of aluminium hydroxide and some other chemical components takes place at the heat transfer wall surface, which reduces the performance of the equipment over a period of time and if remedial steps are not taken, the likelihood of the equipment failure could not be ruled out.

In the following, CFD simulation was conducted and a workstation with two XEON processors with 3.40 GHz and 128.0 GB RAM was used. This paper will introduce the microscopic mechanism of aluminum hydroxide scaling on the heat transfer wall, study the characteristics of wide-channel welded plate heat exchanger after scaling in the flow passage, and finally propose a novel approach i.e. "vertical wide-channel plate heat exchanger" for cooling of slurry in the precipitation area and the equipment quantitative performance management implemented by an intelligent IIot platform.

2. Microscopic Mechanism of Scaling

In the heat exchanger, scaling often takes place on the heat exchange surface, as shown in Figure 1. This is mainly because fine aluminium hydroxide particles precipitate out from the low-temperature sodium aluminate solution in the boundary thermal sublayer, which directly stick to the wall, or bond with other fine aluminium hydroxide particles and then stick to the surface. The particle agglomeration mechanism, the particle capture mechanism in the viscous sublayer, and the thermodynamic mechanism of scaling will be introduced in the following.

Figure 1. Scale on the heat transfer wall.

2.1 Agglomeration Mechanism

In sodium aluminate solution, small aluminum hydroxide particles are first combined by collision to form a flocculate, which is further bonded to form a firmer agglomerate. STEENTON found that the agglomeration mainly occurred between fine particles with similar sizes, and it was difficult to occur between particles with different particle sizes [1]. Since the agglomeration could be explained by the binary collision theory, LI calculated the collision frequency of two particles, and the results showed that it was difficult to coalesce between coarse particles [2]. Although the collision frequency between fine particles and coarse particles was high, there was no coalescence between them due to the low activity of coarse seeds. Therefore, the particles smaller than certain critical size could form agglomerates, and the agglomeration efficiency increases with the decrease of particle diameter.

2.2 Hydrodynamics Mechanism

In the viscous sublayer, particle movement has an important effect on the scaling: (1) - If the particle size is small enough within the viscous sublayer, particle is completely trapped and travels at very low velocity (see Figure 2). (2) - When the particle size is large compared to the thickness of the viscous sublayer, the impingements between the particles and the wall become significant. So, the interaction mechanism between the particles and the wall scaling strictly depends upon the ratio of particle size to boundary layer thickness. In order to quantitatively describe the mechanism, a dimensionless particle size d_p^+ is proposed [3, 4] :

$$d_p^+ = \frac{\rho_f d_p u_f^*}{\mu_f} \quad (1)$$

$$u_f^* = \sqrt{\tau_{w,f} / \rho_f} \quad (2)$$

where u_f^* is the friction velocity of the fluid, namely the square root of the ratio between the fluid wall shear stress $\tau_{w,f}$ and the fluid density ρ_f 。

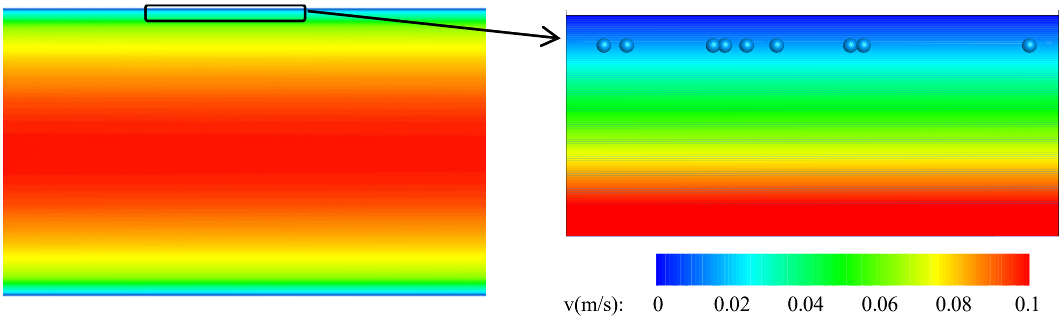

Figure 2. Velocity contour of liquid-solid two phases in viscous sublayer.

There are many fine particles of aluminum hydroxide in the solution of sodium aluminate. Among them, the particles with d_p^+ much less than 5.0 are so small that they are easily captured within the viscous sublayer, and then efficiently collide with other fine particles in the viscous sublayer.

2.3 Thermodynamic mechanism

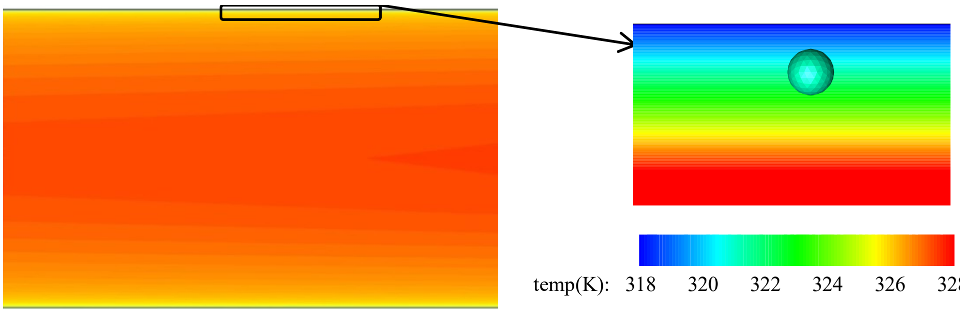

Figure 3. Temperature contour of liquid-solid two phases in thermal sublayer.

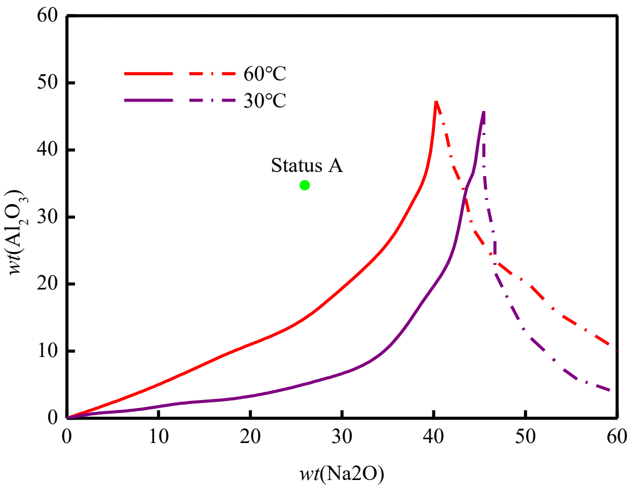

Figure 4. Equilibrium phase diagram of Na_2O-Al_2O_3- H_2O at different temperatures.

In the cooling process of sodium aluminate solution, the maximum temperature gradient locates in the thermal sublayer where is close to the wall. The fluid temperature in the thermal sublayer is approximately equal to the cooling water temperature, and the bulk temperature is 15-35 °C higher than the former, as shown in Figure 3. The high-temperature liquid phase in the bulk entering in the thermal sublayer through vortex motion and molecular diffusion is suddenly cooled. In the equilibrium phase diagram of Na_2O-Al_2O_3- H_2O system shown in Figure 4, this process means that the supersaturation of point A sharply increases, and the fine particles are rapidly precipitated out. The precipitated fine particles are adhered to the wall surface, or to low velocity fine particles in the sublayer and then stick to the wall.

3. Operation Characteristics

After serious scaling on the heat transfer wall, the heat transfer performance, the participation yield, the local erosion rate of the stainless steel wall, and the pump's power consumption are significantly influenced. The performance deterioration can be monitored. For instance, scaling in the flow passage would lead to lower total heat transfer coefficient (K value) and higher slurry pressure drop (P), while scaling at other locations inside the euqipment only results high slurry pressure drop (P). In addition, PQ represents pump's power consumption, which can reflect energy-saving status. The performance deterioration can be overcome by accurate quantitative management of the heat exchanger implemented by monitoring operation parameters.

3.1 Performance of the Heat Exchanger

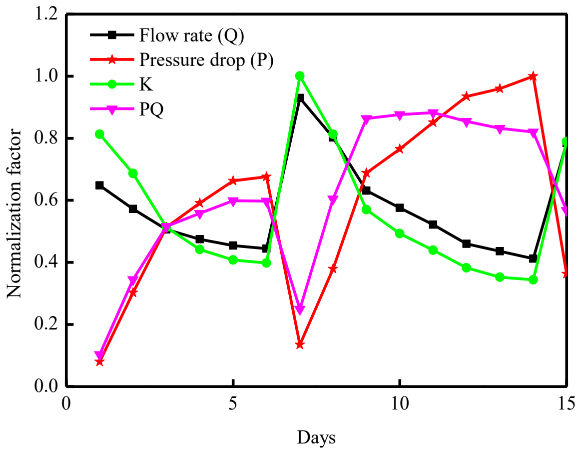

Figure 5. The profiles of slurry operating parameters over date.

The analysis was conducted over the 15 days operation data of a wide-channel welded plate heat exchanger. K value, Q, P, and PQ were divided by their own maximum data to obtain the normalized parameter values, as shown in Figure 5. It can be seen that with the heat exchanger running, the slurry flow and K value gradually decrease, and the slurry pressure drop and pump's power consumption (PQ) gradually increase. The phenomenon was mainly caused by the aluminum hydroxide scaling on the wall which blocks partial or the whole flow passage. After chemical cleaning, the operating parameters could be restored to the design values.

Chemical cleaning has an important influence on the performance and pump's power consumption of heat exchanger. The 160 days operation data of another wide-channel welded plate heat exchanger was analyzed. The normalized parameters were shown in Figure 6. As can be seen from Figure 6, slurry flowrate did not change significantly. K gradually decreased, and P and PQ gradually increased, which indicated that some scale has existed on the heat exchange wall.

During the running stage, accurate monitor of operation parameters is necessary. Based on these monitor data, the dynamic quantitative relationship between the chemical cleaning cycle and the equipment status could be established to improve the heat exchanger performance.

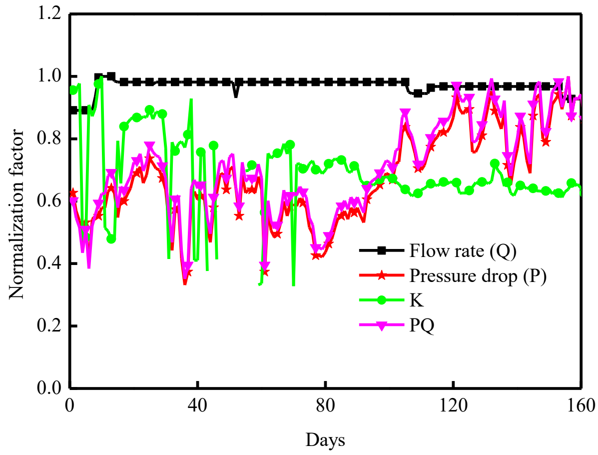

Figure 6. The profiles of slurry operating parameters over date.

3.2 Precipitation Rate

Wide-channel welded plate heat exchanger can help the owner to obtain the highest yield in the shortest time and so improve the profit. If the equipment quantitative management cannot be well conducted, the scaling of hydrate at the heat transfer surface will lead to the deterioration of heat exchange. The influence of heat transfer efficiency on the precipitation rate of sodium aluminate by stopping part of the wide-channel plate heat exchangers working is investigated.

In a particular alumina refinery, there are 2 precipitation lines. Each line has 16 precipitation tanks and 5 plate heat exchangers. The heat exchangers are installed on the #4, #6, #8, #10, and #12 tank, respectively. The volume of each tank is about 4648 m^3. The slurry flow rate and the area of each heat exchanger are about 740 m^3/h and 600 m^2, respectively.

In line 1, the 4#, 8#, and 12# plate heat exchangers stopped working, while all the plate heat exchangers were in application in line 2. The temperature and the precipitation rate of the sodium aluminate solution in each tank were tested and the results were shown in Figure 7. The final precipitation rate of sodium aluminate solution in line 1 was about 45.3 %, while that in line 2 can reach 49.4 % after sufficient cooling. In addition, for 4# precipitation tank, the precipitation rate could get 37.6 % by utilizing the plate heat exchanger, while the precipitation rate was just 34.5 % without cooling. Therefore, the precipitation rate decreased with the increase of the temperature of the sodium aluminate solution.

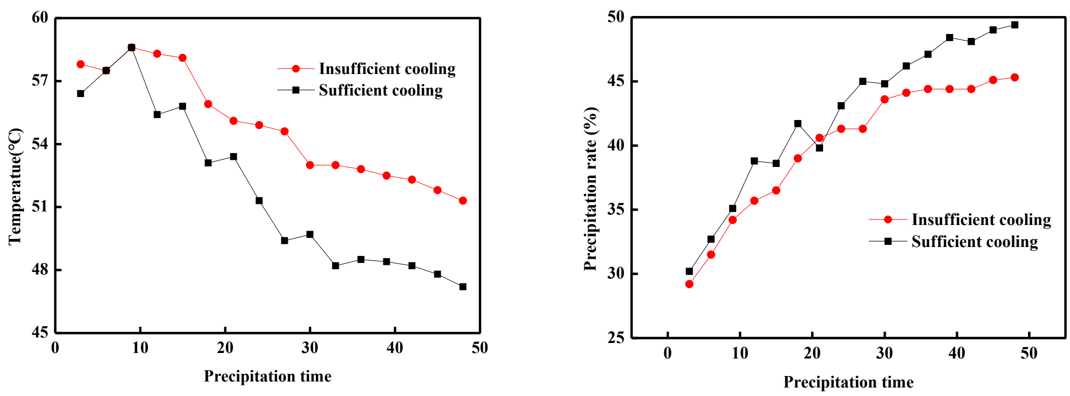

Figure 7. The influence of temperature decreasing program on the tank temperature and precipitation rate.

3.3 Local Plate Erosion

If the equipment quantitative management cannot be well conducted, the scaling of aluminum hydroxide on the heat transfer wall will gradually cause serious blockage of the flow passage, as shown in Figure 8. Assuming that the scaling is cuboid with a certain round angle, the Euler-Euler multiphase flow model, the standard k-ε turbulence model, and the KTGF (Kinetic Theory of Granular Flow) model were adopted to simulate the flow field and the plate erosion at the flow velocity of 1.2 m/s, as shown in Fig. 9. As can be seen from Figure 9, serious local erosion of the plate take place. Thus, the scaling would introduce a greater tendency of scaling and erosion, resulting in shortening the service life of the equipment.

Figure 8. Schematic diagram of fouling in the channel.

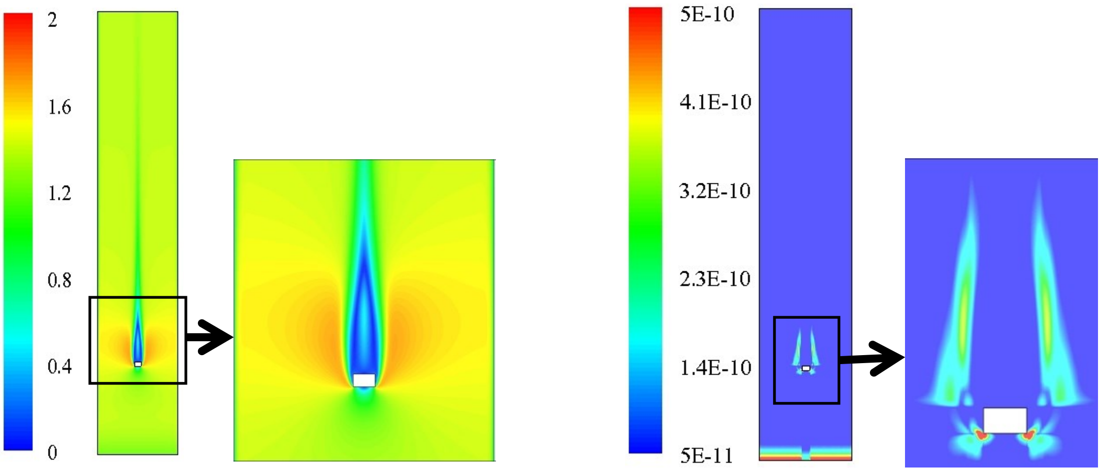

Figure 9. Simulation results when the channel is clogging: (a) velocity contour (unit: m/s); (b) erosion index (unit: kg/(m²·s)).

4. Optimal Design of Heat Exchanger and Perspective

Horizontal wide-channel welded plate heat exchanger is the main cooling equipment for Bayer precipitation process, in which the particle movement direction is perpendicular to its gravity direction. The solid phase volume fraction near the lower wall is very high, while the flow velocity is low, resulting in a high probability of scaling. Based on the CFD-DEM model with strong coupling between liquid and solid phases, the particle velocity contours of the horizontal and vertical wide-channel heat exchangers are shown in Figure 9, respectively. It can be seen that in the vertical equipment, particles are uniformly distributed in the entire flow passage and slurry is discharged smoothly under the action of gravity at shutdown. Therefore, the vertical wide-channel plate heat exchanger can overcome the problem of scaling at the heat surface to a certain extent.

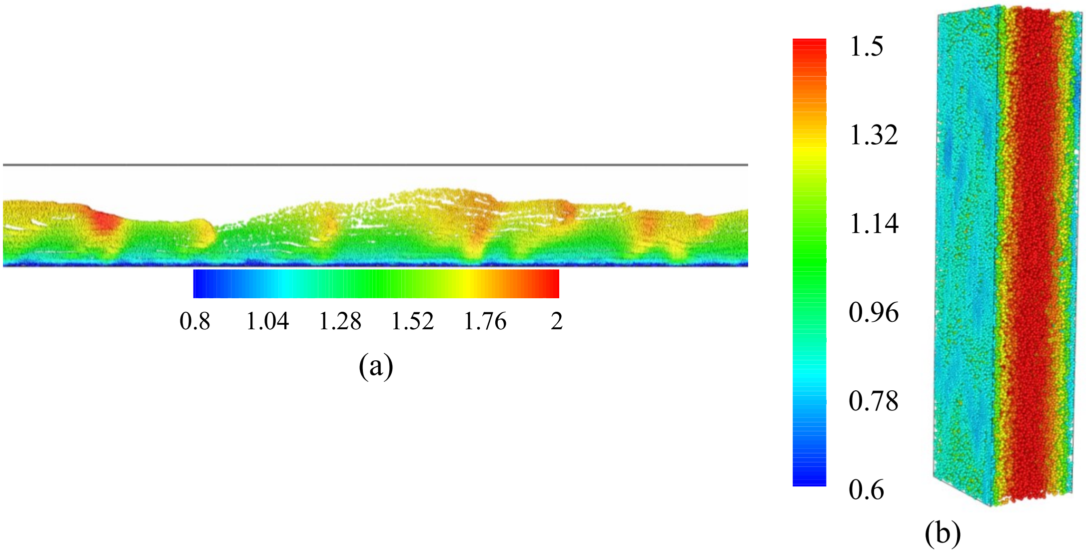

Figure 10. Particle velocity contour (unit: m/s): (a) channel in horizontal equipment; (b) channel in vertical equipment

The quantitative management of the heat exchanger is very necessary, which has become one of the issues to further increase the owner's profit and prolong the service life of the equipment. Up to now, there has been few reports on the real-time and accurate monitoring of the heat exchanger used for Bayer precipitation process. So far, liquid-solid two phase flow technology in the vertical and horizontal narrow channels with 12 mm height has been studied [5-7], such as the liquid-solid two phase flow characteristics, solid phase distribution, and the slurry pressure drop. This work perfected the dense liquid-solid two-phase flow theory, which could accurately predict the performance of heat exchanger without scaling at heat exchanger surface. The deviation between the above prediction performance and the operating performance after scaling can reflect the amount of scaling. In addition, Internet of Things (IoT) is an emerging technology that combines Internet technology, sensor technology and equipment to form a huge network, which can collect the operating parameters of the equipment and send them to the terminal, which plays a more and more important role in the equipment maintenance.

Rapid development of IoT technology and accurate performance prediction of the liquid-solid heat exchanger without scaling at heat exchanger surface lay a solid foundation for quantitative management of the plate heat exchanger. The IoT monitoring platform of the liquid-solid flow heat exchanger have been running for one year and could accurately calculate the equipment performance according to the deviation between the monitor parameters and the predicted values calculated on the assumption that no scaling is in the heat exchanger, which can be feed back to the operator in real time and reminder the operator to take some actions if necessary. In addition, the platform also has such functions as fault alarm and fouling prediction that lead to better planning and maintenance control strategies, and so on, which will be described at the next ICSOBA conference.

Figure 11 IoT monitoring graphical interface

5. Conclusions

The mechanism of agglomeration, hydromechanics and thermodynamics of scaling of aluminum hydroxide on the heat transfer wall were introduced. After scaling, the heat transfer coefficient and the slurry flow rate decrease, the pump's power consumption and the pressure drop on the slurry side increase. The precipitation rate of the sodium aluminate solution decreases with the decrease of heat transfer coefficient. Scale could also accelerate plate erosion, and shorten the service life of the equipment. Finally, a verticle wide-channel welded heat exchanger and an intelligent maintenance system for heat exchanger used for cooling of the sodium aluminate solution are proposed. In the intelligent system, the difference between the monitor parameters and the predicted values calculated on the assumption that the heat transfer wall is clean could reflect the performance state of the heat exchanger.

6. References

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