AA17 - Erosion Investigation of Liquid-Solid Two Phase in Wide-channel Welded Plate Heat Exchanger

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Abstract

In the wide-channel welded plate heat exchanger, the two-phase flow characteristics and the wall erosion in the channel with existence of cylindrical objects was studied. The finding shows that the liquid velocity around the cylindrical objects increases sharply and consequently the erosion on the plate surface surrounding the cylindrical object is accelerated, and the erosion rate increases with the increase of inlet velocity and wall roughness. Compared with the smooth wall, the particles impact the rough wall with higher energy and higher frequency, leading to faster erosion. Therefore, it is important for equipment user to keep appropriate inlet flow velocity, monitoring function of strainer, setting up effective CIP (cleaning in place, CIP) mechanism and observing heat exchanger performance regularly, so as to prolong service life of the equipment.

Keywords: Erosion, Foreign objects, Wide-channel welded plate heat exchanger.

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. The wide-channel welded plate heat exchangers are widely applied in alumina precipitation process thanks to its advantages of high heat transfer efficiency, compact structure and small footprint. The wide-channel welded plate heat exchangers are often used in process industry where medium contains solid particles or fiber suspensions due to its smoother channel structure than conventional heat exchanger. Nevertheless, when there are foreign objects in the channels, such as precipitation of aluminum hydroxide or bottle caps (Figure 1(a)), solid particles would accelerate erosion of heat transfer surfaces (Figure 1(b)). According to the statistics, equipment life could be shortened by about 1 / 3 to 1 / 2 when foreign objects exist. Therefore, it is of great significance to study the erosion in the liquid-solid two-phase flow field in the channels with unexpected foreign objects, so as to guide the design and the operation of the wide-channel welded plate heat exchanger.

The erosion rate caused by the slurry in the wide-channel welded plate heat exchanger is slow, and the experimental measurement has disadvantages like long period and difficulty in obtaining accurate erosion information, therefore, in this article, the Euler-Lagrangian model is applied to study the influence of erosion rate in the area surrounding foreign objects caused by flow velocity and surface roughness, and then to provide information for the design and operation of the wide-channel welded plate heat exchanger for equipment manufacturer and user respectively.

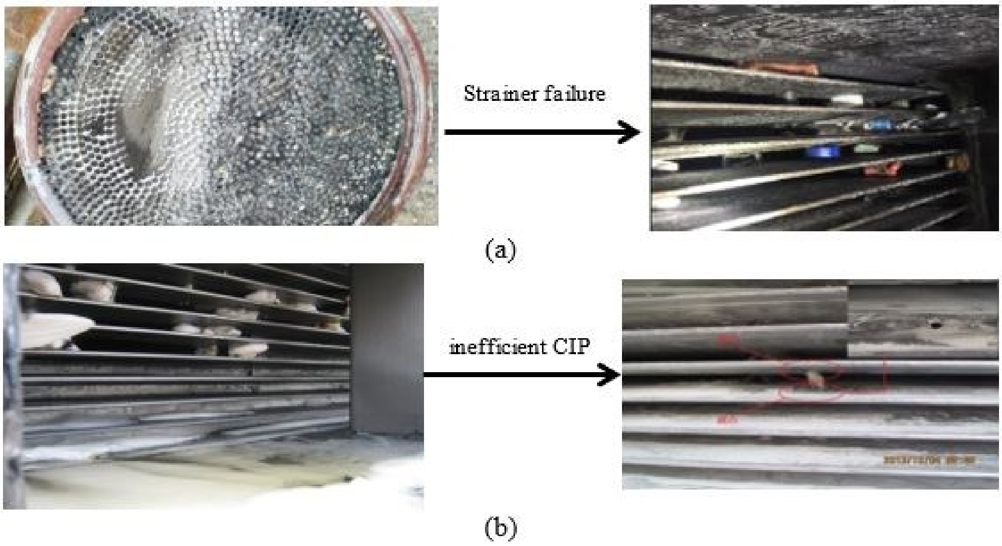

Figure 1. Foreign Objects.

Figure 2. Eroded plate by foreign objects.

2. Governing Equation

Euler method was applied to describe liquid phase flow while Lagrange method is applied to describe particle movement. For single solid particle, Oka erosion model [1,2] was used to compute the wall erosion rate by sparse particles in liquid-solid two phase stream by volume removal rate of the target plate wall caused by solid particles per unit mass (mm^3/kg).

3. Simulation Method

The size of the computation domain was 1200 mm (length) × 30 mm (width) × 12 mm (height), and the foreign object was the bottle cap with a size of ф 27.9 mm × 12 mm. The density and the viscosity of liquid was 1200 kg/m^3 and 4.0 cP respectively and the density of solid particle was 2400 kg/m^3. The finite volume method was used to solve the liquid governing equation and the coupled algorithm was used for iterative computation.

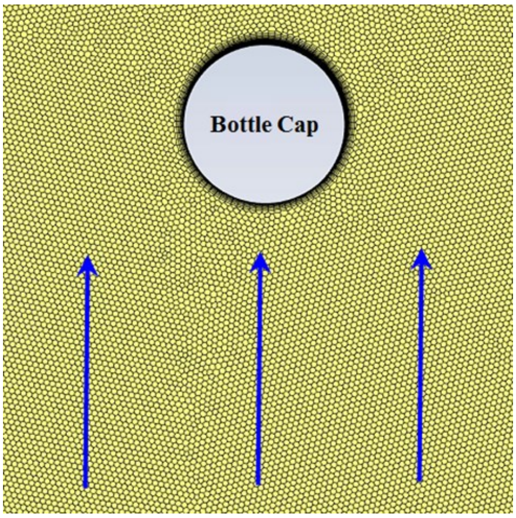

Figure 3. Model schematic diagram.

4. Results and Discussion

The dimensionless Stokes number St describes the ratio of relaxation time of particles to characteristic time of fluid, reflecting follow-up property of particles to fluid [3]. The calculation formula is:

$$St = \frac{\rho_d \cdot d_p \cdot V_f}{18\mu_f} \quad (1)$$

The smaller the St number, the more the particle movement path is in line with the liquid streamline. The particle St number in this study is very small, and the particles have good follow-up properties. The liquid flow field can greatly affect the distribution of erosion rate. In the flow channel with existence of cylindrical objects, the contour of erosion on channel surface caused by liquid-solid two phase stream is shown in Figure 5. As seen from Figure 5, before disturbed by cylindrical objects, the particles move forward at nearly same magnitude speed with liquid phase, and the erosion rate on exchanger surface by liquid-solid stream is very low. However, after disrupted by the cylindrical bottle cap, the liquid flow field is disordered (as shown in Figure 4), the liquid velocity around the cylindrical object increases sharply. The solid particles trapped in liquid phase flush and wear the channel surface near the cylindrical object more drastically, leading to greater erosion rate in this area. The simulated result is in consistent with what is observed in Figure 2. Therefore, the erosion around the cylindrical object increases sharply. It is imperative to install a strainer before the inlet of process fluid in front of the heat exchanger and to keep the strainer in function.

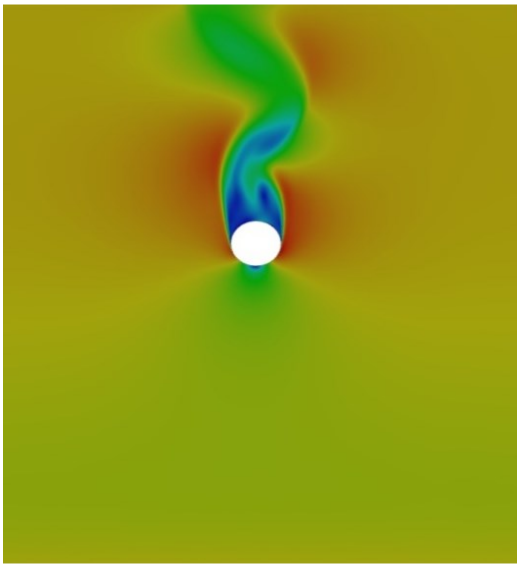

Figure 4. Contour of liquid-phase velocity (SI: m/s).

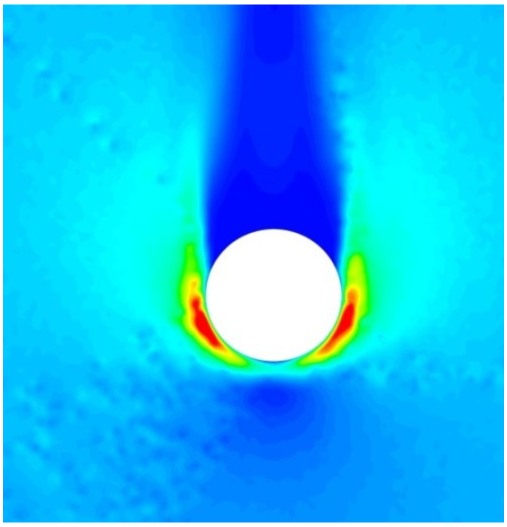

Figure 5. Wall erosion contour.

The multiple erosion field of the channel wall in liquid-solid two phase stable flowing, the impacting mass flow rate, velocity and the angle of solid particles at several moments were averaged in time and space respectively, and the averaged erosion field distribution was obtained. An axial coordinate system with center of the bottle cap being original point was established. The numerical simulation results show that severe erosion occurs on the flow channel wall in the annular area 0~2.5 mm ahead of the cylindrical object.

Inappropriate flow velocity can accelerate erosion of the wall around the cylindrical foreign object. Generally, the solids are non-spherical and the non-sphericity is expressed by the sphericity coefficient, which is calculated by the ratio of the surface area of a spherical particle that is the same volume as a non-spherical particle to the surface area of the non-spherical particle. The slurry flow velocity in the channel is usually 1~2 m/s. Under the condition of the hydrodynamic smooth wall and the solid particle with the diameter of 60 µm and the sphericity coefficient of 0.76, the annular distribution profiles of the wall erosion rate and other impacting parameters at different velocities are shown in Figure 6. As can be seen from Figure 6, with the increase of flow velocity, particles obtained greater impacting energy and the mass flow rate of particles impacting the wall per unit time increases, consequently the impacting by solid particles on the wall was intensified, and leading to faster wall erosion rate. Furthermore, the direct flushing and solid particles inertia result in quicker erosion at the channel wall near the front of the cylindrical object and two sides of it. During the conversion from low to high flow velocity, the erosion rate of the wall close to the two sides of the cylindrical object is gradually strengthened, so the peak values of particle impacting mass flow, velocity and erosion rate gradually migrates from the front of the cylindrical object to its two sides. The above findings show that proper flow velocity shall be kept in equipment operation.

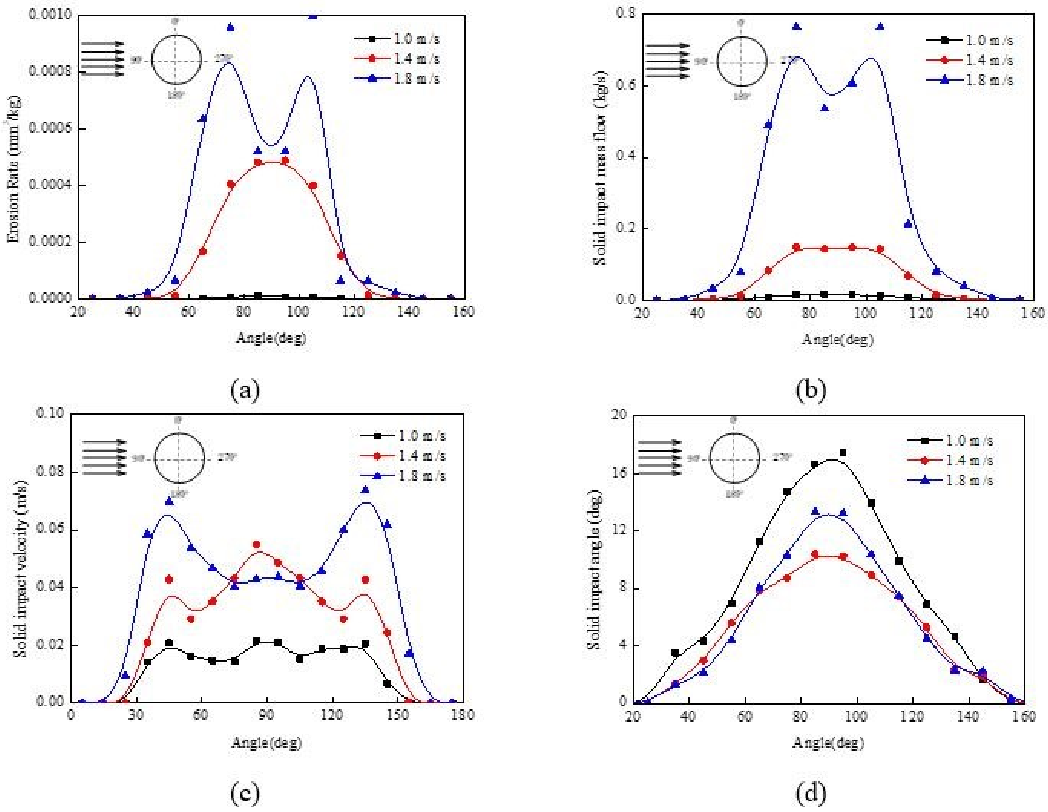

Figure 6. Circumferential distribution profiles of wall erosion rate and other impacting factors under different velocity.

Precipitation often results in wall roughness, which in turn influences erosion in the area surrounding the cylindrical foreign object. Surface roughness is another important factor affecting the erosion. With 1.4 m/s two-phase flow velocity and the particles with diameter of 60 μm and sphericity coefficient of 0.76, the circumferential distribution profiles of wall erosion rate and other impacting parameters under different surface roughness are shown in Figure 7. The results show that the erosion rate increases with the increase of surface roughness. When the surface roughness is less than 0.3 mm, the erosion profile is similar to that of the hydrodynamic smooth wall, and the erosion mainly occurs on the wall surface which is 30 °~150 ° annular area in the front of the cylindrical object. With the increase of surface roughness, the erosion appears at whole channel wall in annular area in the front of the cylindrical object, and the maximum erosion rate migrates from area in front of the cylindrical object to two sides of it, and the erosion rate curve exhibits ‘M’ shape. When the particles bypass the cylindrical object, the kinetic energy of the particles decreases, the erosion rate of the wall surface in rear area of the cylindrical object gradually decreases, as shown in Figure 7.

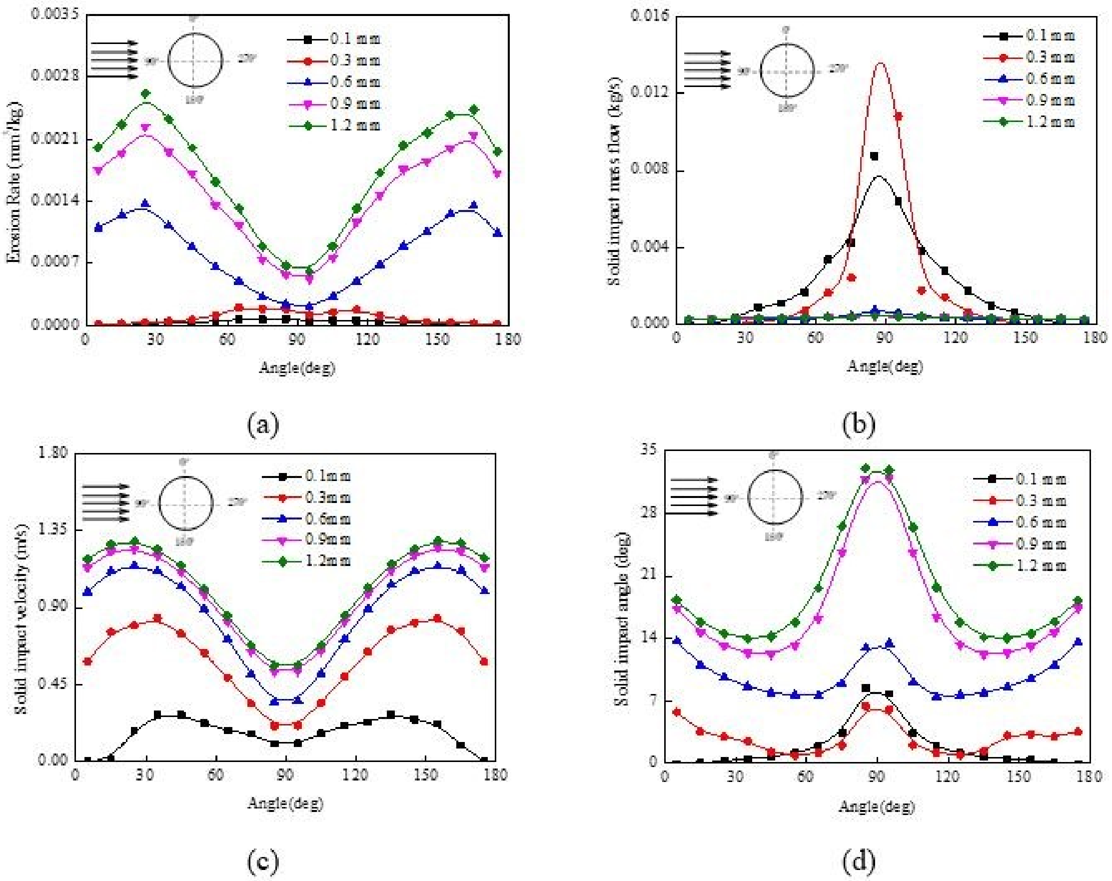

Figure 7. Circumferential distribution profiles of wall erosion rate and other impacting factors under different surface roughness.

With the wall roughness 1.2 mm, the movement path of some particles near the cylindrical object is shown in Figure 8. The particles try to struggle away from the liquid capture to move towards the center of the flow channel during interaction with rough wall and adjacent liquid. When the liquid in the center of the channel encounters the cylindrical object, it jumps on the wall and pushes the particles to the wall. Under the action of the above two forces in opposite directions, the particles at points A, B, C and D impact the wall at high frequency, leading to severe wall erosion at higher surface roughness. In addition, under the condition of high surface roughness, particles impacting the channel wall near both sides of the cylindrical object at larger velocity and angle (as shown in Figure 7(b) and (c)), eventually leading to severe erosion at two sides of cylindrical object as well. Therefor an effective CIP cleaning mechanisms and regular heat exchanger performance monitoring mechanism shall be established by equipment user.

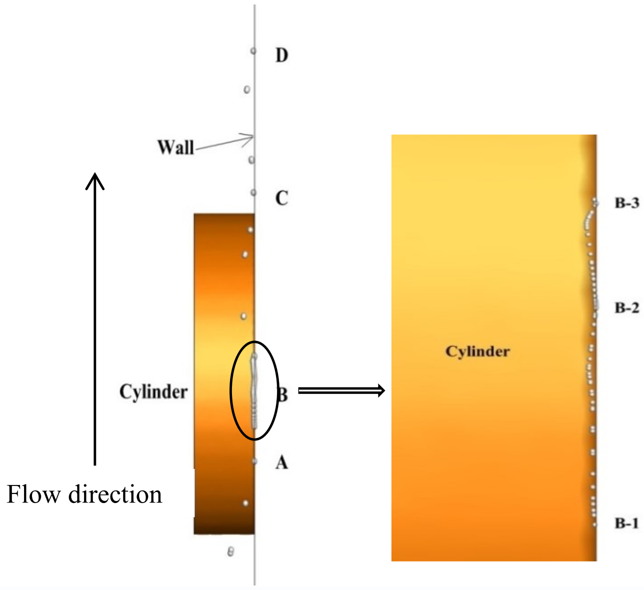

Figure 8. Particle movement morphology diagram when the surface roughness is 1.2 mm.

5. Conclusions

The two-phase flow and the wall erosion characteristics in the wide-channel welded plate heat exchanger with existence of unexpected cylindrical objects were studied. The findings show that the liquid velocity increases sharply due to unanticipated foreign cylindrical objects which in turn worsens erosion of the wall, and the erosion rate increases with the increase of inlet velocity and wall roughness. Compared with smooth wall, the particles impact the rough wall with higher energy and higher frequency, resulting in faster wall erosion. In summary, it is important to keep appropriate inlet flow velocity, making sure the function of the strainer (the strainer should be easy to open and then clean up. The hole size in strainer plate is smaller than the size of all possible foreign bodies), setting up effective CIP mechanisms and regularly monitoring heat exchanger performance, which helps in extending life of the equipment.

6. Prospect

In the wide-channel welded plate heat exchanger, a large number of fouling of saturated liquor decomposition or unwanted foreign objects will worsen heat exchanger performance and decrease product quality, shorten equipment service life. For the case of fouling of saturated liquor decomposition, the resistance of heat transfer increases. For the case of unwanted foreign objects, the retention area behind the foreign objects increases. In either case, the heat transfer performance decreases and so the hot/cold flow rate increases in order to take away a given heat duty, leading to increased energy consumption and carbon emissions. Therefore, it is particularly important to monitor the performance of wide-channel welded plate heat exchanger. The performance audit system of wide-channel welded plate heat exchanger developed by Shanghai Heat Transfer Equipment Co. Ltd. can evaluate the blockage extent of blockage and the performance of heat exchanger. The performance audit system could calculate the equipment performance according to the monitor values and the results can be immediately feed back to the handler in real time. Besides, this system could give the handler a report according to the past operating data. The performance audit system could calculate the best operation parameters and adaptive CIP cleaning period (non-fixed CIP cleaning period). It can predict CIP cleaning date 3~5 days ahead so to leave enough time for user to prepare for CIP job. In this way, it is possible to have the performance of the heat exchanger in its best running state safely and extend service life by 1.5~2 times.

7. References

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