

STUDY ON THE PREDICTION MODEL OF HEAT TRANSFER COEFFICIENT DURING TUBE DIGESTION

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Abstract

Based on the actual production data of gibbsite refinery in Vietnam, prediction model of heat transfer coefficient is established due to the mechanism of heat transfer, which is validated by actual production data. The results show that the predicted and the actual ones are in good conformity. The main factors affecting the heat transfer coefficient are analyzed, and the main measures to control the scale are put forward. It can help to arrange the cleaning period, ensure the digestion technical indexes, and stabilize production process.

Introduction

Digestion is the critical unit in the Bayer process, which affects the alumina capacity and energy consumption. Tube digestion has become the popular standard facility in the model alumina refinery due to high heat exchanger efficiency and low energy consumption^[1,2]. In the tube digestion process, firstly, the slurry exchanged heat with second vapor from flash tank, then, the slurry was heated to the required digestion temperature with live steam before entry into the holding tank. Some chemical reaction and steam fouling took place in the tube exchanger which caused the scale. This scale formation creates serious effects, such as the decrease of the heat transfer coefficient (HTC), the increase of pressure drop, cause the contamination of product and so on. It was previously reported that a thin layer of 1 mm of sodalite scale reduces heat transfer coefficient by 77%^[3-5]. Routine cleaning of heat exchanger is the most effective solution in the alumina refinery.

HTC was effected by many factors, it was very difficult to use a specific model to calculate the value. We usually choice an empirical data in the design of new alumina refinery. K.Yamada etc.^[6] developed a mathematical heat transfer model through the laboratory experiment. In this paper, another predicted mathematical model of HTC was presented base on the actual data from a certain alumina refinery in Vietnam. The predicted overall heater transfer coefficients seemed to agree well with refinery data.

1 Heat exchange process

The temperature of tubular exchanger heating with live steam is 145~150°C in the gibbsite digestion process. It is the convection heating exchange as indicated below in Figure 1 between slurry and live steam.

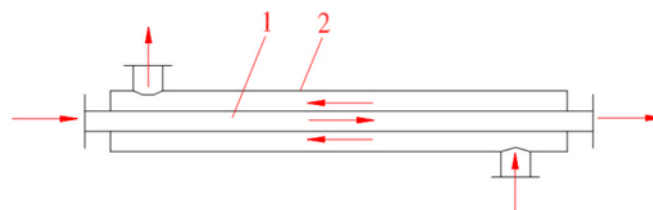


Figure 1 Digestion heating exchanger
1 Slurry 2 Steam

In heating exchange process, the slurry is in a turbulent state, live steam become condensate to release latent heat. The heat transfer process can be summarized as the forced convection heat transfer fluid phase transition in the alumina dissolution.

Convective heat transfer is a complex heat transfer process. HTC can be affected by many factors such as the properties of slurry, the operating conditions and the heat exchanger type etc. In the heat transfer process, the temperature is varied along the direction of slurry flow, the convection heat transfer rate of casing and heat transfer of different position also varies, so the rate of heat transfer equation for general use of Newton's equation as expressed in equation (1) and (2).

$$dQ = K(T - T_w) dS \quad (1)$$

$$Q = KS\Delta t \quad (2)$$

K=Heat transfer coefficient, W/(m².°C)

S=Heat exchanger area, m²

Δt=Logarithmic temperature difference, °C

After a period running of heat exchanger. There active silica present in bauxite ore is readily attacked by caustic liquor at low temperature digestion and forms desilication product (DSP), which reduces the HTC of tubular heat exchanger. The heat transfer rate dropped significantly. The laboratory is very different with actual refinery production, which is more fluctuating due to bauxite grade, operating level, control level and so on. The theoretical calculation of HTC model is not agree well with the refinery data. So, it is important to get a predict model of HTC based on actual refinery data to guide the design of alumina digestion process.

2 HTC predict model

2.1 Raw data

The input parameters of tubular heat exchanger temperature, volume flow, live steam temperature and live steam mass flow are come from a certain alumina refinery in Vietnam. The capacity of the refinery is 650kt/a, which dissolve gibbsite using low temperature Bayer process at 148°C, live steam temperature is 165°C. The volume flow is 480m³/h according to live steam tubular

heat exchanger area 840m². The digestion raw data is shown in table 1 which recorded once every two hours.

Table 1 The digestion raw data of a certain alumina refinery in Vietnam

Day	Recording time	Volume flow m ³ /h	Temperature of tubular heat exchanger /°C		Live steam °C	Mass flow of Live steam t/h
			Inlet	Outlet		
1	12:00	454	114	151	159	38
1	14:00	400	112	146	160	34
1	16:00	400	96	145	160	40
1	18:00	400	97	147	157	36
1	20:00	400	97	149	160	39
1	22:00	400	98	149	159	37
2	7:00	400	97.41	144.2	158.6	37.13
2	9:00	420	97.5	142.2	161	41.09
2	11:00	450	98.81	138.66	174.8	41.4
2	13:00	450	98.23	142.8	168	45.24
2	15:00	450	98.9	145.5	173	45.8
2	17:00	450	98.99	149.81	156	47
128	8:00	410	99.5	147.8	160.8	97.6
128	10:00	416	99.4	148.4	161.4	97.6
128	12:00	422	99.7	149.6	162.4	96.6
128	14:00	415	100.3	149.7	162	91
129	8:00	305	108	144	157	58
129	10:00	303	108	143	157	58
129	12:00	305	109	145	160	61
129	14:00	304	109	148	161	62
129	16:00	300	113	147	161	58
129	18:00	450	113	146.8	160	44
129	20:00	450	115	148.6	159	42
129	22:00	450	116	149	161	39

2.2 HTC model development

The extraction of alumina from bauxite in low Temperature digestion circuit frequently involves a desilication step in which kaolinite dissolves and re-precipitates as sodalite, a caustic in soluble sodium alumina silicate. Thus formed insoluble sodium alumina silicate gets scale inside the tubular heat exchanger. The live steam tubular heat exchanger get most scale due to high temperature. In this paper, we developed a predict model based on live steam tubular heat exchanger. The HTC (K) was calculated by equation (3).

$$C_p \times M \times \Delta t = K \times S \times \Delta t_m \quad (3)$$

Where:

C_p= Specific heat of slurry (kcal/kg.°C)

M=Mass flow of slurry (t/h)

Δt=Temperature difference of live tubular heat exchanger (°C)

K= Heat transfer coefficient (kcal/m².h.°C)

S= Tubular heat exchanger area (m²)

Δt_m= Logarithmic temperature difference (°C)

When we developed the predict model, we considered that the actual volume flow didn't achieved the design data. It indicated that energy consumption of slurry (C_pMΔt) was lower than design. It need less tubular heat exchanger area when the slurry achieved to the same digestion temperature. The HTC will decrease if we calculated the HTC by the design data. So it is necessary to revise the actual tubular heat exchanger area according to the actual volume flow. If the volume flow was 450m³/h, the actual tubular heat exchanger area was calculated by equation (4) and (5).

$$\text{Actual tubular heat exchanger area} = \frac{\text{actual flow}}{\text{design flow}} \times \text{designed tubular heat exchanger area} \quad (4)$$

$$\text{Actual tubular heat exchanger area} = \frac{450}{480} \times 840 = 787.5m^2 \quad (5)$$

The HTC of live steam tubular heat exchanger was calculated based on actual volume flow, the relationship between HTC and the operating time of the heat exchanger was showing in Figure 2.

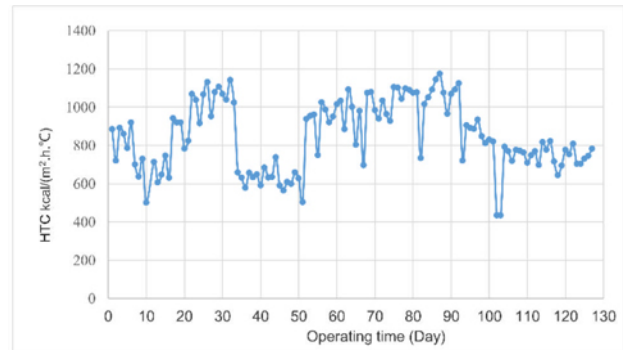


Figure 2 Decrease rate of HTC in live steam tubular exchanger

It can be seen from Figure 2, the HTC actual data was very fluctuating at the commissioning stage. Especially, in the starting 73 days, that a variety of factors of production was not stable. Mainly because of frequently start-stop, frequently adjusting instrument in the commissioning period, it resulted in the heat transfer coefficient of live steam without any tendency. After 73 commissioning days later, the production data was more stable because of dissolution process instrumentation debugging. Figure 3 shows the new diagram date from 74 days.

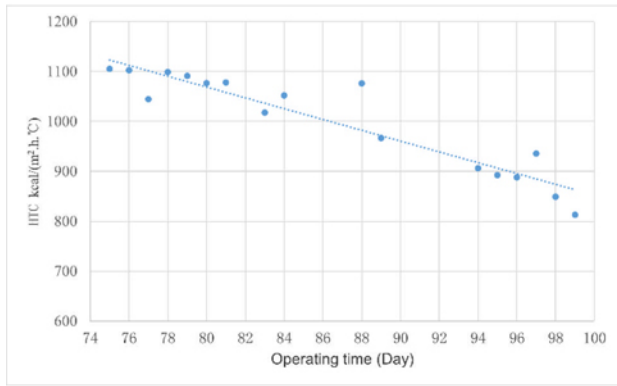


Figure 3 Decrease rate of HTC in live steam tubular exchanger data from 74 day

The predict model was deduced showing in equation (6):

$$HTC = 2603.6e^{-0.0111day} \quad (6)$$

2.3 Model verification

Figure 4 finally shows the correlation between actual HTC and predicted HTC, it shows a good agreement between the data determined from refinery and the data calculated by predicted model.

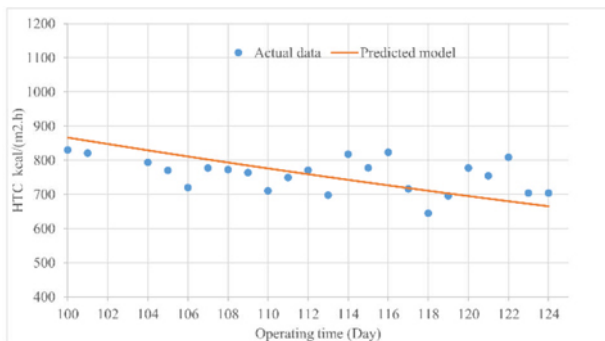


Figure 4 correlation between actual HTC and predicted HTC

3 HTC affecting factors discussion

3.1 Main affecting factors

The main factors affecting the heat transfer coefficient are: DSP scale, shellside fouling at steam side of the pipe, slurry velocity, pipe diameter, and so on. According to the definition of Nusair number and the fluid in a turbulent flow equation of circular slurry pipe, heat transfer coefficient has a direct ratio with the velocity of slurry, inverse relationship with pipe diameter. However, increasing the velocity of slurry will enhance the pipe resistance, increasing pump energy, resulting in improving investment and operating costs. Therefore in the new alumina refinery design process, it should choose a suitable heat exchanger diameter and a flow velocity.

When the heat exchanger was built, another factor affecting the HTC was scale. T.Oku and K.Yamada [7] developed the relationship between thickness of scale with HTC of heat exchanger, showing in Figure 5. It can be find that the HTC will decrease the times when the thickness of scale is 0.9mm. The scale will seriously affect the digestion technology index, resulting in a

live steam consumption increased. Therefore, it is critical to reduce or inhibit the scale as far as possible for improving the heat transfer coefficient.

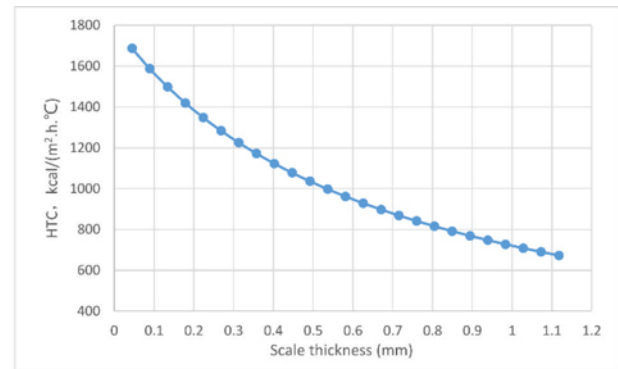


Figure 5 Effect of scale thickness on heat transfer coefficient

3.2 Scale in the Heat Exchangers

T.Oku and K.Yamada[7] had obtained the desilication rate equatin expressed by equation(7) and (8) through the laboratory experiment(Temperature range 100~180°C).

$$-\frac{dS}{dt} = \exp\left(26.376 - 14.44 \times 10^{-3}A - \frac{10960}{T}\right) \cdot (S - S_{\infty})^2 \quad (7)$$

$$S_{\infty} = 2.7 \times 10^{-5} \cdot N \cdot A \quad (8)$$

Where:

S SiO₂ concentration

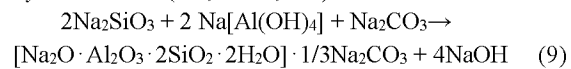
A Al₂O₃ concentration

N Causitic concentration

t Time

T Temperature

According to the desilication rate equation, it is the function of temperature, Al₂O₃ concentration, Causitic concentration and time. As the temperature of the solution increases in the tubular heat exchangers, sodium aluminate and silicate react to form sodalite scale on vessel walls (especially inside of live steam tubular exchangers), according to the chemical reaction expressed by Equation 7. Notice that CO₃²⁻ in sodalite is sometimes substituted by other anions (Cl⁻, SO₄²⁻, etc.)^[8].



There are some solutions for inhibiting the scale to prevent the heat transfer coefficient dropped too quickly, and ensure refinery operation stably.

- 1) Addition predesilication unit. Predesilication can help silica chemical react to sodium sodalite, one the other hand, the sodium sodalite can play the role of active seed in the digestion heating process. Precipitation of new phase priority in the sodium sodalite surface, thereby reducing the scale of the heat exchangers.
- 2) Addition some actived lime. Lime can form hydrogoant with silica in high temperature. The addition of lime can effectively purify and reduce process impurities, reducing the scale.
- 3) Heat exchanger shell side fouling also reduces heat

transfer capacity and is often overlooked during maintenance. The cause of shell side fouling is poor vapour quality that contains entrained liquor and sometimes mud particles relating to high rising vapour velocities. It is necessary to reduce or eliminate future fouling during to develop digestion flash system.

- 4) Other preventive measures such as: addition red mud as the desilication seed, the use of anti-adhesion material, ultrasonic anti-scale etc.

At the present stage, although the above methods can be used to prevent or reduce the heat exchanger scale, but it is inevitable, there is no solution to generate completely prevent scale, periodically clear the scale is currently the most effective measures [2]. Typically, heat exchangers that are scaled with Bayer sodalite are regularly cleaned with high pressure water.

4 Conclusions

- 1) Based on the actual production data of gibbsite refinery in Viet Nam, prediction model of heat transfer coefficient is established due to the mechanism of heat transfer, which is validated by actual production data. The predicted heat transfer coefficient agree well with the actual data.
- 2) The predicted model can help the refinery arrange the scale cleaning period and production plan. It plays an important role in the stable operation of the alumina refinery.
- 3) The main affection factors of heat transfer coefficient are slurry velocity, pipe diameter, pipe scale etc. Choosing suitable pipe diameter and flow velocity should consider the equipment investment and operation cost in the refinery design process. Heat exchanger scale is the most significant cause for heat transfer coefficient, regularly cleaning is the effective solution at the present stage.

References

- [1] E. Singhoffer and J. Steiner, "Experiences for the Reconstruction of Traditional Digestion Lines with the Application of Tube Digestion Elements in the Hungarian Alumina Plants", *Light Metals*, 1990, 27-34
- [2] A. G. Suss, I. V. Paromova, et al. "Tube Digesters: Protection of Heating Surfaces and Scale Removal", *Light Metals*, 2004, 137-142
- [3] Sébastien Fortin and Raymond Breault, "Bayer Process Heat Exchangers Cleaning Efficiency: Optimizing the Acid Dissolution of Sodalite Scale", *ECI Digital Archives*, 2003
- [4] Jamialahmadi, M., Müller-Steinhagen, H., and Robson, B. J. "Effect of Process Parameters on Scale Formation from Spent Bayer Process Liquor Part I: Experimental Observations", *Aluminium*, 1993(69) 823
- [5] Delgado, M., Manocha, R., and Fort, K., "Effect of Increased Liquor Concentration and Scaling on Performance of the Thermal Areas", *Light Metals*, 1992, 151
- [6] K. Yamada, M. Yoshihara. "Properties of Scale in Bayer Process", *Light Metals*, 1985, 223-236
- [7] T. Oku and K. Yamada. "the Dissolution Rate of Quartz and the Rate of Desilication in the Bayer Liquor". *Essential Reading in Light Metals*, 2013(1): 247-254
- [8] Duncan, A., Groemping, M., Welch, B., and MüllerSteinhagen, H. "The Effect of Silica, Temperature, Velocity, and Particulates on Heat Transfer to Spent Bayer Liquor", *Light Metals*, 1995, 63