

Gold Recovery



- ◆ Butyl Diglyme – Novolyte’s agent for efficient gold recovery
- ◆ Gold sources include: – Precipitates, alloys, or electrode slimes
- ◆ Recovery process is selective – Even in the presence of other metals
- ◆ Butyl Diglyme can easily be recycled



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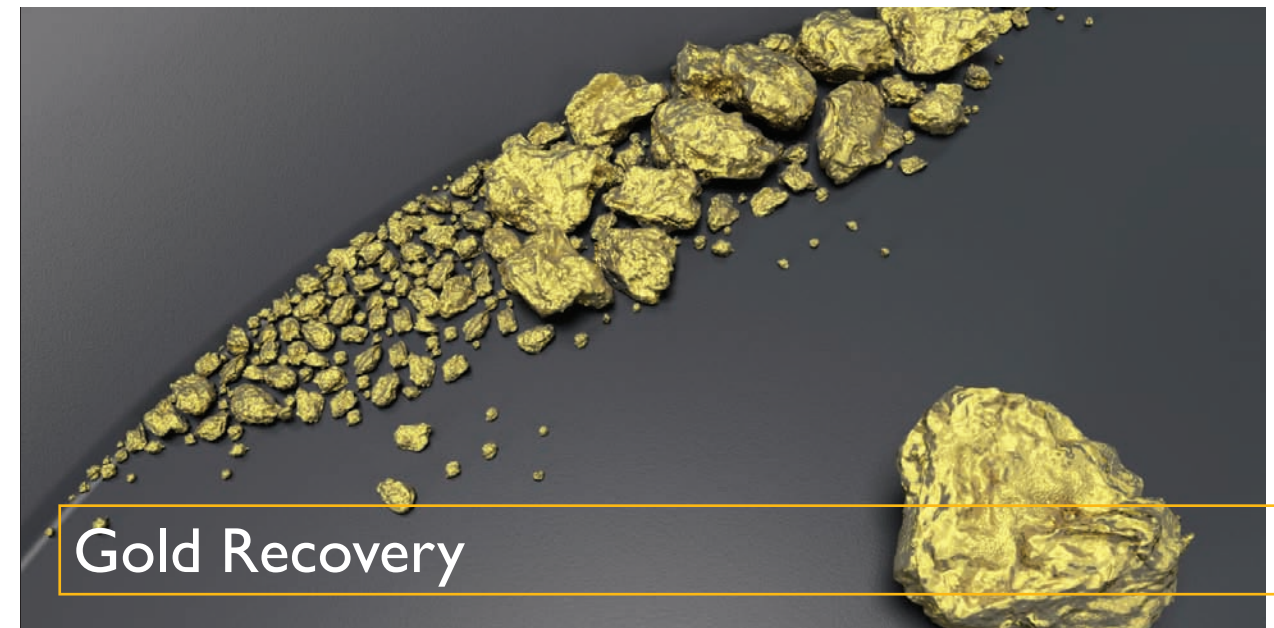
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About Novolyte Technologies, Inc.

Novolyte Technologies is a world leading manufacturer and supplier of specialty electrolyte materials, high performance solvents, aryl phosphorus derivatives and technically demanding custom manufactured products. Novolyte, previously Ferro Fine Chemicals Division, is headquartered in Independence, Ohio USA. Novolyte serves the needs of its diverse, international customers through two state-of-the-art, ISO-certified manufacturing facilities located in Baton Rouge, Louisiana and Suzhou, China. The Company's Baton Rouge facility is famous for its production flexibility and its ability to produce numerous products based on complex chemistries and materials. The China plant produces specialty solvents and electrolytes for the Asia energy storage markets.

Novolyte is the exclusive North American producer and a global leader of primary and secondary lithium battery electrolytes, ultracapacitor solutions, specialty solvents and aryl phosphorus derivatives. With over 50 years of technological and product innovation, Novolyte has developed a comprehensive offering of performance based and built-to-specification products, which are among the highest purity available in the industry. Our products are used in a wide array of demanding applications including organic energy storage devices, complex pharmaceutical synthesis, gas scrubbing, adhesives, coatings, inks, cleaning detergents and engineered fabrics.

Novolyte focuses on markets where high-purity products, technical expertise and unique manufacturing capabilities offer a compelling competitive advantage to our customers.

Novolyte is your partner in creating value in your business. Please see our product application sections of our website or contact us for further information. Read on to find out about the application of Novolyte Butyl Diglyme for gold recovery!

Introduction

Find a penny, pick it up – all the day, you'll have good luck. Nothing wrong with copper, but two rows down on the periodic chart is the REAL MONEY! Why not 'pick-up' the extra gold in your ore or electrode slime – especially since you have already done the hard and expensive work of getting the material to your plant.

Gold recovery and refining methods employ a variety of mechanical and chemical operations to produce precious metal or commercial purity. Depending on the quality of a gold source and its composition, any one of several different refining methods can be utilized to recover and refine gold to high purity.

While the use of solvent extraction to recover metals is not new technology, it is an under-utilized technology even though there is ample evidence and experience validating this technique. In many cases, solvent extraction can provide significant reductions in operational costs in comparison to more traditional methods of metal recovery and refining.

Polyethers, such as glymes, form complexes with numerous metals.¹⁻⁷ This property can be applied to the recovery of transition and noble metals from ores and process streams.

One of these commercially proven applications of metal complexation uses butyl diglyme (i.e. dibutyl carbitol, E444) to extract gold (III) chloride from aqueous solutions. Sources of gold include various ores, concentrates^{1,2}, anode slimes⁸⁻¹⁰, cathode sludges¹¹, electrolytic plating operations and gold coated electronic parts.¹² Butyl diglyme extraction is both a cost effective and an environmentally friendly metal recovery process.

Advantages

The advantages of using a solvent extraction system based on butyl diglyme (dibutyl carbitol or E444) can be summarized as follows:

Health, safety and environment:

Butyl diglyme is a non-HAPS (Hazardous Air Pollutants) solvent with an LD₅₀ of 3900 mg/kg.

- Butyl diglyme is biodegradable and not biotoxic. The bacteria used in aerobic digestion of industrial waste can be acclimated to digest butyl diglyme under mildly acidic conditions.
- Butyl diglyme has low solubility in water (0.3 wt% or ~3g/L at 20°C).



Economics:

- A butyl diglyme process delivers nearly quantitative yields (>98%) of high purity gold (98 to 99.99wt%).
- Butyl diglyme is very selective for gold (III) chloride. Butyl diglyme provides a clean and facile separation of gold (III) chloride from the chlorides of the platinum group metals. If present, platinum and palladium will also dissolve in the aqueous oxidizing chloride solution, and they can then be recovered by extraction and precipitation.
- A butyl diglyme process also is suitable for small or large scale operations.
- Butyl diglyme is easily recycled with minimal material losses without degrading its extracting performance. No major reprocessing is necessary for recycling.
- The cost of butyl diglyme consumed in this extraction process is approximately \$0.50/oz of gold.
- Energy requirements¹⁴ for butyl diglyme processes are 0.3% of those required for traditional electro/ pyrolytic processes.
- The Butyl diglyme process greatly reduces the amount of gold "locked-up" during a processing cycle.
- Butyl diglyme extraction is a well documented technology.
- Butyl diglyme is readily available in commercial quantities.

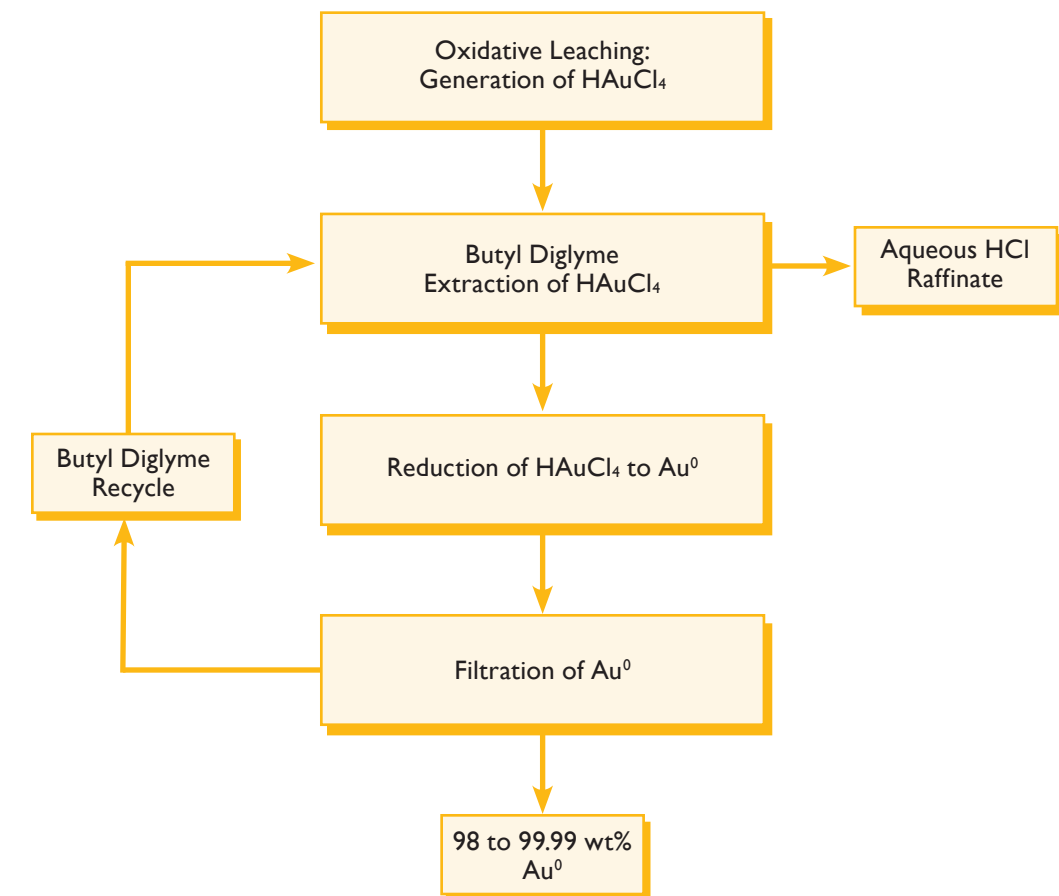
Process Summary

There are five steps necessary (Figure 1) for a gold extraction process based on butyl diglyme:

- Oxidative leaching converts crude metallic gold or gold (I) to an aqueous solution of gold (III) chloride.
- Solvent extraction selectively transfers the gold (III) chloride as chloroauric acid from the aqueous solution into the butyl diglyme phase.
- A wash of this organic extract with dilute HCl removes trace metallic impurities.

- Reduction of gold (III) to metallic gold is accomplished with a variety of chemical agents that convert the solubilized gold (III) into a metallic gold precipitate which is collected and then cast into ingots.
- Butyl diglyme is then recycled back into the process after minimal processing.

Figure 1: Butyl Diglyme Based Solvent Extraction Scheme:

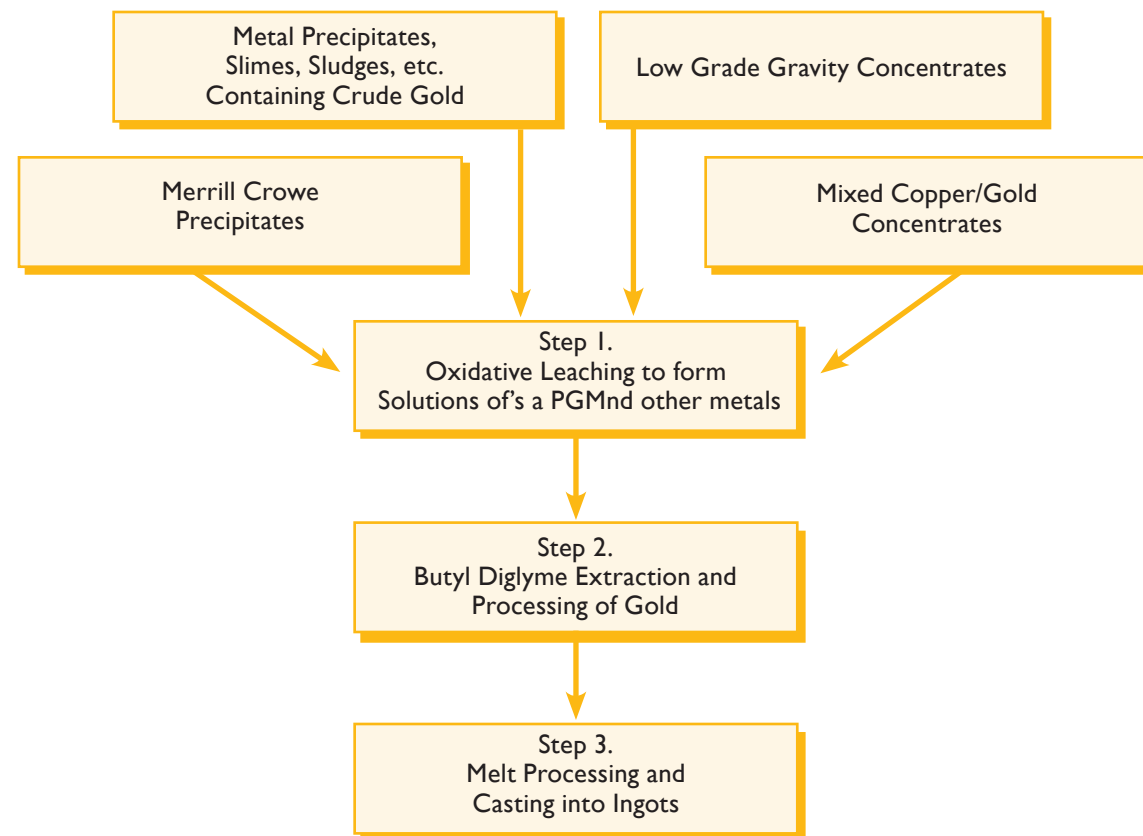


Process Details

Oxidative Leaching: The Conversion Of Metallic Gold To Gold (Iii)

Figure 2 shows the various crude gold sources that can serve as raw materials of a butyl diglyme extraction process. The diagram indicates that butyl diglyme extraction technology can augment or even replace more traditional refining technology.

Figure 2: General Processing Required to Refine Gold:

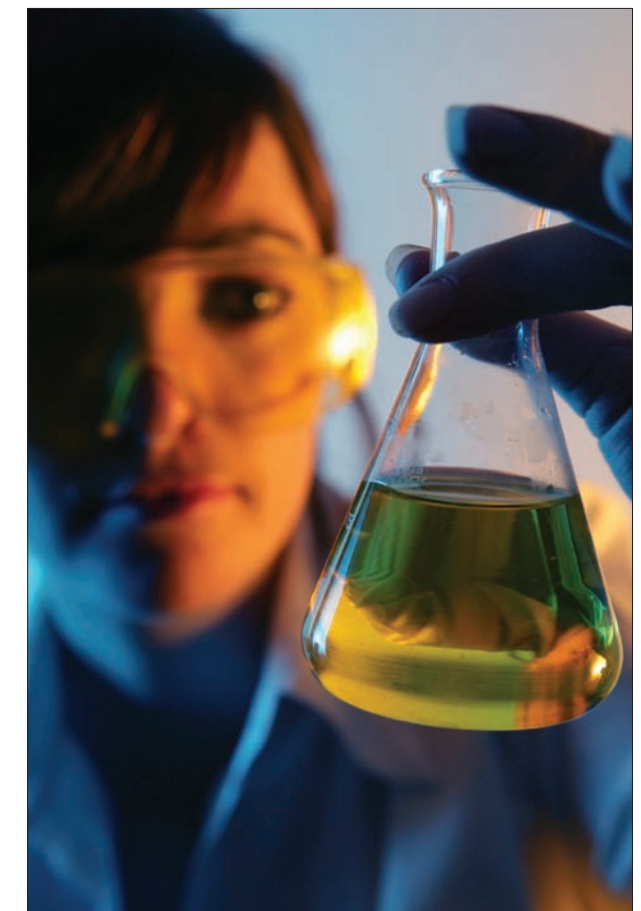


Oxidative leaching refers to a chemical process by which crude gold is oxidized and solubilized into an aqueous solution. These aqueous gold (III) chloride oxidation streams will be acidic if aqua regia¹⁰ or chlorine leaching (Cl₂) in HCl are used for gold oxidation.^{10, 13, 15, 17-20} Aqua regia (a mixture of nitric and hydrochloric acids in volume ratios that vary from 10:1 to 1:10) is useful for secondary gold recovery operations from metallic slimes, sludges and precious metal scraps. Although used in secondary recovery of precious metals, aqua regia has not been used for primary recovery of gold from gold bearing ores.

An alternative oxidative technique known as chlorine leaching can be applied directly to gold ores and to a wide variety of secondary non-ferrous metal pulps such as electrolytic sludges and anode slimes.^{16,21-22} One type of leaching solution consists of chlorine gas (Cl₂) dissolved in HCl at 40-50°C. Not only will this system oxidize crude gold to gold (III) but it will also convert gold (I) cyanide to gold (III) chloride. Done under pressure, any HCN released by this process is decomposed rather than released as a gaseous side product. A simple and effective way to get the oxidative leaching is to combine the gold source and dil HCl, then slowly and carefully with stirring add either conc. bleach or conc. H₂O₂¹⁰. Neutral solutions of high concentration of bleach can also work, but the reactions are slow and there is sometimes difficulty getting all the gold out.

Complex hypobromites can be an excellent choice for some gold sources.

Oxidative leaching does not require a great excess of oxidant. Excess oxidant not only increases raw material costs, but it also creates problems down stream from the leaching step. Excess oxidant that becomes entrained in the butyl diglyme during the solvent extraction step contributes to solvent degradation and it can increase the amount of reducing agent required to strip the gold (III) from solution. The best way to monitor oxidant level is to use an ORP meter. Run most of the oxidation at 700 to 1000 mv, and at the end make sure the ORP level stays constant for several minutes at around 700 to 800 mv.



Butyl Diglyme Extraction

Experimental data is abundantly available for gold extractions from HCl streams.^{1, 13-16, 23-25} The partitioning of gold (III) into a butyl diglyme phase is efficient enough that these extractions can be performed using either continuous or batch-wise techniques.

Table I: Distribution ratio (D) of Gold (Au) between Butyl Diglyme and Water using a V_{org}/V_{aq} ratio of 1 for various initial amounts of gold as a function of HCl concentration at room temperature¹:

Initial Gold Concentration in the Aqueous Phase: M (moles/L)	Concentration of Aqueous HCl: M (moles/L)			
	2M ^a	3M	4M	5M
6.09×10^{-7} M or (1.2 $\times 10^{-4}$ wt% Au)	20.8 ^b	29.4	45.6	82.0
3.20×10^{-2} M or (0.63 wt% Au)	118	295	1065	2590
3.84×10^{-1} M or (7.56 wt% Au)	885	1820	3066	5380

a) To convert molarity to ~ wt%, just multiply HCl molarity by 3.645: e.g. 5M ~ 18.2 wt%

b) Distribution Ratio: $D = [Au] \text{ in Butyl Diglyme} / [Au] \text{ in Aqueous HCl}$

The data in Table I shows that >99% extraction of gold (III) can be achieved in a single extraction between equal volumes of butyl diglyme and aqueous phases with HCl concentrations greater than 1M. For an aqueous feed solution containing 4g (Au³⁺)/L, a butyl diglyme to aqueous volume ratio of 1 to 6 suffices for >99% gold extraction¹³.

Results obtained by Morris and Khan¹ are also confirmed in more recent work by Zhu et al.¹⁰ This more recent investigation (Table II) reports a 99% recovery of gold (III) chloride from aqueous concentrations as low as 340 ppm:

Table II: Extraction Yields¹⁰ of Recovered Gold (III) from 1M HCl (i.e. ~3.65 wt% HCl) as a function of initial aqueous Gold (III) concentration at room temperature using a V_{org}/V_{aq} ratio of 1:

Initial Aqueous Gold (III) Concentration	6.25ppm ^a	220ppm	340ppm	850ppm
% Gold (III) extracted into Butyl Diglyme	61.60%	94.77%	99.26%	99.65%

a) 100 ppm = 0.01 wt%

Both sets of data in Tables I and II show that higher concentrations of acid and higher concentrations of gold (III) lead to higher extraction efficiencies.

The extraction yield is excellent over a broad loading range. Thus a batch of butyl diglyme can be repeatedly recycled through several batches of oxidative leachings before the loaded solvent gets stripped of its gold. Such efficiency is due in part to the favorable thermodynamic parameters for extraction of gold (III) into butyl diglyme. The free energy (ΔG°), enthalpy (ΔH°) and entropy (ΔS°) for extraction of chloroauric acid [HAuCl₄] from an aqueous HCl solution into butyl diglyme²⁶ is - 8.51 kJ/mol; -84.24 kJ/mol and -0.25 kJ/mol-K^o respectively.

In practice, where other precious metals are also recovered, gold loadings in butyl diglyme are kept between 25-100g/L. A loading of 25g/L of gold (III) chloride into butyl diglyme from an acidic aqueous solution leaves a residual concentration of ~10mg/L gold (III) chloride in an aqueous phase. Gold (III) loadings in butyl diglyme should not exceed ~12 wt% or 120g/L because a phase inversion will occur when the density of a loaded butyl diglyme exceeds that of the oxidative leaching solution. Furthermore, as the two phase densities approach equivalency, the rate at which phase separations occur will be slowed.



Minimizing Metallic Impurities

As shown in table (III), the molarity of hydrochloric acid in the initial oxidative leach solution is important for minimizing co-extractions of "base" metal impurities such as tin, selenium and tellurium. These impurities are removed by washing the gold/butyl diglyme extracts of the oxidative leach with dilute aqueous hydrochloric acid prior to reduction.

Table III: Estimated solubility of other metal chlorides relative to Au (III) in butyl Diglyme as a function of HCl concentration.¹

Metal	Molarity of HCl in Aqueous Phase ² :				
	1.5M	3.0M	4.0M	5.0M	6.0M
Au+3	100 wt%	100 wt%	100 wt%	100 wt%	100 wt%
Fe+3	2	30	90	98	100
Sb+5	3	5	40	93	98
Sn+4	40	65	83	90	95
As+3	2	15	35	70	90
Sb+3	67	72	64	59	58
Te+2	3	3	8	20	50

a) To convert to ~wt% just multiply HCl molarity by 3.645

Data in Table III suggest that to minimize co-extraction of other metal chlorides an optimal acid concentration for the oxidative leach is 1.5M HCl. However, the need to minimize the amounts of water required to gold processing suggest that target acid concentrations in the spent oxidative leach need to be adjusted down to ~4.0M before extraction. Co-extraction of tin (IV) needs

to be monitored because in high concentrations tin (IV) can form a gel in butyl diglyme making solvent recovery difficult. Since these solubility equilibria are established rapidly,^{1, 13-16} various "base" metal contaminations of the crude gold (III) butyl diglyme solution can be removed by simply washing this organic phase with 1.5M HCl.

Structure of Gold (III) Butyl Diglyme Complex

Data from a combination of U.V./visible, infrared, far infrared and Raman spectrophotometry are all consistent with a square planar structure for $[\text{AuCl}_4]^-$, the tetrachloride anion of gold (III). Sergeant and Rice²⁷ argued, based on the similarity of spectra for both aqueous and butyl diglyme solutions of HAuCl_4 , that butyl diglyme does not complex directly with the gold (III) ion. Instead one or more butyl diglyme molecules replace some of the water molecules that form a

secondary solvation sheath around $\text{H}[\text{AuCl}_4]$. By complexing with hydrated protons like $[\text{H}_5\text{O}_2]^+$, $[\text{H}_7\text{O}_3]^+$ or $[\text{H}_9\text{O}_4]^+$, butyl diglyme forms an ion pair with $[\text{AuCl}_4]^-$ that readily dissolves into the bulk organic phase. The selectivity of butyl diglyme for gold (III) chloride is attributed to favorable charge/size ration for an ion pair between the butyl diglyme solvated proton and $[\text{AuCl}_4]^-$.

Reduction of Gold (III) to Metallic Gold

Many different reagents have been useful in reducing gold compounds into metallic gold. Three important considerations affect the choice of reducing agent for this process. Does the reducing agent yield metallic gold of sufficient purity? Is the reduction rapid? Is the form of metallic gold (i.e. sponge, sand or flake) appropriate? Data indicate the actual form of precipitated gold depends on the type and amount of reducing agent used, as well as on the process conditions (temperature and agitation) used during reduction.

Table IV: Typical reducing agents for reduction of Gold (III) solutions in butyl Diglyme:²⁸

Reductant	Concentration wt% in water	Time For Reduction, hr.	Form of Gold
Oxalic Acid ^b	5	3-5	gold sand/flake
Formic Acid	5	2-2.5	gold flake
Sodium Nitrite	5	1.5-2.0	gold flake
Hydrogen Peroxide ^c	5	0.5-1.0	gold flake/sponge
Hydrazined	5	0.5	black flake
Hydrazined	1	1.0	black flake

a) Reaction at 70-80°C; b) Oxalic acid has a solubility in butyl diglyme of 11.3 g/L; c) Results were sensitive to contaminating metal ions in process water; Use of tap water slowed the reaction to 1 hour; distilled water gave the shorter reaction time of 0.5 hr; d) On ignition, metal became normal gold color.

Solvent Recycle

Oxalic acid is one of the more selective agents²⁸ for Gold (III), capable of producing 99.999 wt% gold. Reduction mole ratios of oxalic acid/gold range from 2.5/1 to 1.1/1.

Reynolds et al.²⁸ proposed that the reductions reported in Table IV occur in the aqueous phase and not in the organic phase nor even along the org./aq phase boundary. Also Reynolds et al. have shown that water is necessary for these bimolecular reductions to occur. Second order rate constants (L/mol sec) at 68°C averaged 0.791 ± 0.28 for oxalic acid; 0.126 ± 0.05 for hydrogen peroxide. Cooling the reaction temperature down to 55°C decreased the rate constant for hydrogen peroxide reduction by about 50% to 0.062 ± 0.002 with an activation energy for peroxide reduction of 12 kcal/mol.

Conflicting statements have appeared about gold recovery using butyl diglyme.^{10,13,29,30} For example, one of these publications²⁹ suggested that there were filtration problems in recovering reduced gold from butyl diglyme. However, there was a lack of information about the gold (III)/butyl diglyme extract composition or conditions used for reduction, nor were the filtration problems quantified. Reduction data in Table IV does suggest that both the reductant chosen and reduction conditions effect the form of metallic gold produced (sand, sponge or flake). Any metallic gold sediment in such a system should rapidly sink because the difference between gold and butyl diglyme specific gravities are

large (18.43 at 20°C), and butyl diglyme possesses a low viscosity (i.e. 2.4cP at 20°C). Trace amounts of butyl diglyme solvent absorbed on the metallic gold can be washed off or be decomposed to carbon dioxide and water when the gold powder is melted into ingots.



High and very low butyl diglyme losses during recycle are described in the literature. Some losses appear to be due to unnecessary attempts to reprocess or in some way purify the butyl diglyme as part of an extraction process. In one report²⁹, butyl diglyme was distilled from one or more of the aqueous raffinate streams. Based on experience with this butyl diglyme application^{13,14,18,22} there is no indication that such additional processing steps are necessary for butyl diglyme recycle.

The amount of butyl diglyme consumed for a complete cycle of this extraction process was reported by Liu²¹ to be 0.73 kg per kg of gold produced. It is not clear from his and other reports^{13,20,29,30} whether butyl diglyme consumption results from losses due to butyl diglyme solubility in the various process streams or as a result of chemical degradation during extraction of oxidative leaching streams.

The literature on butyl diglyme extraction contains qualitative and quantitative statements about the amount of solvent lost to the aqueous process streams during a complete cycle of extractions and washings.^{13,20,29,30} Actual amounts of butyl diglyme lost as

a result of water solubility depend on the total ratio of water to glyme used, as well as the solubility of glyme in those process streams. (Table V) For example, to obtain a total loss of 4 wt% due completely to solubility for a given extraction/reduction cycle using an average solubility of 0.58 wt% from Table V for ~ 1.5M HCl, would require a total process water to glyme weight ratio of about 6.9 to 1.

Chemical stability also was evaluated as a function of acid (H⁺) concentration. Table V shows how butyl diglyme degrades when treated with four different concentrations aqua regia (80 HCl/20 HNO₃;V/V). There are several products formed when butyl diglyme undergoes acid catalyzed hydrolysis by dilute acid solutions, 1-butene, n-butanol, 2-chlorobutane and in concentrated (i.e. > 5N HCl) 1-chlorobutane. Since 1-butene and the chlorobutanes do not have an appreciable solubility in water, they are sensitive internal markers for the extent of butyl diglyme decomposition.

Table V: Partitioning of butyl Diglyme and Water in Aqueous HCl at 23°C:

Molar Concentration Of HCl in H ₂ O (moles/Liter)	11.9M ¹³	5.95M	2.98M	1.49M	0.744M	0.0M
Amount of H ₂ O in the Butyl Diglyme Layer	Completely Miscible	0.72 wt%	1.02 wt%	1.19 wt%	1.22 wt%	1.4 wt%
Amount of Butyl Diglyme in the H ₂ O Layer	Completely Miscible	2.18 wt%	0.73 wt%	0.575 wt%	0.545 wt%	0.3 wt%

Gold (III) Extraction – How-To

Table VI: Degradation of Butyl Diglyme as a function of Aqua Regia concentration at 23°C:

Molar Concentration of 80/20 HCl/HNO in H ₂ O (moles/Liter)	6.56M	3.28M	1.64M	0.82M
Initial time; t ₀	99.85 ^b	99.85	99.85	99.85
141.5 hr; 11.5 days	99.20	99.66	99.85	99.85
336 hr; 14 days	98.42	99.19	99.81	99.81

a) This data derived from batch aging; b) Area % of butyl diglyme at time

Both the rate and extent of decomposition are related to acid strength, residual oxidant, and temperature. The presence of oxidant enhanced the decomposition rate of butyl diglyme. However, as long as acid concentrations, residual oxidant levels are minimized, then losses due to butyl diglyme degradation will be minimized.

Based on the data above in Table V and VI, it would appear that most of the butyl diglyme lost during processing results from solubility of butyl diglyme in the various aqueous streams. Losses resulting from any chemical degradation of butyl diglyme are minor when excess oxidant is minimized.

Summary Of Butyl Diglyme Advantages:

The use of butyl diglyme to extract gold metal from gold anode slimes was first described in 1968 by Morris and Kahn.¹ Gold recovery based on butyl diglyme extraction technology can provide gold recoveries of almost 100% yield with gold assays in excess of 99.99%. Butyl Diglyme extraction technology lowers operating costs when compared to traditional electro/pyrolytic refining operations. Major cost reductions are possible because butyl diglyme extraction technology requires a fraction (0.3%) of the energy typically required to produce 1 kg of gold by traditional methods.¹⁴

Other important economic incentives for considering a refining process based on butyl diglyme extraction included the need to reduce both health hazards and environmental impact of metal recovery operations. Hidden cost savings also will be realized because butyl diglyme extraction technology reduces the amounts of precious metal retained or "locked-up" in a refining operation.



Oxidative Leaching: The crude gold is reacted with aqua regia. Aqua regia is a mixture of concentrated hydrochloric and nitric acids in a volume ratio of HCl to nitric that can vary from 10:1 to 1:10. In practice, the conditions of this oxidative leaching step with aqua regia are controlled so that the resulting aqueous gold solution does not have a nitric acid concentration in excess of 0.1M. Any insoluble raffinate left behind may contain insoluble chlorides of silver, and possibly some rhodium, ruthenium and iridium. After filtering an acidic oxidative leaching solution the acid concentration is reduced, if necessary, to about 4M HCl by adding water. This aqueous solution contains the chlorides of gold, platinum, palladium and some or all other PGM's.

Extraction: The oxidative leach solution is extracted with an equal or less volume of butyl diglyme, typical ratios of organic to aqueous run from 1:1 to 1:10. Extraction of the oxidative leach solution separates gold and some base metals from the aqueous solution of platinum and palladium chlorides. Butyl diglyme extraction is quite selective for gold (III). Liu²¹ reported selectivities for extraction of Au/Pt: 8688 and for Au/Fe: 760! This butyl diglyme extract should be washed three times with 1.5 M aqueous HCl (volume of HCl is about 25% of the butyl diglyme volume for each washing) in order to reduce "base" metal impurities.

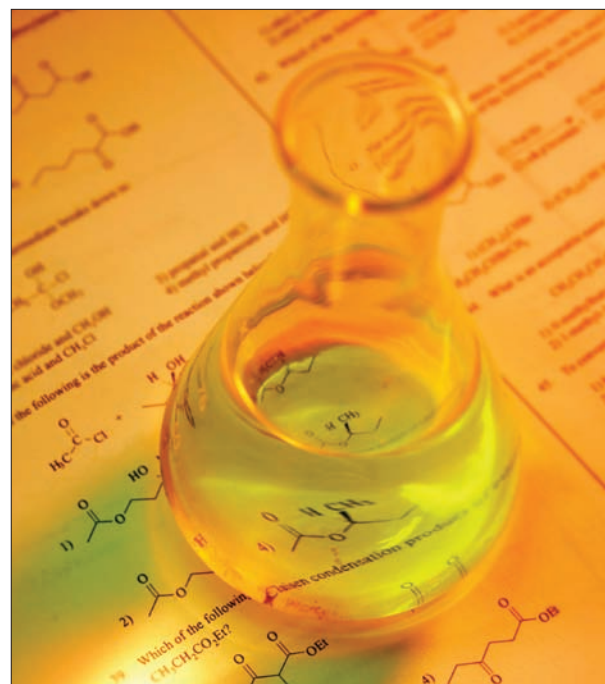
Reduction¹: This purified butyl diglyme extract is charged to a flask containing an aqueous solution of 5 wt% oxalic acid and heated on a steam bath 70-80°C for 4-5 hours. Agitation is required to ensure complete reduction of gold (III) to metallic gold. The metal precipitate is filtered and washed with 4M HCl, then with water and finally with methanol. Any isolated metal is then placed in a crucible and ignited until the gold attains a constant weight. Yields of recovered gold averaged 99.84% for four experiments.¹

Safety

Analytical Chemistry of Gold (III) Butyl Diglyme complex and Kinetics of extraction: ^{28,30,30}

Butyl diglyme solutions of gold (III) chloride are yellow in color possessing two absorptions, one with a λ max at 240 nm with a molar extinction coefficient (ϵ) of $2.02 \times 10^4 \text{ L/mol cm}$ and another λ max at 316 nm with an ϵ of $4.61 \times 10^3 \text{ L/mol cm}$. these gold (III) solutions are very sensitive to light. As a result samples should be prepared and run immediately to minimize absorbances decay from photo reactions. A $3.11-2.17 \times 10^5 \text{ g/mL}$ butyl diglyme solution of $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ loses 7-12.5% of its absorbance values in 1 hour of storage in a darkened cabinet. It has been reported that glassware used to make these gold solutions should be acid washed.

If the concentrations of several metals are to be assayed simultaneously then techniques such as atomic absorption or x-ray fluorescence are recommended.



General Notes Of Caution For Handling Solvents:

All solvents should be used in keeping with good chemical hygiene practices. Solvents should be handled only by trained personnel using adequate personal protective equipment as well as exposure monitoring in keeping with applicable OSHA standards:

1. Avoid exposure to vapors or mists.
2. Avoid all skin contact. Remove contaminated clothing and wash exposed skin immediately with soap and water.

Caution

3. Aqua regia is a mix of very corrosive acids, and is a strong oxidizer.

Table VII. Physical and Toxicological Properties of Butyl Diglyme:

Physical Property:	Butyl Diglyme (BDGL):
Boiling Point at 760mm Hg	256°C
Specific Gravity	0.881
Flash Point TCC (clsd cup)	118°C
Vapor Pressure (mm Hg @ 20°C)	<0.01
Solubility in Water (wt% @ 25°C)	0.3
Solubility of Water in BDGL	1.4
Toxic Effects:	
Acute Toxicity LD ₅₀ (mg/kg)	3900
Vapor mass (g/liter of head space @ 20°C) ^a	1.2×10^{-4}
TLV and STEL (ppm)	None established at this time.

a) Determined using ideal gas law; P=vapor pressure at 20°C

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