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Bayer Process Efficiency Improvement

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Abstract

The process efficiency has a great influence on the production yield, energy consumption, investment and operation cost in Bayer process.

The factors affecting the Bayer efficiency are particularly discussed in this paper. Reducing the molar ratio of pregnant liquor and raising the molar ratio of spent liquor and the caustic concentration of spent liquor will enhance whole output efficiency in Bayer process. Higher concentration of spent liquor will bring about higher productivity in digestion process and a higher pregnant liquor concentration will be required for reducing energy consumption at evaporation stage as well.

The key technology development to improve the Bayer efficiency in Chinese alumina production is revealed.

Introduction

The energy consumption is of great significance to the operation cost in all the alumina refineries, about 40% of which is related to energy consumption in China including vapor for Bayer digestion and evaporation, gas for calcination and power for pumps, agitators and fans etc.

Nevertheless the energy consumption depends on the Bayer process efficiency to a great extent. The process efficiency has a great influence on the production yield, energy consumption, investment and operation cost in Bayer process.

The efficiency improvement will lead to more productivity for the same flow rate and energy consumption reduction for unit output in the Bayer cycle. So the energy saving could be achieved not only by application of energy saving processes and equipment, such as fluidized calcinations instead of rotary kiln, indirect preheating in digestion process, efficient red mud settling and sweetening process etc. but also by increasing the Bayer process efficiency without much change for the process and equipment.

Bayer efficiency improvement becomes more important and necessary since the technology and equipment in almost all the stages in Bayer process have been up-to- dated in the past years. Energy shortage and its price rise have driven alumina producers to reduce energy consumption and operation cost. The best way is to improve Bayer process efficiency.

A further study on the factors to influence process efficiency and how to improve efficiency should be carried out for the relevant technology development.

It is known from the systematic analysis and study on Bayer process that the efficiency in Bayer process is closely related to three important parameters: caustic concentration of spent liquor, alumina extracted from bauxite during digestion and alumina precipitated from pregnant liquor during seeded precipitation.

In this paper the factors are analyzed in detail and the possibility to develop technology for process efficiency improvement is discussed.

Analysis of the factors impacting Bayer efficiency

Bayer process is mainly composed of four stages: bauxite digestion, red mud separation, seed precipitation and liquor evaporation as shown in Fig. 1.

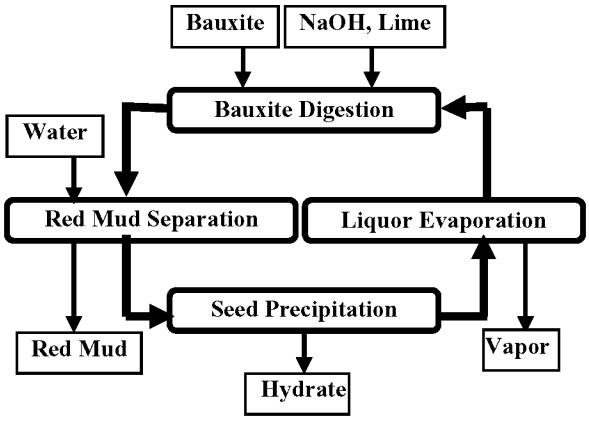

Figure 1. Typical Bayer Cycle

In Bayer process red mud separation and liquor evaporation are basically physical processes without major chemical reactions to take place. Bauxite digestion and seeded precipitation are the main chemical reactions. And the processes occurred in the stages can be considered as the reverse reactions:

$$Al(OH)_3 \text{ (or AlOOH)} + NaOH \rightleftharpoons NaAlO_2 + H_2O$$

It can be considered that the Bayer process is a stable cycling process and the spent liquor for digestion remains in a same composition after every cycle, that means its caustic and alumina concentrations will keep the same. And it is supposed that all the alumina extracted from bauxite in digestion will decomposed to alumina hydrate in precipitation process without any loss to residue.

Based on the above the alumina output (A) for every cubic meter of spent liquor in a Bayer cycle could be considered as follows:

$$E = Ap - As$$

where:

Ap is the alumina concentration in pregnant liquor in g/L

As is the alumina concentration in spent liquor in g/L

E is the Bayer efficiency in kg/m^3

Since the molar ratio of Na_2O to Al_2O_3 in liquor will not be changed in flash tanks and during slurry dilution a technical term (molar ratio MR) is used for efficiency study:

$$MR = 1.645*Nk/A$$

in which A is alumina concentration in g/L;

Nk is caustic concentration in g/L

Therefore,

$$E=1.645*Nk*(1/MRs-1/MRp)$$

where, MRs and MRp is the molar ratio of spent liquor and pregnant liquor respectively; and the caustic concentration Nk is considered unchanged from the beginning to the end during digestion.

So the Bayer process efficiency E is directly proportional to caustic concentration of spent liquor and related to MR change before and after digestion.

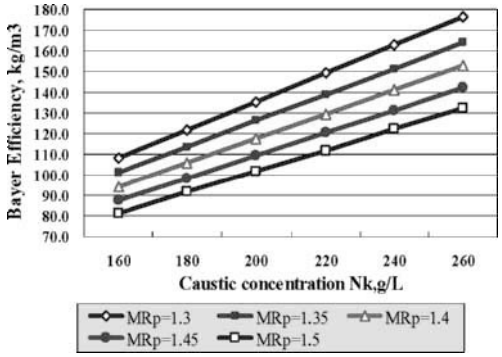

Figure 2. Bayer efficiency E vs. Nk

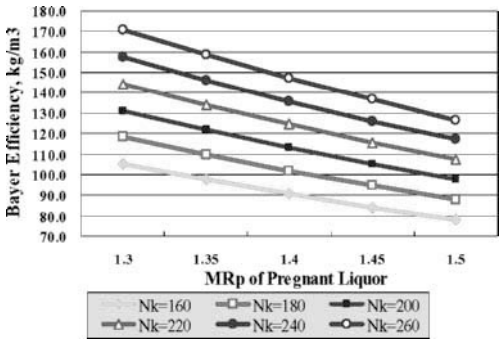

Figure 3. Bayer efficiency E vs. MRp

It can be seen from Figures2 and 3 that the higher Bayer efficiency can be achieved by increasing caustic concentration and reducing MRp, i.e. MR of pregnant liquor.

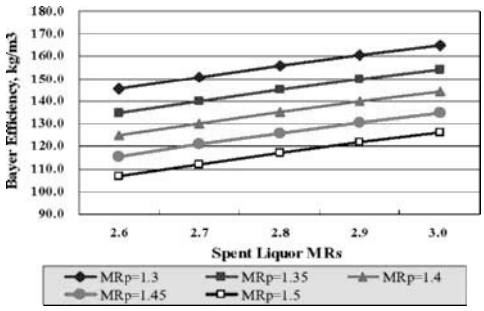

Figure 4. Bayer efficiency E vs. MRs

Figure4. shows that the higher MRs of spent liquor is the higher Bayer efficiency can be achieved.

In order to increase Bayer cycling efficiency in a refinery three kinds of process improvement can be carried out:

(1) Increasing caustic concentration Nk;

(2) Reducing MRp;

(3) Increasing MRs.

MRs usually is in the range from 2.5 to 3.2 and MRp is between 1.2 and 1.6 for a general Bayer process.

It can be found by comparison of Figures 3. and.4. that slopes of the curves for E vs. MRp are much higher than the slopes of E vs. MRs. The detailed calculations show that the increase of E by 0.1 reduction of MRp will be about four times higher than that by 0.1 increase of MRs. Therefore reducing MRp will lead to a greater Bayer efficiency improvement than increasing MRs.

The most important chemical reactions happen in the digestion and precipitation stages in the Bayer process. So the Bayer efficiency improvement is closely related to the reaction efficiency and productivity in both stages.

The digestion temperature, caustic concentration and MRs are the major technical parameters for bauxite digestion. And the digestion efficiency and MRp are the major results to impact Bayer efficiency. The higher caustic concentration Nk and MRs will increase digestion efficiency and reduce MRp, which bring about higher Bayer efficiency.

Precipitation is the longest stage in Bayer process and its productivity determines the output efficiency for whole Bayer process to a great extent. The higher precipitation efficiency (lower MRs) can be achieved by seed addition, temperature control, residence time and suitable caustic concentration. The higher caustic concentration in precipitation will probably lead to reducing the precipitation efficiency but higher precipitation output. So a trade off analysis should be considered for the best results.

Reduction of the caustic concentration difference between digestion and precipitation is very important for the energy saving

at evaporation process. So a higher Bayer efficiency can be achieved by increasing Nk of spent liquor and a systematic energy saving can be obtained by higher Nk of pregnant liquor as well.

The optimization of concentration system in whole Bayer cycle is very important for higher Bayer efficiency and lower energy consumption in the refineries.

Technological solutions to improve Bayer efficiency

It is well known that the operation cost of alumina production in the refineries mainly depends on energy consumption, operation efficiency and investment cost etc.

All the factors are closely related to the operation efficiency in whole Bayer process and at the different stages. As discussed above it is concluded that the best way to achieve a higher Bayer efficiency and energy savings are to reduce molar ratio of pregnant liquor, relatively increase the molar ratio and caustic concentration of spent liquor and decrease liquor concentration differences as much as possible.

Firstly all the stages in Bayer process should be intensified for a higher stage efficiency, i.e. higher digestion efficiency, precipitation efficiency and evaporation efficiency etc. The intensification of the process stages by improvement of process parameters and application of more efficient equipment will provide better process conditions and higher caustic concentrations for the chemical reactions to complete in a shorter period and to save energy and raw materials, such as bauxite, caustic and lime etc.

Secondly the systematic optimization of the Bayer process is another important technical solution for improving Bayer efficiency, which includes optimizations of the caustic concentration and molar ratio systems in whole Bayer process.

A series of key technology have to be developed to achieve the goals of both intensifying all the stages and realizing systematic optimization of Bayer process.

Reducing the molar ratio of the pregnant liquor

Reducing the molar ratio of pregnant liquor as much as possible is the most important technological solution for improving Bayer efficiency.

Relatively lower MRp can be obtained by intensifying digestion process including suitably raising digestion temperature, increasing digestion time and caustic concentration. Digestion temperature is the key condition to intensify the process and depends on the equipment limitation, heat resource, energy and water balance etc.

The intensifying digestion technology has been developed and applied in China since 20 years ago. Since all the Chinese refineries have to treat diasporic bauxite the higher caustic concentration Nk and higher digestion temperatures are used for a better digestion efficiency. Figure 5, shows a technical scheme of intensified digestion process.

The problem for the intensifying digestion is the lower digestion operation rate due to fast scaling on the indirect preheating surface. The technical solutions developed in China are as follows:

(1) Reducing scale by enlarging the preheating surface and increasing slurry flow rate;

(2) Installing more spare equipment and developing fast switch technology for scale removal;

(3) Setting up predesilication tank(s) before digestion and in the stage to reduce reactions of silica minerals on preheating surface.

The operation rate has been greatly increased by scaling inhibition mentioned above.

On the other hand on order to improve Bayer efficiency higher digestion caustic concentration and MRs should be provided, which depend on the Nk and efficiency in precipitation stage and evaporation.

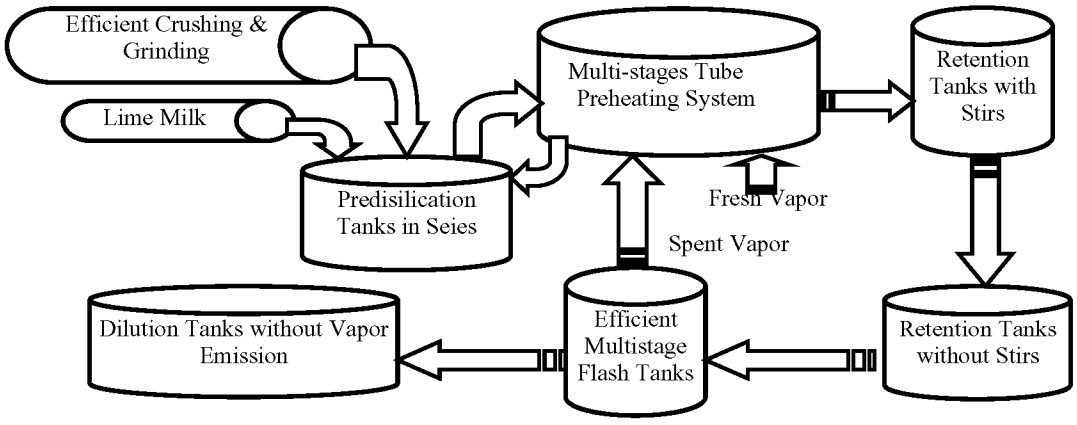

Figure 5 Schematic diagram for the intensified digestion stage

To keep accurate recipe during bauxite slurry grinding is necessary for obtaining both better MRp and higher bauxite digestion efficiency. An online bauxite and slurry test technology is developed for this purpose.

The key technology of intensifying digestion is widely applied in Chinese refineries for both higher digestion efficiency and lower MRp at the higher Nk.

In order to make MR of pregnant liquor for precipitation as close to that of bauxite digestion slurry as possible the precipitation which might occur in the red mud settlers and washers should be alleviated, i.e. the MR difference between both liquors should be reduced. The best way for this is to keep the settling process at higher temperatures and Nk.

Sweetening process is an effective solution for lower MR of pregnant liquor and higher productivity at precipitation. .

Increasing molar ratio of spent liquor

Increasing MRs of spent liquor is a key factor to improve Bayer efficiency and digestion productivity.

Increase of MRs mainly depends on the precipitation efficiency and reduced hydrate suspension in spent liquor after hydrate filtration. The precipitation efficiency basically relies on the precipitation temperature system including the liquor primary and final temperatures and the temperature reduction gradient in the process. And it also depend on the seeding system including seed rate, seed size distribution and washing and addition ways, and liquor caustic concentration, precipitation time and additives as well. The lower precipitation temperature and MRp and higher seed content will make higher MRs and precipitation efficiency, which mainly relies on the process parameters control and optimization.

A key precipitation technology with higher efficiency for sandy alumina has been developed in China. The technical solutions are:

(1) Increasing Nk and reducing MRp for higher precipitation productivity;

(2) Optimizing the temperature reduction gradient during precipitation by using well designed intermediate heat exchangers;

(3) Forecasting of hydrate size distribution change by regular testing the minor hydrate size and analysis and control system.

(4) Applying the additives for a stable hydrate size distribution.

There has been a great progress in the field of reducing hydrate suspension from 2-10 grams per liter to less than 1 g/L in the filtrate from hydrate filtration.

Optimizing liquor concentration system

Optimization of the liquor concentration system is carried out based on the principles: greater Bayer efficiency, larger productivity at the main stages and smaller liquor concentration difference between the digestion and precipitation processes for reducing energy consumption at evaporation.

The relatively higher spent liquor concentration is more important for diasporic bauxite digestion and anelevated digestion productivity will be obtained. Nevertheless a higher precipitation concentration is needed for reducing evaporation energy consumption. Increasing pregnant liquor concentration might have a negative effect on precipitation efficiency and sandy alumina production. So the optimized caustic concentration system has to be specially designed according to the status of the process parameters and major equipment.

Figure 6. shows the optimized high efficient Bayer process with series of key technologies including intensified and efficient digestion, low loss settling, efficient precipitation for sandy alumina and energy saving evaporation..

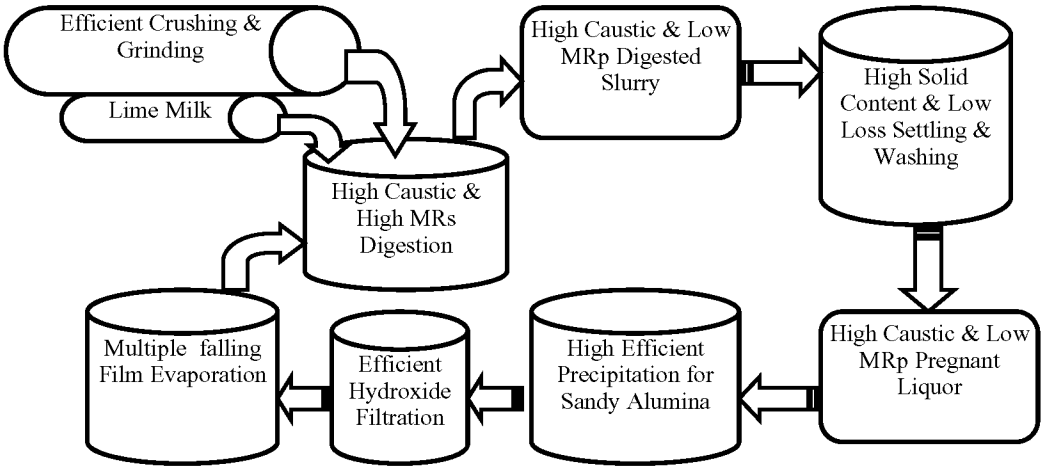

Figure 6 Schematic diagram of optimized high efficient Bayer process

It is concluded that the design of a new alumina refinery should be optimized based on both technological and economical considerations for a relatively higher operation efficiency and productivity, lower raw materials and energy consumption. And for an old refinery some process parameters are supposed to be improved for achieving the same goals.

Conclusion

(1) The Bayer efficiency mainly depends on the caustic concentration of spent liquor, MR of pregnant liquor and spent liquor. The Bayer efficiency will be improved by increasing liquor caustic concentration, reducing MR of pregnant liquor and enhancing MR of spent liquor.

(2) Reducing MRp will lead to the greater Bayer efficiency improvement than increasing MRs.

(3) Bayer efficiency is improved by increasing liquor caustic concentration, which will bring about lower precipitation efficiency and higher evaporation energy consumption. So a optimized caustic concentration system should be designed for both higher Bayer efficiency and lower energy consumption.

(4) The key technologies to intensify all the stages in Bayer process will provide the basic conditions for high Bayer efficiency.

(5) An optimized caustic concentration and MR system are put forward to build a high efficient Bayer process for systematic energy saving and all the consumption reducing.

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