Selective removal of arsenic(V) from a molybdate plant liquor by precipitation of magnesium arsenate

Yi Yong Park b, Tam Tran a, Yeon Ho Lee a, Young Il Nam a, Gamini Senanayake c, Myong Jun Kim a,*

a Department of Energy and Resources Engineering, Chonnam National University, Gwangju, Republic of Korea
b Ministry of Knowledge Economy, Republic of Korea
c Parker Centre, Faculty of Minerals and Energy, Murdoch University, WA 6150, Perth, Australia

Abstract

Precipitation of Mg$_3$(AsO$_4$)$_2$ for the removal of arsenic (As) from a molybdenum oxide processing plant liquor containing 70.9 g/L Mo(VI) and 469 mg/L As(V) was performed. The Stabcal software was used to model the speciation and solubility equilibria, and to identify the pH conditions at which optimum precipitation can be carried out. The optimum pH range for As(V) removal is between pH 7.5 and 10.2. This avoids the need to adjust the liquor pH to affect the precipitation. By adding magnesium chloride or sulphate at a Mg:As molar ratio of at least 2:1, As(V) could be removed to less than 5 mg/L at pH 10.2 resulting in a pure Mo(VI) liquor from which a high purity product of 99.9% MoO$_3$ could be produced by acidification.

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1. Introduction

Different techniques have been established for the removal of arsenic from ground water, wastewater and process liquors (Table 1). The science and technology behind these techniques have been reviewed extensively in several studies (Jeikel and Seith, 2000; Mohan and Pittman, 2007; Choong et al., 2007; Sharma and Sohn, 2009). For process liquors containing high levels of metal ions and anions such as sulphate and chloride, the use of adsorption, ion exchange or membrane techniques for arsenic removal is not effective as these process compete with As(V)/(III) anions in the separation processes. Precipitation is the best option in this respect and the process has been used widely in commercial practice.

Following the pioneering work of Nishimura and Robins (1996), ferric arsenate is considered the most stable for disposal (Meng et al., 2000; Katsoyiannis and Zouboulis, 2002; Lenoble et al., 2005; Fujita et al., 2008). In plant practice, a dosage of ferric chloride or sulphate at pH ~ 8.5 will remove arsenic(V) in the form of a sludge, which is then filtered and disposed (Han et al., 2002; Choong et al., 2007). The precipitated iron hydroxyl compounds also act as good adsorbents to produce the most stable Fe(III)–As(V) species (Katsoyiannis and Zouboulis, 2002; Lenoble et al., 2005). Ferric arsenite sulphate hydrate (6Fe$_2$O$_3$.5As$_2$O$_3$.2SO$_3$.12H$_2$O) is stable within the range of pH 2.0–3.5, beyond which it becomes unstable (Nishimura and Robins, 2008). An oxidant such as chlorine, ferric chloride or ferrate (FeO$_4^{2–}$) is generally added to oxidize As(III) or mixed As(III)/(V) systems to maintain all arsenic as As(V) prior to precipitation. In practice ferric chloride is found to provide a more efficient removal compared to ferric sulphate (Kartinen and Martin, 1995; Zouboulis and Katsoyiannis, 2002). The chloride salts of Fe(VI)/Al(III) were more effective than aluminium free Fe(VI) or Fe(VI)/Fe(III) in the oxidative precipitation of As(III) to concentrations less than the WHO recommended value of 10 μg/L (Jain et al., 2009).

Lime has also been used extensively to remove arsenic during water/waste water treatment (Choong et al., 2007) as there are several Ca(II)–As(V) species that can be precipitated over a wide range of pH (Brown and Bothe, 1999; Raposo et al., 2004). At a high temperature above 100 °C, As(III) as high as 1 g/L could also be removed effectively with Ca(OH)$_2$ addition due to the formation of several stable Ca(II)–As(III) species such as Ca$_5$(AsO$_3$)$_3$(OH)$_4$.4H$_2$O and Ca$_6$(AsO$_3$)$_5$OH (Itakura et al., 2007) in a process similar to hydrothermal mineralization. Other alkali earth metal ions such as Ba$^{2+}$ and Mg$^{2+}$ also form stable compounds with As(V) (Raposo et al., 2004; Zhu et al., 2005).

Of interest to this study are the results reported by Swartzbaugh and Sturgill (1998) on the use of Ca, Mg and Fe salts to remove As(V) from the semiconductor wastes containing arsenic, gallium and other metal ions. The precipitation of Mg(II)–As(V) salt was carried out at pH 8.4–8.8 and a Mg/As ratio of 1.5/1 to 5/1. The treated wastes contained residual arsenic varying between 16 and 18 mg/L. As, thus, the selection of a precipitating reagent for arsenic depends upon the oxidation state as well as other ionic species in solution.

Details of a flowsheet (Fig. 1) and performance of a molybdenum oxide processing plant operated by Kwangyang Ferro Alloy Co.
(Korea) to produce high purity molybdenum chemicals have been reported in earlier publications (An et al., 2009a,b). The grade of MoO₃ of the calcine produced by roasting Mo–Cu–As–sulphide can be improved from 56.6% to 57.7% by sulphuric acid washing to partially remove copper and arsenic. The solid residue from acid washing is used for the production of ferro-molybdenum alloy. The purity of MoO₃ at various stages of the flowsheet in Fig. 1 and as listed in Table 2 shows the partial dissolution of molybdenum and arsenic. This leads to partial loss of molybdenum to the wash liquor. Both molybdenum and arsenic can be separated from copper in the wash liquor by a 3-stage solvent extraction using Alamine 304-1 (10%, v/v in Anysol 150 diluent) and ammonia stripping. The acidification of the leach liquor with HCl precipitates MoO₂H₂O of high grade suitable for the production of high purity molybdenum products (Fig. 1). However, the concerns over arsenic contaminants from the low grade feed materials have to be addressed as As(V) anions follow the molybdate recovery in every step of the process.

The equilibrium reactions illustrating the stability of several hydroxides, arsenates and molybdates relevant to the study, are shown in Table 3. The use of lime or any calcium additive to remove arsenic by precipitating Ca(II)–As(V) compounds according to reaction R1 is precluded as calcium also precipitates molybdate (reaction R2). The speciation modeling based on Stabcal program yielded accurate stability diagrams of Ca–Mo–H₂O system which were used to successfully determine optimum pH conditions for several Mo–H₂O precipitation systems taking place during plant operation as discussed in previous publications (An et al., 2009a,b). Sodium hydroxide cannot be used for pH adjustment either due to the formation of sodium molybdate (reactions R3 and R4) at neutral conditions (An et al., 2009a,b).

The removal of As(V) by precipitation of Mg(II)–As(V) is ideal as Mg(OH)₂ can also be added as a neutralizing agent in the flowsheet shown in Fig. 1. For the general salt of formula MAₓ, the solubility equilibrium can be represented by Eq. (1).

$$M_{\alpha\gamma}A_y = xM + yA_{\text{charge of cation and anion ignored}}.$$

If the solubility of the salt MAₓ is expressed by S mol/L, the concentrations [M] and [A], and activities aₓ and a₀ of ions are:

$$[M] = xS, [A] = yS$$

$$a_m = \gamma_m[M] = \gamma_m[xS]$$

$$a_A = \gamma_A[A] = \gamma_A[yS]$$

which lead to the solubility product:

$$K_{sp} = (a_m)^x(a_A)^y = (\gamma_m x S)^x (\gamma_A y S)^y = (\gamma_m^x \gamma_A^y x^y y^y) (S)^{x+y}$$

Then the solubility of salt MAₓy and the concentration of anion A are expressed by the respective equations:

$$S = (K_{sp})^{1/(x + y)}$$

$$[A] = yS = y(K_{sp})^{1/(x+y)/(x+y)}$$

The solubilities of AsO₃²⁻ and MoO₄²⁻ predicted from their respective Kₛₚ values of 2.1×10⁻²⁰ and 2.4×10⁻¹¹ (http://www.csudh.edu/oliver/chemdata/data-ksp.htm, Rai et al., 1984) for Mg₂(AsO₄)_3 and MgMoO₄ using Eqs. (1)–(4), assuming unit ionic activity coefficient γₓ = γₐ = 1, are approximately 1.2×10⁻⁴ mol/L and 0.5 mol/L, respectively. This indicates that there is a possibility of selectively precipitating As(V) using Mg²⁺ ions without precipitating MgMoO₄. However, the nature of the precipitate formed during the addition of Mg²⁺ to an alkaline solution of Mo(VI)–As(V) and the residual ion concentrations are likely to depend upon the relative concentrations of dissolved ions, pH, as well as activity coefficients of species involved in reactions listed in Table 3.

This study investigates the possibility of selective precipitation of magnesium arsenate using speciation diagrams, solubility measurements and characterization of the precipitated product by XRD. The Stabcal program was used for the Mo–Mg–As–H₂O system to identify the window of pH in which molybdate is stable during the selective precipitation of arsenic and to avoid the loss of Mo. A comparison is made between the predicted and measured solubilities after adding MgCl₂, MgSO₄ or MgO to solutions of different pH values and different As(V)/Mg(II) molar ratios to highlight possible application in the molybdenum oxide processing flowsheet in Fig. 1.

2. Experimental

All chemical reagents used in the laboratory tests were of analytical grade. In previous studies the molybdenum loaded organic phase was stripped with ~20% (w/v) NH₃ which produced a liquor of ~0.5 M Mo(VI) which was subsequently treated to recover high purity molybdenum products (Cao et al., 2009; An et al., 2009a). A 100 L sample from the solvent extraction circuit (Fig. 1) was used for this study. Reactions for extraction and stripping are given by Eqs. (5) and (6) where R₂N represents Alamine 304-1 diluted in commercial aromatic dилuent (Samsung Total Anysol 150) (An et al., 2009a):

$$2R_2NH_3^+ \cdot HSO_4^- (org) + MoO_2^{2-} (aq) = [R_2N]_2MoO_4^- (org) + 2HSO_4^- (aq)(loading)$$

$$[R_2N]_2MoO_4^- (org) + 2NH_3 + H_2O = 2R_2N^+ (org) + (NH_4)_2MoO_4(aq)(stripping).$$

The ICP-MS (ICP-8500) analysis of the stripped liquor at a pH of 10.2 produced using 12.5% (w/v) NH₃ revealed a composition of 70.9 g/L (0.74 mol/L) Mo, 469 mg/L (6.26 mmol/L) total As and 0.65 mg/L Mg. The redox potential of the liquor was 410 mV (SCE), which corresponds to Eh=650 mV. This value is well over the Eh of the As(V)/As(III) couple in published Eh–pH diagrams (Muir and Senanayake, 1985) indicating the presence of As(V). The measured Eh is also higher than −300 mV for MoO₂²⁻/Mo₂O₇³⁻ based on HSC 6.1 data at pH 10.2 and the published Eh–pH diagram (An et al., 2009a) indicating that molybdenum in solution is in the form of Mo(VI).

The maximum Mg(II) concentration allowed before MgMoO₄ starts precipitation from a solution of 0.74 M Mo(VI) liquor estimated from its Kₛₚ value of 10⁻⁰.⁶² (Rai et al., 1984) is close to 0.32 M. Accurate amounts (0.3–1.2 g) of MgSO₄·7H₂O or MgCl₂·6H₂O were first dissolved in 50 mL of distilled water. The magnesium solutions were then added to 200 mL of the liquor at different Mg:As molar ratios from 1:1 to 4:1 at ambient temperature (20 °C) to start the precipitation at pH 10.2. The addition of MgO as a precipitating agent was also tested.

Samples were taken at different time intervals, filtered using a 1 μm filter (Advantec SC) and then analysed for both Mg and As. Preliminary results have showed that the precipitation took place very rapidly and the concentration of As(V) reached equilibrium value after 10 min of stirring. All experiments were then conducted for 20 min before the precipitate was filtered. The arsenic analysis of the
final liquors, based on ICP-MS, represents the equilibrium As(V) concentration after precipitation.

In a larger scale experiment a 20 L sample of the ammonia stripped liquor was tested and a large precipitate sample was collected for XRD analysis (Rigaku D/MAS Ultima X-ray diffractometer), SEM photos (JEOL, JSM-7500F + EDS), and for particle size distribution (Sympatec GmbH, HELOS/BR). In a second set of experiments the effect of pH on precipitation of magnesium arsenate from the stripped plant liquor was tested at different ratios of Mg/As = 1/1 to 1/4 in the range pH 6–12 adjusted using NaOH or HCl at 20 °C. The purpose of these experiments was to examine the validity of species distribution and precipitation diagrams predicted from the Stabcal program. The percentage of magnesium precipitated at a higher pH range of 10–12 at 20 °C was also determined at a given molar ratio of Mg/As = 3/1.

Due to the lack of reliable information on As(III) precipitation noted in Section 3.1.1, the effect of Mg(II) addition on a synthetic solution of As(III) prepared by dissolving an appropriate amount of solid As$_2$O$_3$ into 15% w/v NH$_3$OH$_2$O was tested in a third set of experiments, before and after the oxidation of As(III) by H$_2$O$_2$. The oxidation of As(III) to As(V) occurs at a molar ratio of 1:1 (Eq. (7)) with a favourable equilibrium constant of 10$^{48}$ at 20 °C. Thus, the oxidation of the As(III) synthetic solution was conducted by adding H$_2$O$_2$ at a 3:1 molar ratio of H$_2$O$_2$/As. The results of As(V) precipitation from stripped plant liquor and synthetic As(III) solutions of different pH values, before and after oxidation with H$_2$O$_2$, were compared and contrasted.

$$H_2AsO_4^- + H_2O = H_2AsO_4^- + H_2O.$$  \hfill (7)

3. Results and discussion

3.1. Stabcal modeling of equilibrium conditions

3.1.1. Selection of Gibbs free energy data

The equilibrium reactions illustrating the stability of several hydroxides, arsenates and molybdates relevant to the study, shown in Table 3, can be better represented as stability diagrams (Log [concentration] vs. pH) developed from the Stabcal software (Huang, 2008) under conditions relevant to the plant operation. Stabcal does the calculations based on the input of known species and their appropriate Gibbs free energy of formation ($\Delta G_f$). The software has several built-in databases including those from NBS, MinteqAQ and HSC (Outotec) and the selection of appropriate $\Delta G_f$ values used for the calculations is crucial for deriving the accurate diagrams showing the stable species and their equilibrium concentrations at certain solution pH values.

Table 4 lists all the NBS species/data used in the modeling, with the exception of the data for Mg$_2$(AsO$_4$)$_2$ which was calculated from the solubility product $K_{sp} = 2.1 \times 10^{-22}$ as this species is not reported in the NBS database. Species from other databases and their standard Gibbs free energies of formation are also included for comparison and cross-checking as there are large discrepancies in some cases. For example, if the Gibbs free energy of formation value of 2831.82 kJ/mol for Mg$_2$(AsO$_4$)$_2$ from HSC (Outotec) was used for the calculation, a much lower As(V) equilibrium concentration (sub-ppb level) was found. This results in is in contradiction with the findings for Mg(II)–As (V) systems in past studies, where As(V) could be removed only to ppm levels by precipitating Mg$_2$(AsO$_4$)$_2$ (Swartzbaugh and Sturgill, 1998).

Likewise, the inclusion of several As(III) species (such as AsO$_2^-$, Mg (AsO$_2$)$_2$, etc.) reported in the HSC (Outotec) database could not be justified with the existing information in the literature. For example, the calculation based on $K_{sp} = 5.7 \times 10^{-33}$ for Mg(AsO$_2$)$_2$ from HSC (Outotec) in Eq. (3) reveals sub-ppb range residual As(III) in the form of AsO$_2^-$ at equilibrium. This is contradictory to the common knowledge that As(III) has to be oxidized for a more effective removal as As(V). The problem of using species such as AsO$_2^-$ and HAsO$_2$ instead of H$_2$AsO$_4$ and H$_2$AsO$_3$ reported in Eh–pH diagrams (Pourbaix, 1963) would cause inaccuracy in the thermodynamic modeling as stated by Nordstrom and Archer (2003), who referred to these species from the original NBS table collated by Wagman et al. (1982). According to Nordstrom and Archer (2003), the hydrated forms such as H$_2$AsO$_3^-$ and H$_2$AsO$_4^-$ are real species identified by Raman spectroscopy, whereas other forms are considered equivalents and therefore redundant in thermodynamic sense. Thus, no attempt was made to model the participation of Mg(II)–As(III) species reported in HSC (Outotec) database, but experimental results on As(III) and As(V) solubility in the presence of Mg$^{2+}$ are reported and compared in Section 3.2.

3.1.2. Equilibrium species diagrams

The optimum pH conditions were determined after several speciation modeling runs which were conducted to evaluate the possibility of precipitating Mg$_2$(AsO$_4$)$_2$. Fig. 2 shows the equilibrium species distribution based on Stabcal modeling at different Mo(VI)/Mg(II) molar ratios of 0.74/0.20 (Fig. 2a), 0.74/0.30 (Fig. 2b) and 0.74/1.0 (Fig. 2c). The precipitation of MgMoO$_4$ from a solution of 0.74 M Mo(VI) does not occur until Mg$^{2+}$ concentration exceeds 0.3 M, as shown in Fig. 2b. At a pH > 8.5, MgMoO$_4$ should redissolve, causing a rise in MoO$_4^{2-}$ in the solution. Fig. 3a and b shows the profile of As(V) and Mg(II) concentrations at different pH values for the system obtained with 0.0063 M As(V)–0.019 M Mg–0.740 M Mo(VI), simulating the conditions of the ammonia stripped liquor and the precipitation process. Sodium arsenate Mg$_2$(AsO$_4$)$_2$ is the species identified to be stable within the range of pH 7.5–10.2. Above pH 9.5, however, Mg(OH)$_2$ will also be co-precipitated with Mg$_2$(AsO$_4$)$_2$ (Fig. 3a). Following Fig. 3b one can predict that the efficiency of the removal process is very much dependent on the solution pH. The best pH at which As(V) can be removed to approximately 0.8 mg/L is around pH 9.5 at a Mg(II)/As (V) molar ratio of 3/1, above and below which pH there will be higher residual As(V) in the liquor (Fig. 3b). On the other hand residual Mg$^{2+}$ is expected to be less than 10 mg/L at solution pH 10 (Fig. 3a). Actual solubility measurements under practical conditions are essential to examine the validity of these predictions and for flowsheet development.

3.2. Measured precipitation curves — effect of pH

Fig. 4 shows equilibrium concentrations of As(V) at different pH values in the range 6–12 after the addition of magnesium salts into the process liquors. The effect of Mg(II) addition on a synthetic solution of As(III) described in Section 2 is also shown in Fig. 4. The solubility of As(III) added as As$_2$O$_3$ in the pH range 0–7 is as high as 0.3 mol/L (24 g/L) and independent of pH (Muir and Senanayake, 1985). Thus, despite the addition of Mg(II) the initial concentration of 0.45 g/L As (III) remains in solution up to pH 8.3 as shown in Fig. 4 and As(III) starts precipitation at pH > 8. Fig. 4 shows very low As(III) of –20 mg/L at pH 11, while Fig. 3a shows the precipitation of Mg(OH)$_2$ at pH ~11. Further investigation into the mechanism of precipitation of Mg–As (III) compounds is outside the scope of this study. Nevertheless, due to the precipitation of Mg(OH)$_2$ from solution at pH ~9.3 (Fig. 3a), it is believed that the removal of As(III) is by adsorption on Mg(OH)$_2$ precipitate, similar to the removal of As(V) described later.

The oxidation of the synthetic As(III) solution by adding H$_2$O$_2$ at 3:1 H$_2$O$_2$/As molar ratio, starts precipitating Mg$_2$(AsO$_4$)$_2$ at around pH 7 (Fig. 4), resembling the behavior of plant liquor which contained As (V), at the same molar ratio of Mg/As = 3/1. Within the range of pH 9–
11, the residual As(V) measured after 20 min was less than 5 ppm for the Mg/As ratio of 3/1.

The stoichiometric requirement for producing Mg₃(AsO₄)₂ is As(V)/Mg(II) molar ratio of 2/3. The precipitation of As(V) from the plant liquors over the pH range 6–12 as shown in Fig. 4, at different As(V)/Mg(II) molar ratios from 1/1 to 1/4, indicated that a minimum ratio of 1/2 is required. Low arsenic in solution at pH 9–11 in Fig. 4 is also consistent with the Stabcal modeling results of Fig. 3b, which shows that significant precipitation of Mg₃(AsO₄)₂ takes place in the pH range 7.5–10.2 in the presence of appropriate molar ratio of As(V)/Mg(II) = 1/3. There is an optimum range of pH from pH 9–11 (Fig. 4), where the As(V) concentration in stripped liquor can be decreased to a minimum concentration of around 0.8 mg/L at pH 9.5 (Fig. 3b).

The precipitation of Mg(OH)₂ starts at a solution pH higher than 9.3 (Fig. 3a) and this could be an adsorbent for removing more As(V), a process similar to As(V) removal by Fe(III) hydroxide (Katsoyiannis and Zouboulis, 2002; Lenoble et al., 2005). However, the attempts to decrease the equilibrium As(V) concentration at pH values higher than 11 failed as shown by the results plotted in Figs. 4 and 5, as the redissolution of As(V) and precipitation of Mg(II) takes place at pH >11. This is a result of the alkaline hydrolysis of Mg₃(AsO₄)₂ causing the release of As(V) to the solution at pH >11, as confirmed by the higher stability of Mg(OH)₂ and AsO₂⁻ in Fig. 3a–b. Chemical analysis of the clear liquor filtered after the completion of precipitation also confirmed the precipitation of magnesium hydroxide, causing almost all Mg(II) to be removed from the solution at pH 12 (Fig. 5).

The removal of As(V) at pH >11 is believed to be mainly due to adsorption onto Mg(OH)₂, as Stabcal modeling predicts no Mg₃(AsO₄)₂ can be formed at a pH >11 (Fig. 3b). As shown in Fig. 3(b), Stabcal predicts the equilibrium level of As(V) as 7 mg/L and >400 mg/L at pH 10 and 11, respectively, whereas real precipitation tests using plant liquor showed that the residual As(V) was well below 5 mg/L in this range. More effective removal of As(V), than the predicted values, is believed to be due to both the precipitation of Mg₃(AsO₄)₂ and adsorption on the precipitating Mg(OH)₂ in the range pH 10–11, above which mainly As(V) adsorption takes place.

Although Mg₃(AsO₄)₂ is soluble at pH ~7 according to Fig. 3a and b, a decrease in As(V) concentration in solution is observed in Fig. 4 at pH >7. This behavior is of significance to the control of the large scale precipitation process during plant operations, if the pH decreases below 7.0. This is most likely due to the uptake of As(V) by the mixed precipitate MgMoO₄ + MoO₃ at pH <7 according to Fig. 2b and c. According to Fig. 6 a minimum molar ratio of Mg/As = 2/1 is required, compared to the stoichiometric ratio of Mg/As = 1.5/1, for the complete removal of As(V). This may be related to the loss of Mg(II) ions due to the precipitation of Mg(OH)₂ at pH >9 as shown in Fig. 3a. Both MgCl₂ and MgSO₄ are equally effective as precipitating agents to remove As(V) when added to the stripped liquors at pH 10.3 as shown in Fig. 6, but MgO is unsuccessful.

3.3. Characterization of precipitated product

The morphology of the precipitated material is important for plant practice as a subsequent filtration stage after precipitation is required for removing Mg₃(AsO₄)₂ before the liquor is acidified to produce high purity MoO₃ as described in Fig. 1. The precipitate formed was confirmed to be a highly crystalline Mg₃(AsO₄)₂ as determined by XRD, shown in Fig. 7. This is confirmed by SEM, showing the precipitation of well crystalline material (Fig. 8). Particle size measurements showed a D₅₀ of 32 μm and P₉₀<50 μm for this precipitate (Fig. 9).

3.4. Modified flowsheet and product quality

According to the product specifications for commercial MoO₃ listed in Table 5, showing limits for main contaminants, the accepted level is <0.002% As (20 mg/kg). In the absence of a removal stage of As(V) from the ammonia stripped liquor by precipitation proposed in this study, the arsenic grade in MoO₃ product is 105 mg/kg (Table 2), well above the specification (Table 5). This is most likely due to the uptake of residual As(V) by the precipitated MoO₃, at a pH below 4.0 during acidification (Fig. 1). The modified flowsheet for the existing operation at Kwangyang Ferro Alloy Co. (Korea) plant in Fig. 1 shows the removal of arsenic as Mg₃(AsO₄)₂ using MgCl₂ in order to produce a high purity Mo oxide product (99.9% MoO₃ or 66.6% Mo) with low contamination of As as shown in Table 5.

From the precipitation study, optimum plant operation conditions could be set at pH 9–11, ambient temperature and reaction time less than 10–20 min. The measured pH of 10.2 of 0.74 M (NH₄)₂MoO₄ liquor formed by stripping using 12.5% (w/v) ammonia solution ed the precipitation of Mg₃(AsO₄)₂ for the purification of stripped Mo(VI) liquor. The arsenic sludge formed during plant operations is sent to other waste treatment companies to handle the disposal.

4. Conclusions

The removal of As(V) from the molybdenum strip liquor produced from a solvent extraction circuit is essential for the production of high purity MoO₃. The removal is carried out by adding magnesium chloride or sulphate into the liquor at a Mg(II):As(V) molar ratio of at least 2:1 causing the precipitation of crystalline Mg₃(AsO₄)₂. This precipitate can remove As(V) under ambient conditions as long as the solution pH is maintained between pH 8 and 10. At pH 12, all magnesium will precipitate as magnesium hydroxide, making the removal process ineffective. In plant practice, the ammoniacal strip liquor of pH 10.2 does not need further pH adjustment. At optimum conditions, almost all the arsenic can be removed to less than 5 mg/L, to form a well crystallised product of Mg₃(AsO₄)₂ which can be easily separated by filtration. This results in the production of arsenic free liquors which on acidification can yield high purity commercial product of 99.9% MoO₃.