Recovery of Molybdenum and Vanadium from Acidic Leaching Solution of Spent Catalysts by Solvent Extraction

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Abstract

The recovery of molybdenum and vanadium from acid leaching solutions of spent catalysts using solvent extraction has been investigated. Among various acid leaching solutions, sulfuric acid solution is found to be adequate for the recovery of these two metals. The extraction and stripping behavior of the two metals in the absence and presence of other impurity metals by various types of extractants such as cationic, solvating, amine and a mixture of cationic and solvating extractants was discussed. Each type of extractants has advantage and disadvantage in terms of the possibility of separation and of forming a third phase. Among the various types of extractants, a mixture of cationic and solvating extractants seems to be the most promising extractant system for the separation of Mo and V from the acid leaching solutions of spent catalysts.

Key words : spent catalysts, leaching, solvent extraction, molybdenum, vanadium
1. Introduction

Molybdenum and vanadium are important metals used in many technological fields. Molybdenum is a strategic metal which is used in radionuclide, antiradiation, thermocouples, anticathode of X-ray tubes and in the production of special steels.\(^1\) The most important use of vanadium is as an additive for steel. Vanadium compounds are also used in the ceramics industry, in the printing and dyeing of fabrics and in the manufacture of aniline black. In recent decades, the recovery of molybdenum and vanadium from spent catalysts has attracted much attention because large amount of rare metals such as Mo, V, Co, and Ni are contained in the spent catalysts.\(^2\) The spent catalysts mostly consist of molybdenum oxide mixed mainly with vanadium oxides, cobalt or nickel on an alumina carrier. Spent catalysts can be classified into four types like Mo-Fe, Mo-Ni, Mo-Co and Mo-V according to the composition of catalysts.

Reviews on the recovery of Mo and V from spent catalysts have been reported by Zeng and Cheng.\(^3,4\) Molybdenum, vanadium and other metals from spent catalysts were dissolved by leaching and then were recovered from the leaching solutions using conventional separation techniques such as precipitation, adsorption, ion exchange and solvent extraction. It was indicated that acid leaching was used commonly in industry because all of the valuable metals can be dissolved in acid medium. In the separation step, solvent extraction has been found to be the most promising method for the commercial production of the above metals with high purity. Lots of work on the recovery of Mo and V from acid media containing impurities has been conducted using solvent extraction. However, few reviews have been reported to summarize the results. Hence in present review, the results for the extraction and recovery of Mo and V from acid media containing impurities using solvent extraction were summarized in detail.

2. Acid leaching of spent catalysts

In the recovery of metals, several dissolution processes such as acid leaching, caustic leaching, and bioleaching are employed. Each process has suffered several drawbacks but in general acid leaching seems to be more suitable for dissolving all of the valuable metals in the spent catalyst.\(^5\) Among acid leaching process, sulfuric and hydrochloric acid were used commonly.

The leaching of spent catalyst was carried out by varying the concentrations of sulfuric acid from 30 to 70% (v/v) in the temperature range of 100-200°C and more than 90% of metals was dissolved.\(^6\) Mihash\(^7\) reported that most nickel and cobalt could be leached using the mixture of 5 g/L H\(_2\)SO\(_4\) and 20 g/L H\(_2\)O\(_2\). Siemens\(^8\) has used 10% w/w sulfuric acid leaching for the recovery of molybdenum and nickel from a molybdenum-nickel catalyst. Most of Mo, Ni, and V were dissolved from spent petroleum catalyst using 1 M H\(_2\)SO\(_4\) in a single stage within 1h of reaction time.\(^9\) Leaching of Mo and Co from spent catalyst with sulfuric acid alone was not so efficient as with the mixture of sulfuric acid and hydrogen peroxide and with the mixture of nitric acid.\(^10,11\) The leaching percentage of Mo with these two cases was the same while that of cobalt with H\(_2\)SO\(_4\)-HNO\(_3\) was little higher than in the case of H\(_2\)SO\(_4\)-H\(_2\)O\(_2\). Ognyanova\(^12\) concluded that the acidic leaching had an advantage over alkaline leaching because of cheaper price. The author used sulfuric acid as a leaching reagent for the dissolution of Ni, V and Fe from spent catalysts. Using 6 M H\(_2\)SO\(_4\) at 90°C, most vanadium from vanadium ore was dissolved into the solution.\(^12\)

Hydrochloric acid leaching has been found to have some advantage over other acids in that separation of metals from acidic chloride solution is possible.\(^13\) Ward\(^13\) has used hot concentrated hydrochloric acid to recover metals from spent catalysts. Most metals from spent catalyst was dissolved using hot hydrochloric acid when the temperature was higher than 90°C. Sefton\(^14\) also used hydrochloric acid for leaching of Mo, V, Co, Ni and Al from spent catalyst. 3M HCl was optimum condition for the leaching of metals from spent catalyst containing these metals.\(^15,16\)

By comparing the leaching efficiency of HCl and H\(_2\)SO\(_4\), Zeng and Cheng\(^3\) concluded that although hydrochloric acid leaching was more efficient than sulfuric acid leaching, sulfuric acid leaching was more useful because of more flexible material allowance for the construction of reactors, lower cost and better recirculation possibilities.

3. Molybdenum and vanadium speciation in aqueous solution

The species of molybdenum and vanadium in aqueous solution can be categorized as cationic species, neutral species
and anion species. Zheng and Cheng\(^{40}\) reported that the anionic species of molybdenum including Mo\(_{7}O_{23}^{2-}\), Mo\(_{8}O_{22}(OH)_{2}^{2-}\) and Mo\(_{8}O_{24}^{2-}\) are stable in the pH range from 1 to 6. Vanadium is mostly in the form of anionic species such as V\(_{10}O_{28}(OH)_{4}^{6-}\), V\(_{10}O_{26}(OH)_{2}^{6-}\), V\(_{10}O_{24}^{6-}\), V\(_{2}O_{12}^{6-}\) and VO\(_{3}^{3-}\) in the pH range from 2 to 9. The cationic species of molybdenum and vanadium is stable in the pH range 0 < pH < 2 while a small fraction of neutral species like H\(_{2}\)MoO\(_{4}\) and VO(OH)\(_{2}\) exist at pH < 3. In a solution with 2 to 3 M acid concentration, VOCl\(_{4}^{-}\), MoO\(_{3}Cl^{-}\) and MoO\(_{2}(SO_{4})_{3}Cl^{-}\) are formed while neutral species of MoO\(_{2}Cl_{2}\), VOCl\(_{4}\) and VO\(_{2}Cl^{-}\) are predominant in high acid concentration.\(^{4,17}\)

Molybdenum and vanadium species in aqueous phase has been studied by Nekovář and Schröterová.\(^{48}\) Equilibria involving MoO\(_{2}^{2-}\) protonsion are described as follows:

\[
7\text{MoO}_2^{2-} + (8+n)\text{H}^+ = \text{MoO}_{24+n}(\text{OH})_{8-6n}^{(8-n)^-} + 4\text{H}_2\text{O}, \quad (n = 0, 1, 2, 3)
\] (1)

Under low concentration of molybdenum, monomeric forms are formed:

\[
\text{MoO}_2^{2-} + k\text{H}^+ = \text{H}_k\text{MoO}_3^{(2-k)^-}, \quad (k = 1, 2)
\] (2)

With a minimum solubility occurring at about pH 1.5, crystalline MoO\(_{3}\) is in the equilibrium with MoO\(_{2}^{2-}\):

\[
\text{MoO}_2^{2-} + 2\text{H}^+ = \text{MoO}_3(s) + \text{H}_2\text{O}
\] (3)

Polymeric and monomeric species of V are formed by the following Eqs. 4-5

\[
10 \text{VO}_2^{2-} + 8\text{H}_2\text{O} = \text{V}_{10}\text{O}_{28}(\text{OH})_{4}^{(6-n)^-} + (16-n)\text{H}^+, \quad (n = 0, 1, 2)
\] (4)

\[
\text{VO}_2^{2-} + 2\text{H}_2\text{O} = \text{VO}_{4m}(\text{OH})_{m}^{(3-m)^-} + (4-m)\text{H}^+, \quad (m = 0, 1, 2, 3)
\] (5)

In the region between decanadates and monomeric species, the formation of V\(_{3}\)O\(_{10}\)\(^{6-}\) occurs (Eq. 6)

\[
k\text{VO}_2^{2-} + k\text{H}_2\text{O} = \text{V}_{3}\text{O}_{10}^{k^-} + 2k\text{H}^+, \quad (k = 3, 4)
\] (6)

When solution pH is low, V\(_{2}\)O\(_{3}\) precipitates according to the following Eq. 7.

\[
2\text{V}_2\text{O}_3^{2-} + \text{H}_2\text{O} = \text{V}_2\text{O}_5 + 2\text{H}^+
\] (7)

In sulfuric acid leaching solution, VO\(_{2}^{2-}\) is acting as an oxidant and hydrolyzes easily to form oxy-anion, releasing protons to make up a series of partially protonated poly-anions.\(^{39,40}\) Li\(^{20}\) reported that vanadium species in aqueous solution depends on several factors, such as solution pH value, vanadium concentration, and its valence. Vanadium is mostly in the form of cationic species VO\(_{2}^{2+}\) and H\(_{2}\)V\(_{5}\)O\(_{8}^{4-}\) at pH < 2.0 containing 2-3 g/L while VO\(_{2}^{2}\) are formed in the same pHe range. According to Chagnes\(^{21}\), in non-complexing aqueous acidic media (pH < 1), VO\(_{2}^{2}\) is predominant and for pH > 0.6, vanadium precipitate as V\(_{2}\)O\(_{3}\). However in the presence of sulfate/hydrogeno-sulfate anions, both VO\(_{2}^{2}\) and VO\(_{5}\)SO\(_{4}^{-}\) are formed at pH < 2. When solution pH is higher than 2.0, vanadium precipitate as V\(_{2}\)O\(_{3}\).

4. Solvent extraction

4.1. Molybdenum extraction from acidic media containing single metal

Saberyan\(^{22}\) reported that the extraction efficiency of molybdenum with Cyanex 301 was dependent upon the type and concentration of the aqueous phase acid, extractant concentration, and metal ion concentration. Molybdenum extraction from hydrochloric and nitric acid solutions at pH > 1.0 was quantitative irrespective of the concentration of Cyanex 301 while in the case of sulfuric acid system, the extraction behavior of Mo depends strongly on the concentration of Cyanex 301.

Sato\(^{23}\) also studied the extraction of molybdenum from 0.1 M to 10 M sulfuric, nitric and hydrochloric acids by TOA and TCMAC. The molybdenum extraction with TOA and TCMC at low aqueous acidity was more quantitative than at high aqueous acidity. Especially, TCMC is more efficient than TOA for the molybdenum extraction when the HCl and HNO\(_{3}\) concentration was lower than 4M and 0.55M, respectively. Whilst TOA offered higher extraction efficiency than TCMC when the sulfuric acid concentration was lower than 4M. At high acid concentration (2-10M), there was little difference in the distribution coefficient of Mo from HCl solution by these extractants. However, TCMAC and TOA could not extract Mo from HNO\(_{3}\) (1-5 M) and H\(_{2}\)SO\(_{4}\) (5-10 M) solution, respectively. Moreover, the total chloride and
nitrate concentration had not much effect on the extraction at low aqueous acidity but they were the controlling factor at higher acidity. The extractability was little influenced when the total sulphate concentration was below 1 M.

The polymeric anionic complexes of molybdenum exist in the pH range from 2.0 to 6.5 and it was possible to extract molybdenum from sulfuric acid by primary amine primene JMT. Various heptamolybdadte and octamolybdate anions were rapidly extracted from acidic media (i.e., pH 1-4) by Aliquat 336.24

4.2. Vanadium extraction from acidic media containing single metal

Sato25-27) has studied the extraction of vanadium from hydrochloric acid solutions or mixed solutions of hydrochloric acid and lithium by DEHPA, TOA, Aliquat 336, TBP and TOPO. The obtained results indicated that the controlling factor for the vanadium extraction with TOA, Aliquat 336, TOPO and TBP was total chloride ion concentration. The vanadium extraction from single HCl solution reached a peak in the HCl range 5-7 M, but in the mixture of hydrochloric acid and lithium chloride, it increased continuously with the total chloride concentration. By contrast, the total chloride ion concentration had not great effect on the loading behavior of vanadium using DEHPA.

The extraction of vanadium from HCl, H2SO4 and HNO3 acid solutions using Aliquat 336 was studied by El-Nadi.16) The authors indicated that 3M HCl acid solution was the best solution for the extraction of vanadium. Furthermore, the hydrogen ion concentration at 3M chloride ion concentration had no influence on the extraction while the extraction percentage of vanadium decreased with increasing chloride ion concentration from 3 to 5 M at this acidity (3 M). At pH 1.5-2.0, acidic decavanadate species from sulfuric acid media were rapidly extracted by Aliquat 336, but reddish extracted species turned to olive green within a few days while a black-greenish solid precipitated.24

Li28) reported that the predominant existence of vanadium species in sulfuric acid medium is VO2+ when pH is lower than 3.0. Therefore, this species was extracted easily by D2EHPA, EHEHPA and Cyanex 272. The extraction ability of extractants decreased in the following order: D2EHPA > EHEHPA > Cyanex 272. Moreover, total sulphate ion concentration had little effect on the vanadium extraction.

Lozano and Juan29) indicated that the primary amine Primene 81R can extract vanadium from sulphate media in the range pH of 2-2.5 where HV10(O2)5− is predominant. The overall extraction mechanism is represented as Eq.8. In this process, 5% isodecanol was used as a modifier to avoid the formation of a third phase. The loaded vanadium was stripped with ammonia solution.

\[
5[RNH_3]_{org} + 5H^+_{aq} + [HV_{10}O_{23}]^{-}_{aq} \leftrightarrow [R(NH_2)_5] + 5(HV_{10}O_{23})^{-}_{aq} \tag{8}
\]

Nekovář and Schröterova30) studied the extraction of vanadium from sulfuric acid solution by primary amine primene JMT. The extraction behavior of vanadium was similar to that of molybdenum.

4.3. Molybdenum and vanadium extraction from acidic media in the presence of other metals.

4.3.1. Extraction by cationic extractants

Zhang31) and Zeng and Cheng32) have used LIX 63 to extract Mo and V from sulfuric acid solution containing Al, Co, Ni and Fe. It was indicated that both Mo and V can be extracted over other metals in the pH range of 1.0-2.0. A pure V(IV) and Mo(VI) solution can be obtained by selectively stripping V and Mo from the loaded LIX 63 using H2SO4 and NH4OH, respectively.29 By contrast, Zeng and Cheng30) indicated that Mo(VI) and V(V) from loaded LIX 63 cannot be stripped with strong sulphuric acid solution. Mo(VI) was still not completely stripped although the stripping of V (V) was complete using 10% ammonia solution. Moreover, the authors showed that 1M NaOH solution could strip most of Mo and V from the loaded organic. Both pure molybdenum and vanadium products were obtained by two separation processes. First, vanadium was recovered as ammonium vanadate after the precipitation of vanadium from the strip liquor. Secondly, a pure molybdenum solution was obtained by further removing small amount of vanadium using Aliquat 336 at pH 8.5.

Zhang31) have studied selective extraction of molybdenum and vanadium from sulfuric acid solution containing Ni, Co and Al using PC88A. The co-extraction of molybdenum and vanadium was obtained at a low pH based on the differences in equilibria and kinetics of...
extraction between these metals. Li reported that molybdenum and vanadium were quantitatively co-extracted at pH 2.0 using EHEHPA, where molybdenum and vanadium species like MoO$_{2}^{2+}$ and VO$_{2}^{+}$ is predominant. The extraction reaction of molybdenum and vanadium by EHEHPA at pH 2.0 is represented in Eqs. 9-10. Most of V from the loaded organic was first stripped with 1M H$_{2}$SO$_{4}$ and then molybdenum stripping was completed by 10 wt% NH$_{4}$OH and 15 wt% NH$_{4}$Cl.

\[
\text{VO}^{2+}_{(aq)} + 2(\text{HA})_{(org)} = \text{VOA}_{2}^{2-}2\text{HA}_{(org)} + 2\text{H}^{+}_{(aq)} \quad (9)
\]

\[
\text{MoO}_{2}^{2+}_{(aq)} + 2(\text{HA})_{(org)} = \text{MoO}_{2}^{2-}2\text{HA}_{(org)} + 2\text{H}^{+}_{(aq)} \quad (10)
\]

Mishra reported that molybdenum and vanadium can be co-extracted over other metals like Ni, Fe and Al from leach liquor at higher pH or individually extracted at low pH (pH < 0.5) and high pH (pH > 2.0), respectively by LIX 84-I. The molybdenum and vanadium stripping were carried out by using 20% NH$_{4}$OH and the mixture of 20% NH$_{4}$OH - 2 M (NH$_{4}$)$_{2}$CO$_{3}$, respectively. Park also indicated that pH 0.5 was the best condition to extract molybdenum from Ni and Al by LIX-84I. The extraction reaction of molybdenum is represented in Eq. 11.

\[
\text{MoO}_{2}^{2+}_{(aq)} + 2\text{HR}_{(org)} = (\text{MoO}_{2}^{2+}2\text{R})_{org} + 2\text{H}^{+}_{aq} \quad (11)
\]

Wu studied the extraction of molybdenum from leach liquor containing V, As, Fe using cationic extractants. Molybdenum can be extracted over impurities when the initial leach liquor pH was lower than zero using D2EHPA, EHEHPA and Cyanex 272. Moreover, the optimum extractant was found to be Cyanex 272 for Mo and D2EHPA for Fe and V, respectively.

4.3.2. Extraction by neutral extractants

Most molybdenum from 3M HCl leaching solution of spent catalyst was quantitatively extracted while the co-extraction of vanadium did not exceed 3.6% by the use of TOPO. Banda reported that TOPO and TBP can extract molybdenum over cobalt and aluminum from 3M HCl leaching solution. The extraction efficiency of molybdenum with TOPO was higher than with TBP but the stripping of molybdenum from loaded TBP is easier than that from the loaded TOPO. Hence, TBP was recommended as an extractant for the separation of molybdenum from Co and Al.

The solvent extraction reaction of molybdenum in hydrochloric acid solution with TOPO extractant can be represented as follows.

\[
\text{H}_{2}\text{MoO}_{4}^{aq} + 2(\text{TOPO})_{org} = \text{H}_{2}\text{MoO}_{4}^{aq}2\text{TOPO}_{org} \quad (12)
\]

\[
\text{MoO}_{2}^{2+}\text{Cl}_{2}^{aq} + 2(\text{TOPO})_{org} = \text{MoO}_{2}^{2+}\text{Cl}_{2}^{aq}2\text{TOPO}_{org} \quad (13)
\]

4.3.3. Extraction by anionic extractants

Olabal reported that Alamine 336 and Aliquat 336 could be used in separating vanadium and molybdenum. Molybdenum can be separated completely from vanadium at pH < 1 with Alamine 336. Aliquat 336 can be used to extract vanadium in the presence of molybdenum in the pH range from 8 to 9. The authors also showed that stripping efficiency of Alamine 336 was higher than that of Aliquat 336. The simultaneous extraction of Mo(VI) and V(V) by Aliquat 336 has been investigated in the absence and in the presence of phosphate and it has been observed that solid compounds also was slowly precipitated from the loaded organics.

A process for the extraction of molybdenum in the presence of other metals from sulfuric acid medium was studied by Valverde Jr. Two extractants were tested: Alamine 304 and Alamine 336. Although both extractants can extract molybdenum when the pH value of acid leaching solution was about 1.8, the best performance was found for Alamine 304. Pathi also has used Alamine

<table>
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<tr>
<th>Organic phase composition</th>
<th>Synergistic coefficient (R)</th>
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<tbody>
<tr>
<td></td>
<td>Mo</td>
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<tr>
<td>10% (v/v) Cyanex-272 + 20% (v/v) secondary caprylic alcohol</td>
<td>0.82</td>
</tr>
<tr>
<td>10% (v/v) Cyanex-272 + 10% (v/v) TBP</td>
<td>4.4</td>
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304 for recovery of molybdenum in the presence of Co, Ni, Cu and Fe. Most molybdenum was extracted over other metals at pH 1.6. It should be noted that in order to prevent third phase formation or emulsification in the organic medium, the concentration of Alamine 304-I should be below 10% (v/v). Molybdenum from the loaded Alamine 304-I was stripped easily by using 5M NH$_4$OH-2.5M (NH$_4$)$_2$CO$_3$. The extraction reaction of molybdenum in sulfuric acid solution with Alamine 304-I was presented in Eqs.(14) - (16).

\[
\begin{align*}
R_3N_{(org)}^+ + H^+_{(aq)} + HS0_4^-_{(aq)} & \rightleftharpoons R_3NH^+_{(org)} + HSO_4^-_{(aq)} \quad (14) \\
2R_3NH^+_{(org)} + MoO_2^-_{4(aq)} & \rightleftharpoons 2 [R_3NH^+]_{(org)} + [HSO_4^-_{aq}] \quad (15) \\
2R_3N_{(org)}^+ + 2H^+_{(aq)} + MoO_2^-_{4(aq)} & \rightleftharpoons 2 [R_3NH^+]_{(org)} + [MoO_2^-_{4(aq)}] \quad (16)
\end{align*}
\]

The selectivity for molybdenum extraction from solution (pH = 2.0) containing copper, magnesium, manganese, iron, cobalt and aluminum with DIDA was carried out by Gerhardt.$^{[7]}$ The co-extraction of iron, cobalt and impurities did not exceed 1-2% while the extraction percentage of copper, manganese and aluminum was negligible.

### 4.3.4. Extraction by the mixture of cationic and neutral extractant

The main problem encountered during the use of Cyanex 272 is that the extracted Mo-Cyanex 272 forms an insoluble small colloidal particle in the organic phase and secondary caprylic alcohol and TBP were used as a modifier.$^{[3]}$ Besides preventing the formation of colloidal particle, TBP had a synergistic effect for Mo extraction while there was no effect on the extraction of Mo using secondary caprylic alcohol (Table 1). The authors showed that a mixture of 15% Cyanex 272 and 15% TBP at an equilibrium pH of $\sim 0.05$ was adequate for the selective extraction of Mo from leach liquor containing V, Fe and As and the molybdenum from loaded organic was stripped by the use of ammonia solution.

Li$^{[38]}$ reported that D2EHPA could extract vanadium from solution containing Al, Fe and Si when pH value of solution was higher than 1.0. However, the problem for D2EHPA is the formation of third phase due to the hydrolysis of Al(III) and Fe(III) and to the presence of SiO$_2$ when the initial pH was higher than 2.5. Therefore, TBP was added as an effective phase modifier. The mixture of D2EHPA and TBP was also used to extract vanadium from leach liquor in the presence of iron (II) and other metals.$^{[39,40]}$ Stripping with 15% H$_2$SO$_4$ gave high efficiency and the concentration of vanadium in stripping solution can be enriched while the iron concentration can be reduced to 0.6 g/L. Li$^{[29]}$ reported that TBP can be added not only as a phase modifier to inhibit the emulsification of organic phase and the formation of third phase, but also as a synergistic extraction reagent to improve metal extraction compared to single extractant. In vanadium extraction process from sulfuric acid solution containing Fe(III), Fe(II), Mg(II), Al(III) and K(I) by a mixture D2EHPA and TBP, it was suggested

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Fig. 1. A general schematic process flow sheet for the recovery of valuable metals from spent catalyst.
that the acid leaching solution was pretreated with Na₂SO₃ to reduce Fe (III) to Fe (II) and the Al (III) and Mg (II) concentrations should be lower than 10 g/L for avoiding co-extraction. By considering the stripping efficiency and free sulfuric acid in the strip solution, 1.5 M H₂SO₄ solution was found to be the optimum condition for vanadium stripping from the loaded organic. The stripping solution contained a small amount of impurities which would not affect the following precipitation of vanadium.

A summary of the extraction and stripping of molybdenum and vanadium from acid leaching solution of spent catalyst using solvent extraction and a general schematic process flow sheet for the recovery of valuable metals from spent catalysts are shown in Table 2 and Fig. 1, respectively.

5. Summary

Solvent extraction has been employed to recover molybdenum and vanadium from acid leaching solutions of spent catalyst. The extraction behavior of molybdenum and vanadium from acid leaching solution of spent catalysts by four types of extractants has been reviewed: cationic, anionic, neutral and a mixture of cationic and neutral extractants. Neutral extractants can separate molybdenum from cobalt, vanadium and aluminum at high HCl solution but not much investigation has been reported in the separation of molybdenum from vanadium. With cationic and anionic extractants, separation of molybdenum and vanadium from other impurity metals was achieved. However, some problems may be en-
countered when a solvent extraction plant was operated, including emulsification of organic phase, the formation of third phase and appearance of precipitates. It was indicated that a mixture of cationic and neutral extractants had the advantage of being free from the formation of an emulsion and of a third phase, especially from the formation of precipitates in loaded organic. The synergistic solvent extraction system consisting of Cyanex 272, D2EHPA and TBP was favorable for the recovery of molybdenum and vanadium, respectively. Moreover, molybdenum and vanadium from these loaded organic was stripped easily by using ammonia and sulfuric solution, respectively. Consequently, use of a mixture of cationic and neutral extractants is promising for the effective separation and recovery of molybdenum and vanadium from acidic leach solution, in particular from sulfate leach liquor of spent catalyst.

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