A diaspore tubular digestion process environmental sciences essay

A simulation model is developed to predict the performance of a tubular digestion process of a very low A/C ratio diaspore bauxite type. The Elec-NRTL property method is used to calculate the equilibrium and thermodynamic properties of the slurry. The Aspen Plus simulator is employed as a platform to solve the reaction and thermodynamic submodels simultaneously. The model consists of several ideal operational blocks, which are combined in an appropriate manner. The model prediction was compared to industrial experimental data in terms of the flash tanks temperatures, and close agreement was found. The simulation model was utilized to predict the digestion process behavior at various operating conditions. Moreover, some case studies were performed. One practical output of this work is directing the exhaust vapor from the last flash tank to the pre-heater. It results to eight percent decrease in the furnace fuel consumption and leads to increase water recovery in the digestion unit.

Introduction

Diaspore bauxite disintegration in comparison with other bauxite types has more complicated operational conditions and requires higher temperature, pressure and caustic concentration [1], [2] and [3]. Bauxite ores originated from separate mines are different in chemical composition, mineralogical properties and other characteristics [4]. The silica bearing minerals in bauxite is an important factor which causes increase in process energy costs and chemical losses., and as a result decrease in the aluminum hydroxide production rate and quality [5], [6] and [7]. In some cases, it occurs in the form of chamosite (Fe2+3Mg1. 5AlFe3+0. 5Si3AlO12(OH)6), causing more harmful effects [8]. Jajarm bauxite (Table 1) is of the diaspore-chamosite type and its alumina to silica mass ratio (hereafter referred to as A/S), is very lower than other bauxite ores originated from distinct mines of other countries [9], [10] and [11]. It is well known that lower amount of A/S and presence of chamosite results in more severe digestion process condition [7], [5] and [8]. For each mineral ore resource and extraction process, a particular combination of parameters can lead to optimal digestion process performance. Table1: Average chemical composition of Jajarm bauxiteComponentMass%Al2O349. 1SiO211. 2Fe2O319. 2TiO25. 6LOI11. 6OthersRem. The Iran alumina complex is fed by the Jajarm bauxite reserves of the diaspore-chamosite type. Due to operational and technical problems that had arisen in the high-pressure tube digestion unit during the start-up period, the production rate has not reached the nominal capacity until now. Therefore, several modifications have been made on various aspects of the process, particularly on the digestion unit [12], [13] and [14]. Consequently, changes have been made on several operational parameters; the digestion temperature, pressure and duration time were among the most extensively changed [15] and [16]. These alterations have been resulted in lack of detailed knowledge about the effect of various factors on the digestion process. Since experimental investigations are very expensive and time-consuming on industrial scale, simulation can be viewed as a proper approach to appropriately comprehend and predict the thermal and hydrodynamic behavior of the slurry digestion process. Process modeling and simulation of Bayer and alumina digestion are dealt with in number of publications [17] and [18]. However, very few attempts have been reported in the literature on the modeling and simulation of tubular digestion process of diaspore bauxite type. Various process simulators, such as Aspen plus and

Hysys, are employed for industrial process simulation. These process simulators only include standard, ideal process operation blocks, such as Heat exchanger and stoichiometric reactor based on known fractional conversions of reaction; RStoic. Therefore, it would possible to introduce the digestion process in such simulators by the proper combination of these ideal blocks [19]. The present study was performed on the modeling and simulation of an industrial tubular digestion process of a very low A/C ratio diaspore, Jajarm, bauxite type. Using the developed model, the influence of key operating parameters on the process was predicted. In addition, the effect of the aforementioned parameters on thermo/hydrodynamic behavior of the slurry, with the aim of optimizing the energy consumption of the digestion process, was investigated. Figure1: Digestion stage block diagramHigh P&T water condensate)To red mud separation & alumina precipitation stage (unit 13)Water (Condensate)Condensate flash drumsFurnaceDigester; Tubular reactor and retention tankAlumina slurry flash tanks(from pre-desilicationStage; unit 9)Jajarm bauxite slurryPre-heatersRecovered steam

Process description

The diaspore bauxite slurry, a mixture of ground bauxite, lime and caustic liquor, enters the digestion unit at around 10MPa and about 100°C (Table2). As shown in Figure 1, it passes through high pressure counter current shell and tube pre-heaters, consisting of nine sections, where the slurry is heated by exit vapor from the flash tanks. The slurry is further heated in the digestion furnace to about 270 °C and fed to the tubular digester where the alumina dissolution takes place. The slurry then continues its way through holding tank to provide the adequate residence time where the dissolution reaction becomes completed. According to the laboratory’s test results, about 73 percent by mass of the alumina which is presented in bauxite slurry transforms to a soluble form as sodium aluminates [9], [14] and [20]. Table2: The average chemical composition of digestion unit inlet and outlet slurrySlurry ComponentLiquid PartSolid Part, Outlet (mass %)Inlet (g/l)Outlet (g/l)Al2O38424017. 9Na2OC167208

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Na2Ot1952455. 9Fe2O3

-

-

27SiO2

-

0. 8814. 8TiO2

-

-

7. 8CaO

-

-

15. 2-: The relevant component does not exist or exists insignificantly. The resulting product of alumina slurry then passes through the expanding stage, where the excess energy in the superheated liquid is flashed off as steam to

recover the thermal energy. Pressure is reduced by using eleven flash tanks which have different sizes and the pressure amount is set by orifices of different diameters at the inlet of each flash tank. The generated vapor from the first nine flash tanks is used to heat the bauxite slurry in pre-heaters where, the vapor condensed and takes its liquefying heat to the passing slurry. The condensed exhaust vapor (water) from pre-heaters then enters other type flash vessels; called condensate drums, where its pressure is decreased and accordingly is vaporized again and transferred to the next pre-heater section. The rest leave the vessels as water stream. Finally alumina slurry leaves the last flash tank at a temperature between 115and 130oC and a pressure of around 0. 16MPa and precipitates as alumina hydrate in subsequent units [13] and [16]. Table 3: Properties of slurry that have been used in the simulationParameterTemperature(°C)Pressure (Mpa)Digestion inlet95-1009. 6-10pre-heater outlet

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7Furnace outlet260-2806. 2-6. 6Digester outlet255-2754. 4-4. 9

Modeling and simulation

The digestion process consists of three phases of solid, liquid and vapor. Its main flow is an electrolytic solution composed of various ions with solid components in the form of slurry which some processes such as water to vapor and vice versa phase conversion, heat exchange, pressure variation and chemical reactions take place during it [17], [4] and [18]. Reactions (1) to (4) can be considered as the Bayer process major reactions which happened from the beginning to the end of the digestion process. Reactions (1) to (3) mostly take place in the earlier stages; milling and pre-disilication

[21], [22] and. Dissolution of alumina is the main reaction of the process. Therefore, only reaction (4) is considered in this work. All other side reactions are neglected. NaOHNa+ + OH- (1)CaO + H2O Ca(OH)2(2)Kaolinite + 2NaOH Na2O. Al2O3. 2SiO2 + 3H2O (3)2AlOOH + 2NaOH 2NaAlO2 + 2H2O (4)Because two types of phenomena, i. e., physical and chemical, exist in the digestion process, suitable property methods that can be capable to describe these two phenomena should be included in the modeling the digestion processes. According to the literatures [23], [24], [25] and [26], there are some property methods which can be used to model aqueous electrolytic process; Pitzer and Elec-NRTL are among them. Each one of these property methods is capable to handle fixed materials in a limited thermo-dynamic properties range [26], [27] and [28]. Previous literatures showed that the Elec-NRTL that first proposed by Chen et al [29], can be used for aqueous electrolytic solutions in different concentrations and conditions. This property method was used by different researchers for modeling of hydrometallurgical processes such as dissolution of alumina and led to reasonable results [17], [18] and [30]. Moreover, experimental data of the steam tables property correlation can be used to predict interaction between different flows of water and vapor [31] and [32]. chart-zahra[01] - Copy. tif

Figure2: schematic simulation diagram of the digestion process

In order to develop a predictive model, two physical and chemical phenomena that coexist in the digestion process should be integrated properly. The physical phenomenon describes slurry's thermo/hydrodynamics behavior and the chemical phenomenon provides the chemical reactions occurring inside the tube digester. The Aspen Plus simulator was used as a platform to solve the reaction and thermo/hydrodynamic submodels simultaneously. The built-in capabilities of the simulator were used in developing the model, i. e., at each section, a proper ideal block was used to model the slurry flow behavior through the heating, digestion and expansion stages, respectively. In this study, based on thermodynamics consideration, several ideal operational blocks were combined together in order to provide a model for the performance of the slurry in the dissolution process by using the sequential modular approach. The physical phenomenon consists of two major stages named heating and expansion. Then for modeling of each stage, ideal operation blocks such Heatx along with Furnace and Flash3 were employed for heating and expansion stages respectively. The alumina dissolution rate, according to the laboratory reports, is 73 percent [9] and [20]. Therefore, the RStoic ideal block was considered for the chemical reaction. Each of the equipment was considered as an individual system that its inlet and exit streams were in the steady state conditions. All the equipments and interconnecting tubes have suitable thermal isolations. Therefore all blocks, except the furnace are considered adiabatic. Other assumptions are as follows: Only the dissolution of alumina; reaction (4), was considered as the digestion reaction, as previously described. All other side reactions are neglected. The entire inlet vapor to pre-heater sections assumed to be condensed at the hot sections. The digestion unit operates at steady state conditions. The slurry and vapor flows inside each flash tank and its outlets are isothermal and isobar. A schematic simulation diagram of the digestion process is shown in Figure 2.

Upon the determination of thermodynamic parameters for the slurry at each section, Aspen Plus solves material and energy balance equations and predicts physical and thermodynamic properties. Table4. Flash tanks slurry pressure that have been used in the simulationFlash Tank0607080910111213141516Pressure(MPa)2. 72. 32. 11. 71. 41. 10. 80. 60. 40. 30. 16

Results and discussion

Input data and operating conditions are given in Tables 2, 3 and 4. Results of the simulation model presented in this work are detailed as follow. Table 5: Comparison between calculated and actual value of flash tanks temperatures using water as input streamFlashTankPressure(MPa)Temperature(°C)Error

%

ExperimentalCalculated64. 42522561. 673. 62432440. 483. 32412400. 492. 62282270. 4102. 02152130. 9111. 52011981. 5121. 11891833. 2130. 71671623. 0140. 41461404. 1The experimental data of using water as the input stream to the digestion unit, belongs to ten years ago, was used for comparison with this model. The water inlet flow rate and pressure were 130 m3/h and 9. 63 MPa respectively. The furnace temperature and digester pressure were 310°C and 5. 54 MPa correspondingly. The other operating conditions and some of the corresponding results are shown in Table 5. Considering the sensitiveness of performance of the slurry flash tanks and their considerable effect on the system performance, measured temperatures of the flash tanks were compared by the calculated temperatures. As seen in the Figure 3, the model satisfactorily fits the experimental data.

Fig. 3: Comparison between experimental and calculated temperatures of flash tanks of using water as input stream

In the next step, the experimental data of actual operating conditions of using the local diaspore slurry as input flow were compared with the model predictions and shown in Figure 4. Cases one to six are measured data of different operating conditions of the digestion process during different times. These data are taken from an investigation done on the behavior of the digestion process during several two-month periods for a total period of two years [16]. This figure also shows the good agreement between the model predictions and actual plant data. Therefore the model can be used to predict the slurry behavior in the digestion process.

Fig. 4: Comparison between experimental and calculated temperatures of flash tanks of using water as input stream

Case studies

Effect of changes in some key parameters on the behavior of the digestion process was investigated based on the model developed in this work. Some of these case studies are given below. The effects from the change in temperature of the slurry exiting from the furnace on the amount of vapor produced by the flash tanks and also the temperature of the slurry exiting from the pre-heater sections are shown in Table 6. The temperature rise causes an increase in the vapor generated by the flash tanks, and therefore, the temperature of the slurry exiting from the last section of the pre-heater (cold stream) will increase. Table 6. The effect of furnace outlet temperature on the vapor generation and the pre-heater outlet temperatureFurnace slurry temperature (°C)260265270275280Vapor created

)kg/h(2420424744257752686128011Pre-heater slurry temperature(°C)183185. 3189. 6194. 1198. 8Figure 5 shows the influence of variation in the digester outlet temperature on the first flash tank slurry and vapor streams behavior. The digestion process inlet slurry flow and pressure were considered 130 m3/h and 10 MPa, respectively. As it can be seen in this figure (right and left), increasing furnace outlet temperature leads to increase created vapor by the flash tank and consequently, causes an increase in the last pre-heater cold stream (outgoing bauxite slurry) temperature. Moreover, reducing furnace outlet temperature to a specific limit, 250°C, leads to eliminate flashing and vapor generation inside the flash tank number 06.

Figure 5: The effect of slurry temperature on the generation of vapor by V06 (left) and the pre-heater cold stream temperature (right)

At the time of fulfill this work, only the thermal energy of flash steam generated in the first nine flash tanks was used in the pre-heater and those of the last two flash tanks were, in some extent, used in the other units of the refinery. The rest of the thermal energy, a considerable amount, was wasted. The alumina slurry leaves the flash tanks at 115-129°C and 0. 11-0. 17 MPa and then enters the slurry homogenization tank stage. From this stage, the slurry enters the mixing tank containing slurry and recovered caustic from the " red mud washing unit" and, thus, its temperature drops to about 105°C. A temperature of 122°C is considered to be the average temperature of the slurry that exits from the last flash tank of the digestion unit. Therefore the thermal energy and water vapor that can be gained from the last two flash tanks and temperature drop to 105°C during the abovementioned steps were computed by the model and presented in Table 7. Table 7: Heat and vapor generated from slurry pressure or temperature drop in different stagesSlurry locationvapor created (kg/h)Heat generated (MJ /h)Pressure drop (MPa)Temperature drop (°C)Flash tanks06 to 1419378255. 423. 1485. 3flash tanks15 and 16664984. 43. 4746from flash tank 16 to the ″mixing″ stage211528. 10. 5517This table shows that, from a total of 367. 9 MJ/h dissipated heat and 28142 kg/h of vapor generated, only 255. 4 MJ/h of dissipated heat and 19378 kg/h of vapor was directed to the pre-heaters. Thus, a considerable amount (30%) of thermal energy and also created vapor (31%) from the last two flash tanks as well as in the path of the exit slurry from flash tank 16 to the " mixing alumina and recovered soda unit", reaching the required temperature, was lost and cannot be reused in the pre-heater. As a result of this investigation, the generated vapor by last flash tank, number 16, is currently directed to the pre-heater sections. Consequently, the slurry exit temperature of the pre-heater and the amount of water recovery in the digestion unit have been increased. Thus, the digestion furnace fuel consumption drops from 2500 to 2300 kg/h and becomes 200 kg/h less than the earlier condition for every line.

Conclusions

A thermodynamic process model was developed for predicting the performance of an industrial tubular digestion process of a very low A/S ratio diaspore bauxite type. The model consists of several ideal operational blocks, which are combined in an appropriate manner. The Aspen Plus simulator was used as a platform to solve the reaction and thermo/hydrodynamic submodels simultaneously. The model prediction was compared to experimental data in terms of the flash tanks temperatures, and close agreement was found. The simulation model has been employed to predict the digestion process behavior at various operating conditions. The outcome of this study could be used by operators and engineers to optimize the digestion unit. One practical output of this work is directing the exhaust vapor from the last flash tank to the pre-heater. It results to eight percent decrease in the furnace fuel consumption and leads to increase water recovery in the digestion unit.