



## Improved precipitation of gibbsite from sodium aluminate solution by adding methanol

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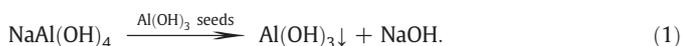
### ABSTRACT

A new method is explored to improve the precipitation of gibbsite from sodium aluminate solution by adding methanol to the pregnant liquor. The stability of sodium aluminate solution decreases in the presence of methanol, leading to faster crystallisation than the normal seeded precipitation process. The effects of methanol amount, caustic concentration, reaction time and temperature, stirring and feeding mode are systematically investigated. Considering possible industrial application, the optimum conditions are 1:1 volume ratio of methanol to sodium aluminate solution, ~170 g/L Na<sub>2</sub>O and 1.55:1 caustic to aluminate ratio at 60 °C. The feeding mode and feeding rate have no significant effect on the final yield when moderately stirred. Under these conditions, 70% precipitation can be reached within 24 h, which is about 20% higher than the Bayer seeded precipitation practice of at least 56 h. Characterization of the crystals using XRD, SEM, and PSD shows a typical gibbsite phase composed of super-thin sheets with an average diameter of ~90 μm. IR and Raman spectra analyses suggest that added methanol captures water molecules from the aluminate ion hydration sphere thus catalyzing the crystallisation process.

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### 1. Introduction

The rate limiting step of the Bayer process is the seeded precipitation of Al(OH)<sub>3</sub> from supersaturated sodium aluminate solution. This takes up to 48–72 h, which is more than half of the residence time of alumina production. Due to the extraordinary stability of supersaturated liquor and the large surface tension of 1.25 N/m between caustic solution and Al(OH)<sub>3</sub> crystal, the nuclei are difficult to form and the fraction precipitated is as low as 50% – even though the seed ratio is high. The seeded precipitation can be described as Eq. (1).



If the crystallisation time can be shortened, the production efficiency can be enhanced. If the yield can be augmented, the plant throughput can be increased.

Many studies have been done and generally three kinds of intensification measures are undertaken: seed activation, adding surfactants, and introducing ultrasound and magnetic field (Chen et al., 2003). Highly active fine seeds were obtained by combining thermal activation and mechanical activation methods (Shang, 1995)

which could increase the precipitation yield above 50% with a seed coefficient of only 0.05. In another study, 280 mg/L anionic surfactant was added into the supersaturated solution (Zhao et al., 2004) which increased the gibbsite yield by about 5%. Yang et al. (2002) showed that the precipitation could be enhanced by adding 2% cationic or non-ionic surfactants and 6% macro-molecular anionic surfactants. Ultrasonic conditioning was first applied to Al(OH)<sub>3</sub> precipitation by Zhao et al. (2000). When the caustic aluminate solution was treated by ultrasound of a certain intensity, the precipitation time for a 45% yield could be reduced from 30 h to 15 h, and the precipitation yield could be increased by 9% within 6 h. However, the high cost and operational difficulty limit the industrial application of the methods mentioned above.

In practical production processes, the main adjustments that can be made to enhance the precipitation include decreasing the molar caustic ratio (MR, mole ratio of Na<sub>2</sub>O to Al<sub>2</sub>O<sub>3</sub>) and the caustic concentration of the refined sodium aluminate liquor, adjusting the temperature control program, and reducing the concentration of sodium carbonate in initial solution (Han and Fan, 2001). However, these measures are not very effective due to limitations of the system phase equilibrium as well as the alumina product quality requirement. In this regard, new methods need to be developed to resolve the problems of low yield and slow rate.

At present, besides the conventional crystallisation processes using different methods such as temperature control and evaporation, more research is focused on anti-solvent crystallisation whose aim is to reduce the solubility of the solute and hence create supersaturated

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solution. Related work has been extensively reported in both the organic and inorganic fields (Kitamura and Sugimoto, 2003; Koutek et al., 1996; Moldoveanu and Demopoulos, 2002). With regard to the sodium aluminate solution system, Andrija (1968) and Wilhelmy (1990) pointed out that up to 20% v/v methanol could promote crystallisation of  $\text{Al}(\text{OH})_3$  from the caustic solution. Nevertheless, to the best of the authors' knowledge, no further research appears to have been carried out. According to Wang et al. (2008a,b), the solubility equilibrium can be changed by the introduction of methanol, leading to a significant increase in the driving force for crystallisation. Methanol can be efficiently recycled by distillation and reused.

In this paper, the crystallisation of gibbsite from caustic aluminate solution in the presence of methanol is systematically studied and the role of methanol discussed. The effects of methanol amount, caustic concentration, time, temperature, stirring and feeding mode on the precipitation yield and morphology are investigated. The products are characterized and analyzed by XRD, SEM and PSD (particle size distribution).

## 2. Experimental

### 2.1. Reagents

All the chemicals used in this work, including  $\text{NaOH}$ ,  $\text{Al}(\text{OH})_3$ ,  $\text{CH}_3\text{OH}$ , and  $\text{HCl}$ , were of analytical grade and manufactured by Beijing Chemical Reagents Company. High-purity Milli-Q water, with a resistivity of above 18.2 M $\Omega$  cm at ambient temperature, was used.

### 2.2. Preparation of supersaturated sodium aluminate solution

The sodium aluminate solution was prepared by dissolving required amounts of aluminum hydroxide into hot sodium hydroxide solution in a polytetrafluorethylene (PTFE) vessel. The solution was heated to the desired temperature (110–120 °C) with constant stirring. When the solution became clear, it was filtered twice and diluted with deionized water to the designed concentration. The obtained solution was reserved for further use in an oven at a constant temperature of 80 °C.

### 2.3. Precipitation reactor and procedure

The batch reactor used in this work was a three-neck flask with a volume of 500 mL. A 60 mm two-blade mechanical stirrer was used to stir the solution and a liquid feed pump was used to add methanol. The reactor was heated by a thermostatic water bath with an accuracy of  $\pm 0.1$  °C and a condenser was used to condense the vapour.

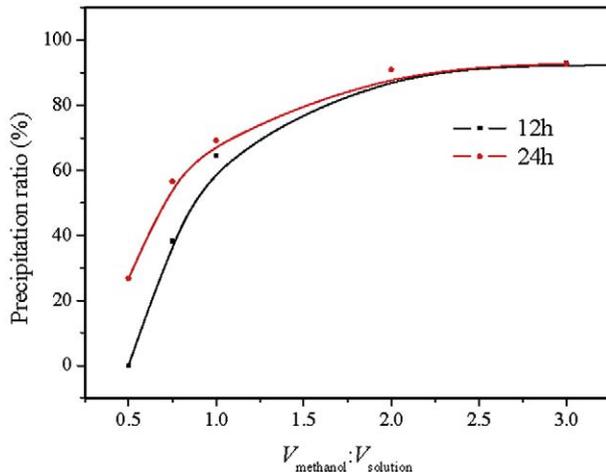


Fig. 1. Effect of volume ratio of methanol to caustic solution on the precipitation ratio. [ $C = 182.3$  g/L,  $A = 186.3$  g/L,  $MR = 1.61$ ;  $T = 60$  °C;  $N = 300$  min $^{-1}$ ;  $n = 1.2$  mL/min].

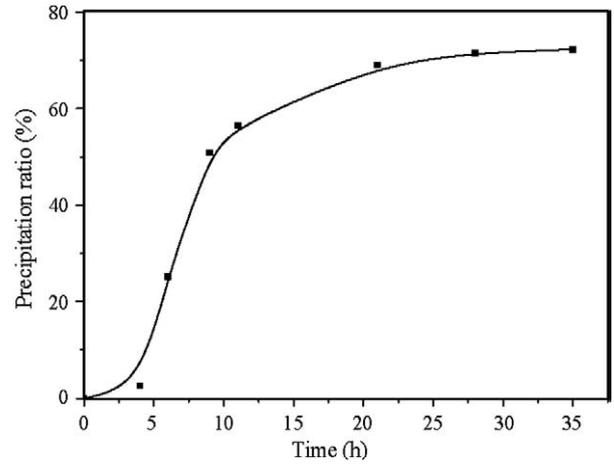


Fig. 2. Effect of reaction time on the precipitation ratio. [ $C = 162.8$  g/L,  $A = 169.2$  g/L,  $MR = 1.58$ ;  $T = 60$  °C;  $N = 300$  min $^{-1}$ ;  $n = 1.2$  mL/min;  $V_{\text{methanol}}:V_{\text{solution}} = 1:1$ ].

After the temperature of the precipitation reactor reached the pre-set value, 150 mL aluminate liquor with pre-adjusted  $\text{Na}_2\text{O}$  and  $\text{Al}_2\text{O}_3$  concentrations was poured into the precipitation reactor. When the system reached a stable state, the required amount of methanol ( $V_{\text{methanol}}:V_{\text{solution}}$ ) was added into the solution with a feeding rate ( $n$ ) controlled by the feed dosing pump whilst the solution was kept stirred at a constant speed ( $N$ ). At appropriate time intervals during a run, approximately 5 mL of the reaction mixture was collected and filtered and the filtrate was diluted with 2% v/v conc.  $\text{HCl}$ . Finally, the sample was analyzed by ICP-OES to determine the concentrations of  $\text{Na}_2\text{O}$  and  $\text{Al}_2\text{O}_3$ .

The yield or precipitation ratio ( $\eta$ ) was calculated with respect to the increase of  $MR$  according to Eq. (2) (Bi, 2006).

$$\eta = \frac{MR_{\text{later}} - MR_{\text{initial}}}{MR_{\text{later}}} \times 100 \quad (2)$$

$$MR = \frac{C}{A} \times 1.645 \quad (3)$$

where  $MR_{\text{initial}}$  and  $MR_{\text{later}}$  are the caustic ratio of the solution initially and after crystallisation,  $C$  is the concentration of  $\text{Na}_2\text{O}$  (g/L), and  $A$  is the concentration of  $\text{Al}_2\text{O}_3$  (g/L).

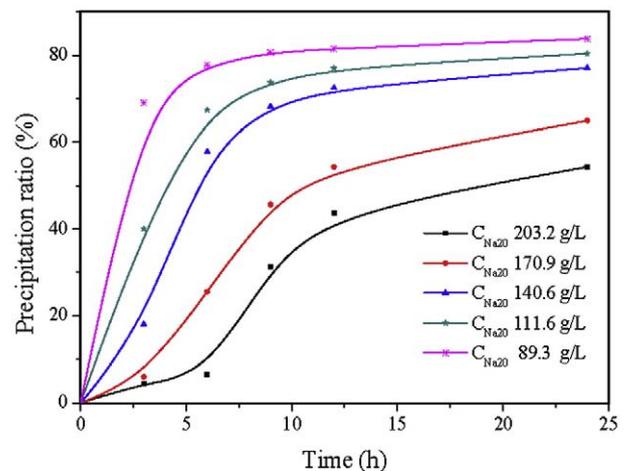


Fig. 3. Effect of  $\text{Na}_2\text{O}$  concentration on the precipitation ratio. [Other conditions as Fig. 2].

### 3. Results and discussion

The physico-chemical structure of sodium aluminate solution is strongly dependent on the concentration of the system and is very critical in the precipitation of aluminum hydroxide from the solution. Due to the difficulty in examining the precipitation mechanism, abundant research work on the effects of different factors has been done in this laboratory to increase the yield.

#### 3.1. Effect of volume ratio of methanol to caustic solution

An important factor is the dosage of methanol added to a fixed system. Due to the differences in the physico-chemical properties of methanol and water and their ability to dissolve  $\text{Na}_2\text{O}$  and  $\text{Al}_2\text{O}_3$ , the ratio of the two influences the  $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3/\text{H}_2\text{O}$  ternary system and changes the precipitation ratio. In this work, the volume ratio of methanol to caustic solution was in the range of 0.5:1 to 3.0:1 and the corresponding results are shown in Fig. 1.

It can be seen from Fig. 1 that the precipitation ratio or yield is strongly dependent on the amount of methanol added, particularly when the volume ratio of methanol to caustic solution is smaller than 1:1. When the volume ratio is higher than 1:1, the increase of the precipitation ratio is moderate because of the dilution effect and the increased binding of solvent molecules via hydrogen bonds. Thus when large amounts of methanol are present, water activity will decrease (Borissova et al., 2004).

According to the solubility curve of  $\text{Al}(\text{OH})_3$  in  $\text{NaOH}$  solution (Bi, 2006), the lower the  $\text{Na}_2\text{O}$  concentration becomes, the lower the saturated  $\text{Al}_2\text{O}_3$  concentration will be. Due to the dilution effect, the amount of water molecules per unit volume decreases and more alumina will be precipitated. Furthermore, the hydrogen bonding with methanol decreases the amount of free water molecules used to dissolve  $\text{Na}_2\text{O}$  and  $\text{Al}_2\text{O}_3$  and thereby leads to the hydrolysis of sodium aluminate solution. According to the definition of surface entropy factor ( $\alpha$ ), the increasing of methanol content decreases the value of  $\alpha$ , and results in a rough interface and consequently high mass crystallisation rates (Barata and Serrano, 1998; Garside, 1985).

Undoubtedly, a higher yield of aluminum hydroxide with high volume ratios of methanol to caustic solution must be weighed against a higher cost of raw materials, a higher energy consumption for recycling methanol and poorer quality of the products. When the volume ratio reaches 2:1, the morphology of gibbsite becomes irregular and hard to control, and according to the SEM images the thickness of the crystal product is only in the nanometer range. Upon decreasing the volume ratio, the crystal thickness increases to 0.3  $\mu\text{m}$  (@ 1:1) and 1.6  $\mu\text{m}$  (@ 0.5:1) and the products become well-formed. In view of these results, further experiments in this work were performed using a volume ratio of methanol to sodium aluminate solution of 1:1.

#### 3.2. Precipitation kinetics

It was known that a longer precipitation time results in a greater yield of aluminum hydroxide. To determine the optimum time, the

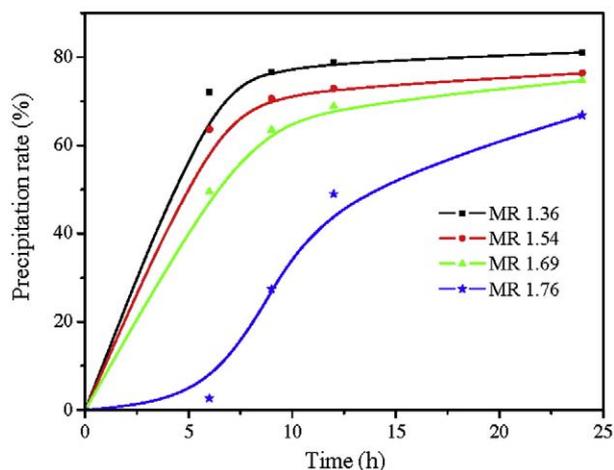


Fig. 4. Effect of MR on the precipitation ratio. [ $C = 153.9$  g/L, other conditions as Fig. 2].

effect of time on the precipitation ratio was investigated as summarized in Fig. 2.

In the early stage of the reaction, the yield is less than 3% because of the characteristic metastability of the solution and the existence of an induction period. Thus, the new method has the similar autocatalysis characteristics to the conventional seeded precipitation process (Vrbaški et al., 1958). When a large amount of crystal nuclei appear in the solution, the precipitation ratio increases rapidly in a period of 12 h. Clearly, the supersaturation coefficient decreases with time (Dash et al., 2007) and results in the slowdown of precipitation. Nevertheless the system reaches a stable state within 24 h and further experiments were performed for 24 h.

#### 3.3. Effect of supersaturation of pregnant liquor

The degree of actual supersaturation is the most important parameter in a crystallisation process. Correspondingly, in the sodium aluminate solution, the concentration, MR, and temperature ( $T$  °C) are the main factors influencing the supersaturation or precipitation driving force. Their relationship can be expressed as  $\sigma$  according to Eq. (4) (Misra and White, 1970).

$$\sigma = \frac{A - A_{\text{eq}}}{A_{\text{eq}}} \quad (4)$$

where  $A_{\text{eq}} = C \times \exp(6.2106 - 2486.7 / (T + 273.15) + 1.0875 / (T + 273.15) \times C)$ . The effects of the three factors on the precipitation ratios are summarized as follows.

##### 3.3.1. Effect of initial $\text{Na}_2\text{O}$ concentration

The effect of the initial concentration of  $\text{Na}_2\text{O}$ , ranging from 90 to 200 g/L, on the precipitation of aluminum hydroxide was studied over 24 h at 60 °C with MR kept at a constant value of 1.60. These

Table 1

Supersaturation coefficient and precipitation ratio of solutions with various caustic concentrations.

C (g/L)	A (g/L)	$\sigma$	$\eta$ (%)
203.2	208.9	0.85	54
170.9	175.7	1.05	65
140.6	144.6	1.29	77
111.6	114.8	1.52	80
87.3	89.8	1.70	84

\*The temperature of water bath was set at 60 °C.

Table 2

Supersaturation coefficient and precipitation ratio of solutions with caustic = 153.9 g/L and different MR.

MR	$\sigma$	$\eta$ (%)
1.36	1.56	81
1.54	1.26	76
1.69	1.06	74
1.76	0.99	67

\*The temperature of water bath was set at 60 °C.

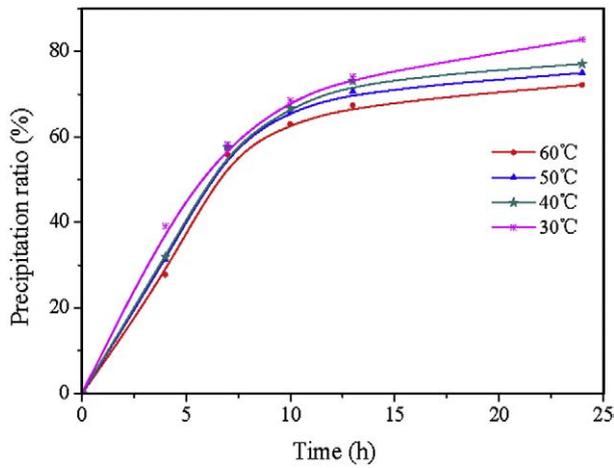


Fig. 5. Effect of temperature on the precipitation ratio. [ $C = 177.0$  g/L,  $A = 189.1$  g/L,  $MR = 1.54$ ; other conditions as Fig. 2].

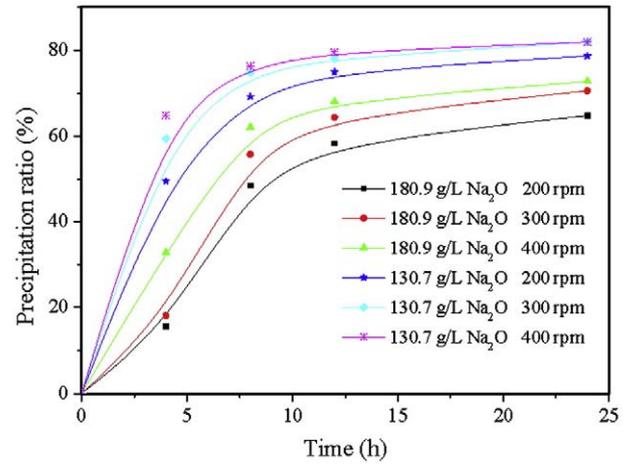


Fig. 6. Effect of agitation rate on the precipitation ratio at two concentrations of  $\text{Na}_2\text{O}$ . [ $MR = 1.57$ ; other conditions as Fig. 2].

conditions are derived from the Bayer industry seeded precipitation process of about 170 g/L  $\text{Na}_2\text{O}$  concentration and 1.50  $MR$ .

Fig. 3 shows that the precipitation ratio declines and the characteristic autocatalysis becomes distinct with the increase of the  $\text{Na}_2\text{O}$  concentration. Changing the  $\text{Na}_2\text{O}$  concentration from 170.9 g/L to 140.6 g/L, increases the yield as much as 23% after only 6 h although the increase drops to 12% after extended time. When the  $\text{Na}_2\text{O}$  concentration is below 140 g/L, the effects of concentration can be neglected.

From theoretical calculation (Misra and White, 1970), the initial supersaturation coefficients ( $\sigma$ ) of the five different systems are summarized in Table 1. Clearly, the larger supersaturation coefficient leads to higher crystallisation efficiency and the experimental results are in accordance with the theory.

Although the low  $\text{Na}_2\text{O}$  concentration gives a higher precipitation yield, it restricts the recirculation of  $\text{NaOH}$  for  $\text{Al}_2\text{O}_3$  digestion in the Bayer process, which requires a  $\text{Na}_2\text{O}$  concentration of 240 g/L. In order to integrate this approach with the Bayer process, a concentration of 170 g/L  $\text{Na}_2\text{O}$  is believed to be the most suitable.

### 3.3.2. Effect of the caustic ratio ( $MR$ )

The results in terms of the effects of increasing the caustic ratio  $MR$  (Fig. 4) show that the precipitation ratio decreases and autocatalysis becomes significantly distinct. Sodium aluminate solution with an  $MR$  value of 1.76 is very stable and shows a long induction period. It is very difficult to nucleate and crystallize, even using the conventional seeded precipitation method. After 12 h, the yield with an  $MR$  value of 1.76 is about 20% lower than that with an  $MR$  value of 1.69 and about 30% lower than that with an  $MR$  value of 1.36. However, the difference drops to 12% after 24 h. Again, the results are consistent with the change in supersaturation coefficients as calculated in Table 2. The viscosity of these systems decreases only a little with the increase of  $MR$  because of low concentration. Hence, the change of the mass transfer resistance can be neglected and the reaction is determined by supersaturation.

Table 3

Supersaturation coefficient and precipitation ratio of solutions with  $C = 177.0$  g/L and  $A = 189.1$  g/L at different temperatures.

$T$ ( $^{\circ}\text{C}$ )	$\sigma$	$\eta$ (%)
60	1.10	72
50	1.60	75
40	2.26	77
30	3.15	83

\* $C$  (g/L) value was 177.0;  $A$  (g/L) value was 189.1.

### 3.3.3. Effect of reaction temperature

The solubility of alumina in sodium hydroxide solution depends greatly on temperature, so the precipitation ratio at different temperatures should be significantly different. In the experiments, the temperatures were controlled to below the boiling point of methanol (64.5  $^{\circ}\text{C}$ ) and the results in Fig. 5 and Table 3 indeed show that the supersaturation degree and precipitation ratio decrease with the elevation of temperature. However, the equilibrium precipitation ratios after 24 h are all  $>72\%$  with a maximum of 83%, which are much higher than that of the conventional seeded precipitation ratio which is about 55%. The lower viscosity at higher temperature is a factor that enhances the yield and makes the effect of temperature small.

### 3.4. Effect of stirring

Agitation is imperative in many crystallisation processes as it reduces the influence of diffusion through the boundary layer. Fig. 6 shows that increasing the agitation rate from 200 to 400  $\text{min}^{-1}$  increases the precipitation ratio by 3–8%, depending upon the  $\text{Na}_2\text{O}$  concentration. This may be attributed to thinning of the boundary layer and more breakage of the crystals, thereby increasing the number of active points (Hash and Okorafor, 2008). The precipitation ratio reaches a plateau after 24 h with a stirring speed of 400  $\text{min}^{-1}$  and a further increase in speed is not justified.

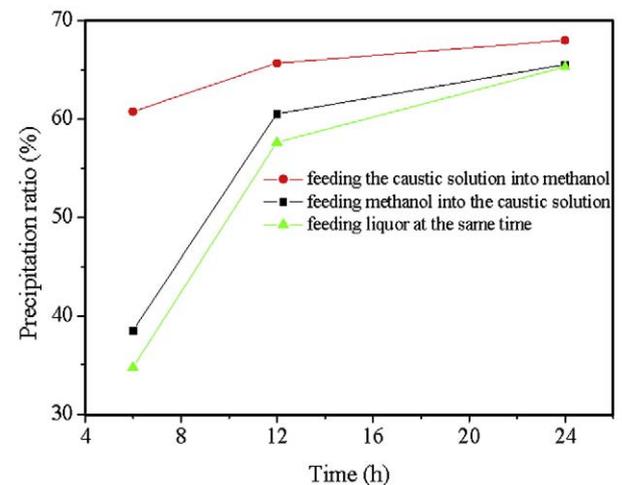
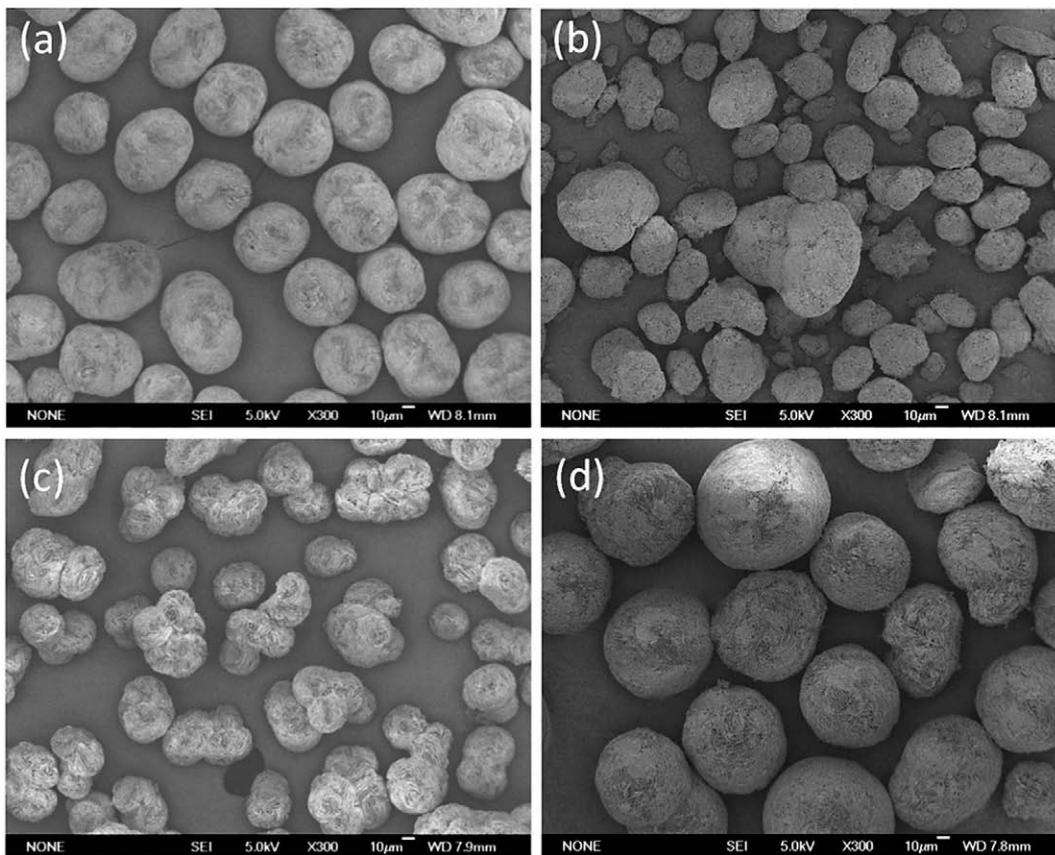


Fig. 7. Effect of feeding modes on the precipitation ratio. [ $C = 176.7$  g/L,  $A = 189.8$  g/L,  $MR = 1.53$ ; other conditions as Fig. 2].



**Fig. 8.** SEM image of gibbsite crystals prepared (a) by adding methanol into the caustic solution; (b) by adding caustic solution into methanol; (c) adding methanol at 15.0 mL/min; (d) adding methanol at 1.2 mL/min.

### 3.5. Effect of feeding mode and feeding rate

The feeding mode of methanol can affect the proportion of methanol to water in the aqueous system at the early stage of the reaction and therefore results in a difference in the solubility of  $\text{Al}_2\text{O}_3$  under same  $\text{Na}_2\text{O}$  concentration. The experimental results of the effect of feeding modes on the precipitation ratio, shown in Fig. 7, clearly demonstrate that there is a large difference in the precipitation ratio in the early stages of the reaction. Fast precipitation rates could be achieved when the aluminate solution was dropped into methanol because of the large supersaturation that exists. However, the final yields were about the same, no matter how the solutions were mixed, since the same equilibrium solution was reached. Likewise, it was demonstrated in other experiments that changing the feeding rate had little overall effect on the equilibrium yield after 24 h. However, the particles size and morphology can exhibit great differences as shown in Fig. 8 due to the influence of changes in supersaturation on the nucleation kinetics. Step-wise changes in supersaturation are beneficial for controlling the morphology and particle size, thus methanol should be added into the caustic solution. Furthermore, methanol needs to be added slowly to produce ideal morphology and a rate of 1.2 mL/min was optimum for this work.

## 4. Product characteristics

In this work, the precipitated aluminum hydroxide was characterized using XRD, SEM, and Mastersizer 2000. From the SEM and PSD analyses, it can be concluded that the size of the precipitate is dependent on the precipitation ratio, which has been confirmed in seeded precipitation processes studied by other researchers. High precipitation ratio leads to small particle sizes and irregular morphology. For example, in this research the average particle size

at 60 °C was 30 µm larger than that at 30 °C and larger particles were obtained with a  $\text{Na}_2\text{O}$  concentration of 170 g/L. When the volume ratio of methanol to caustic solution was greater than 1:1, particles became irregular because the large amount of new nuclei could not aggregate slowly. Slow addition of methanol to caustic solution inhibits nucleation and favors the particle growth. Moderate stirring is also beneficial for producing relatively well-formed particles.

A solution obtained from an alumina plant containing 180 g/L  $\text{Na}_2\text{O}$  with an MR of 1.58 was then tested under the optimum conditions identified in this study (1:1 methanol:solution; 60 °C; 300  $\text{min}^{-1}$ ; 24 h). After the precipitation, the filtrate contained 93.5 g/L  $\text{Na}_2\text{O}$  and 29.2 g/L  $\text{Al}_2\text{O}_3$ , which means a 70% yield after calculation. The solid crystal products were thoroughly washed using hot water and dried at 120 °C before examination.

The XRD shows a typical gibbsite phase of aluminum hydroxide whilst the particle size distribution showed a very narrow size distribution with an average diameter of 90 µm. Individual particles characterized using SEM appeared to be spherical in shape (Fig. 9(a)). The obtained crystals were composed of super-thin sheet units (Fig. 9(b)), which were different from other typical hexagon growth unit that has been reported in the literature (Sweegers et al., 2001). XRF analysis found 0.68% ( $\text{Na}_2\text{O}$ ), 0.0371% ( $\text{SiO}_2$ ) and 0.013% ( $\text{Fe}_2\text{O}_3$ ) and the Al content, analyzed by ICP-OES, was 98.3%  $\text{Al}_2\text{O}_3$ . These values were close to AO-2 of the Nonferrous Industry Criterion for  $\text{Al}_2\text{O}_3$  in China.

## 5. Decomposition mechanism analyses

In order to uncover the function of methanol in the new process, infrared and Raman spectroscopies were used to investigate the structure of the initial pregnant solution, methanol and the mixture. As shown in Figs. 10 and 11, the characteristic IR peaks for sodium

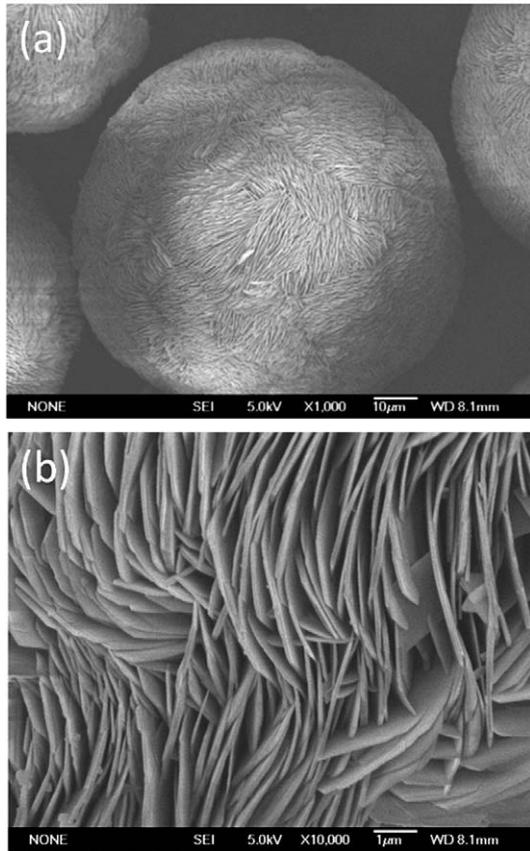


Fig. 9. (a) SEM image of precipitated gibbsite; (b) SEM image of super-thin sheet unit of precipitated gibbsite.

aluminate are mainly at  $725\text{ cm}^{-1}$  and  $630\text{ cm}^{-1}$ ; and at  $625\text{ cm}^{-1}$  and  $540\text{ cm}^{-1}$  in Raman. The former peaks are attributed to the asymmetric and symmetric stretching vibration of  $\text{Al}(\text{OH})_4^-$  (Hong, 1994; Wang et al., 2003), whilst the latter peaks could be due the polymeric ion  $[(\text{OH})_3\text{Al}-\text{O}-\text{Al}(\text{OH})_3]_2^-$  and the Al–O–Al vibration band. Because of the dilution effect of methanol and precipitation from solution, the aluminate ion peak intensity diminishes significantly after 8 h and disappears after 24 h. With respect to the peaks of methanol, there are basically no wave number shifts between pure methanol and the mixed liquor.

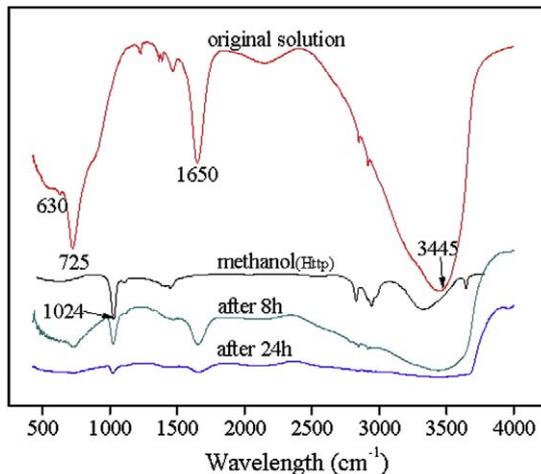


Fig. 10. Infrared spectra of the methanol and sodium aluminate solutions (the spectra of methanol is from <http://webbook.nist.gov/cgi/cbook.cgi?Name=methanol&Units=SI>).

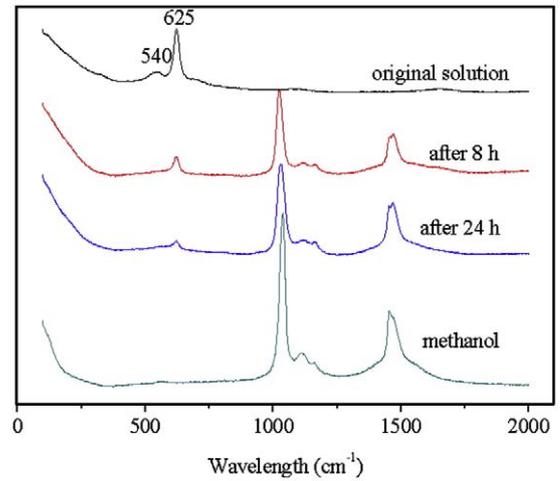


Fig. 11. Raman spectra of the methanol and sodium aluminate solutions.

The spectrum peaks indicate that the structure of  $\text{Al}(\text{OH})_4^-$  in the methanol mixture is similar to that in the conventional seeded precipitation process. When methanol is added into the caustic solution, it forms stable hydrogen bonds with water molecules in the aluminate ion hydration sphere and catalyzes the nucleation and crystallisation of  $\text{Al}(\text{OH})_3$ . Hence, methanol alters the solvent properties.

## 6. Conclusions

The addition of methanol intensifies the nucleation and crystallisation of sodium aluminate solution, which has the potential to enhance the throughput of a Bayer plant. Methanol can be readily distilled from the liquor and recycled whilst the caustic liquor with high MR can be recycled to leach bauxite ore or red mud.

The experiments have shown that many factors, including the amount of methanol, concentration of caustic, time, temperature, stirring and feeding mode influence the degree of supersaturation, rate of precipitation and yield as well as the morphology of the crystals. When industrial practice is taken into consideration, the optimum conditions for well-formed crystals are: slow rate of addition of an equal volume of methanol to sodium aluminate solution;  $170\text{ g/L Na}_2\text{O}$  (MR approximately 1.55); stirring rate  $300\text{ min}^{-1}$  at  $60\text{ }^\circ\text{C}$ . Under these conditions, the precipitation ratio can exceed 70% within 24 h, which is 20% higher than that in the conventional seeded Bayer process. The gibbsite crystal product is spherical with an average diameter of about  $90\text{ }\mu\text{m}$ , which is an agglomerate of super-thin sheet growth units.

IR and Raman spectra of the mixed methanol aluminate solution indicate that aluminum exists mainly as the  $\text{Al}(\text{OH})_4^-$  ion, similar to the seeded aqueous system. Thus methanol appears to serve only as a solvent which hydrogen bonds to the water molecules in the hydration sphere and catalyses the nucleation and crystallisation process.

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