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SIRDARYO TUMANINING SUG'ORILADIGAN MAYDONLARIDAN OLINGAN TUPROQ NA'MUNALARINING TUZ TARKIBINING TADQIQI

Referat. *Muammoning kelib chiqishi.* Respublikaning sug'oriladigan hududlarida sho'rlanish darajasini kamaytirish yo'llarini o'rganish dolzarbdir.

Tadqiqotning maqsadi. Sirdaryo tumanining sug'oriladigan tuproqlarida kationlar (Na^+, K^+, Ca^{2+}, Mg^{2+}) va anionlar (Cl^-, SO_4^{2-}, HCO_3^-) taqsimlanishini o'rganish.

Metodologiya. Tuproq tarkibidagi kation va anionlar analitik kimyoning titrimetrik usullari yordamida aniqlandi.

Ilmiy yangiligi. Sirdaryo tumanidagi «G'anisherBilolber» fermer xo'jaligi hududidan olingan tuproq namunalari tarkibi tahlil qilindi.

Olingan natijalar. Sug'oriladigan yerlar tuproqlarining namligi, pH muhiti va NPK miqdori o'rganilib, ularning o'zgarish diagrammasi tuzildi.

Kalit so'zlar: tuproq, sug'orish, yerlar, pH muhiti, namlik, kationlar, anionlar.

Xususiyatlari:

- tuproqlar kimyoviy usullar yordamida tahlil qilindi;
- namlik, pH va NPK miqdorining qatlamlar bo'yicha o'zgarishi aniqlandi.

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KULDOSHOV SH.M., ADINAEV KH.F., SOATBOYEVA M.O., RASULOVA S.N., YULDASHEV SH.U., ERKINBOYEVA SH.S

HYDROMETALLURGICAL RECOVERY OF GOLD FROM ROASTED PYRITE CONCENTRATE USING A THIOUREA SYSTEM

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Abstract *Background.* Gold extraction from refractory sulfide materials is challenging because gold is encapsulated within pyrite, limiting the accessibility of gold-bearing components to leaching reagents. Therefore, the development of cyanide-free hydrometallurgical systems based on thiourea is relevant due to their potential for rapid gold dissolution and environmental benefits.

Purpose. To investigate gold extraction from thermally activated pyrite concentrate using an acidic $FeCl_3$-thiourea leaching system and evaluate the effects of thiourea concentration, temperature, and leaching time on gold dissolution.

Methodology. The experimental procedure involved grinding and granulating pyrite concentrate, thermal activation at 400-700 °C, and subsequent hydrometallurgical leaching. The concentrate calcined at 600 °C was selected for further investigation. Leaching was performed using thiourea solutions with concentrations of 0.2 and 0.3 mol/L at a solid-to-liquid ratio of 1:4. $FeCl_3$ was used as an oxidant, and the pH was maintained at 1.5 using HCl. Experiments were conducted at 25±2, 35, and 45 °C for 8-16 h with continuous stirring at 600 rpm. The initial and calcined samples were analyzed by scanning electron microscopy (SEM), while the gold concentration in the leaching solutions was determined by inductively coupled plasma optical emission spectrometry (ICP-OES).

Scientific novelty. The effects of thiourea concentration, temperature, and leaching time on gold dissolution from pyrite concentrate calcined at 600 °C in the $FeCl_3$-thiourea system were systematically investigated. Attention was given to the role of the Fe^{3+}/Fe^{2+} redox couple in gold oxidation and the formation of soluble gold complexes.

Results. Thermal activation promotes oxidation of the sulfide matrix, sulfur removal, iron oxide formation, and pore development, thereby improving the accessibility of gold-bearing sites to the leaching solution. In the $FeCl_3$-thiourea system, gold is oxidized and stabilized in solution as soluble complexes. Leaching efficiency depends on thiourea concentration, temperature, and reaction time, whereas excessively oxidative conditions may accelerate thiourea degradation. Dissolved gold was quantified by ICP-OES to evaluate process efficiency and identify favorable operating conditions.

Keywords: pyrite concentrate, gold recovery, thiourea, $FeCl_3$, cyanide-free leaching, thermal activation, hydrometallurgy, ICP-OES.

Highlights:

- Gold extraction from roasted pyrite concentrate using the $FeCl_3$-thiourea system was investigated.
- A thermal activation temperature of 600 °C was selected.
- The effects of thiourea concentration, temperature, and leaching time were evaluated.
- ICP-OES was used to determine the gold concentration in the leaching solution.

Introduction. Gold is an economically and technologically important precious metal, but the depletion of high-grade deposits has increasingly shifted attention toward low-grade and refractory gold ores and secondary resources. In refractory ores, gold is frequently associated with sulfide minerals such as pyrite and arsenopyrite, which can limit reagent access to gold-bearing sites and reduce leaching efficiency. Consequently, pretreatment and alternative hydrometallurgical routes have become important strategies for improving gold recovery from complex sulfide materials [1,4]. Cyanidation remains the dominant industrial method for gold extraction because of its high efficiency and selectivity; however, its toxicity and the associated environmental and detoxification requirements have stimulated extensive research into cyanide-free lixiviants. Among these alternatives, thiourea ($CS(NH_2)_2$) is particularly attractive because it dissolves gold rapidly under acidic conditions through the formation of the cationic complex $[Au(TU)_2]^+$ [7,8]. The process requires an oxidant to convert metallic Au to Au(I), with Fe^{3+} being one of the most effective oxidants for thiourea-based gold dissolution [5,6]. Recent reviews have confirmed that thiourea can provide fast leaching kinetics, although its practical application remains limited by reagent instability and excessive consumption. The efficiency of thiourea leaching is strongly controlled by the redox environment. Fe^{3+} promotes gold oxidation but can simultaneously accelerate thiourea oxidation to formamidine disulfide and subsequent degradation products, reducing the concentration of active ligand available for gold complexation [6,9].

Recent studies have demonstrated that the mineral matrix itself can further influence this behavior. In particular, pyrite and arsenopyrite may catalyze Fe^{3+}-induced thiourea oxidation, thereby decreasing gold dissolution, while additives such as citrate or oxalate can improve thiourea stability and enhance gold extraction [10,12]. Pretreatment is therefore an important component of refractory gold processing. Thermal activation or roasting can oxidize sulfide minerals, alter their crystal structure, generate iron oxide phases, and increase mineral porosity, thereby improving the accessibility of gold-bearing sites to subsequent leaching reagents [2,3,13]. Particle size is also important because finer particles provide a greater reactive surface area and can facilitate contact between gold-bearing phases and thiourea solutions [11,6]. Experimental studies on refractory gold calcines have shown that mechanical activation and optimized pretreatment can substantially improve thiourea-based gold extraction [13,14].

Bio-oxidation followed by thiourea leaching has also been shown to enable complete extraction of gold from double-refractory ores, demonstrating the compatibility of oxidative pretreatment with thiourea chemistry [15]. In addition, thiourea-Fe^{3+} systems have been successfully applied to secondary materials such as municipal solid-waste incineration residues, confirming the broader potential of this lixiviant for recovering gold from complex resources [16,17]. The available literature also indicates that the optimum conditions for thiourea leaching are highly dependent on mineralogy and redox conditions and therefore cannot be directly generalized between different raw materials. [18,19]

Accordingly, the present study investigates the hydrometallurgical recovery of gold from thermally activated pyrite concentrate using an acidic $FeCl_3$-thiourea system. The effects of thiourea concentration, leaching temperature, and reaction time on gold transfer into solution are systematically evaluated, while XRD, XRF, SEM, and ICP-OES are employed to characterize phase transformations, chemical composition, morphological changes, and dissolved gold, respectively. The study aims to establish the physicochemical relationships governing gold dissolution and to identify favorable conditions for cyanide-free processing of roasted pyrite concentrate. The experimental design and analytical approach follow the research framework described in the submitted manuscript

Methods and materials. Pyrite concentrate obtained from the Almalyk Mining and Metallurgical Complex (Uzbekistan) was ground, granulated, and thermally activated at 400-700 °C for 1.5-2 h. Based on the preliminary results, the sample roasted at 600 °C was selected for leaching. Gold was leached from 30 g of roasted concentrate using 120 mL of 0.2-0.3 M thiourea solution in the presence of $FeCl_3$ at pH 1.5. Leaching was conducted at 25 ± 2, 35, and 45 °C for 8-16 h under continuous stirring at 600 rpm. The raw and roasted samples were characterized by XRD, XRF, and SEM**,** while dissolved gold was determined by ICP-OES**.**

Results and Discussion. Thermal activation of the pyrite concentrate resulted in significant structural changes in the mineral matrix. As illustrated in (*Figure 1)*, roasting at 600 °C for 2 h promoted decomposition

of the sulfide matrix and increased the porosity of the particles, facilitating the exposure of gold-bearing sites. These structural modifications are favorable for subsequent hydrometallurgical treatment because they improve the contact between the leaching solution and the mineral surface. The activated concentrate was subsequently subjected to $FeCl_3$-thiourea leaching under acidic conditions (pH ≈ 1.5). In this system, Fe^{3+} acts as an oxidizing agent, promoting the oxidation of metallic gold, while thiourea stabilizes the dissolved Au(I) through formation of the soluble $[Au(TU)_2]^+$ complex. As shown in, the sequence of roasting, structural modification, thiourea leaching, and complex formation provides a continuous pathway for transferring gold from the solid phase into solution.

The final gold concentration in the leach solution was determined by ICP-OES, allowing the influence of the leaching parameters to be evaluated. Thus, the results indicate that thermal activation and subsequent $FeCl_3$-thiourea treatment are closely interconnected: roasting improves mineral accessibility, whereas the oxidative-complexation mechanism facilitates gold dissolution and its stabilization in solution. Summarizes the proposed process pathway and the principal physicochemical transformations responsible for gold recovery.

Thermal activation of the pyrite concentrate produced noticeable changes in the mineral structure and created more favorable conditions for subsequent gold leaching. Comparative thermal treatment at 400-700 °C showed that the sample roasted at 600 °C for 2 h was suitable for further hydrometallurgical processing. At this temperature, partial decomposition of the sulfide matrix, sulfur removal, and formation of iron-containing oxide phases occur, accompanied by an increase in particle porosity and accessibility of gold-bearing sites. These structural changes facilitate penetration of the leaching solution into the modified mineral matrix and improve contact between the reagent and gold-bearing surfaces. The general sequence of thermal activation, structural modification, oxidative leaching, and analytical determination of dissolved gold is illustrated in.

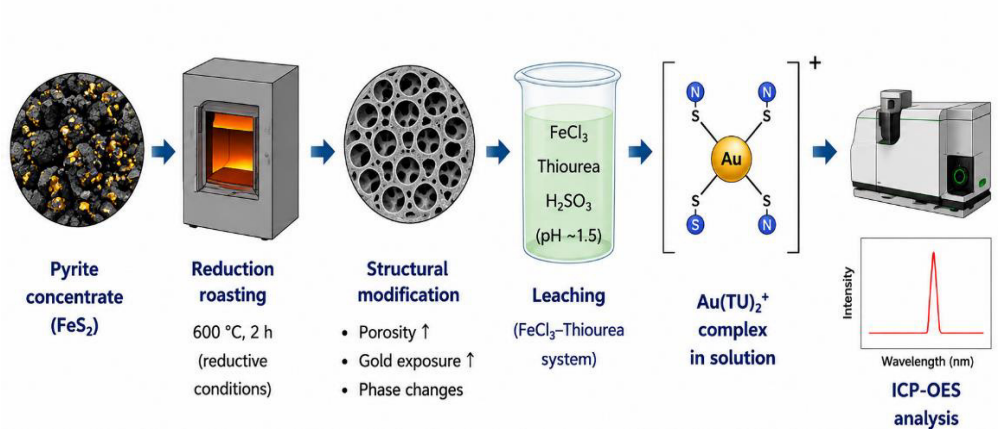


Figure 1. Method for granulating and thermally activating pyrite concentrate

Thermal activation of the pyrite concentrate produced noticeable changes in the mineral structure and created more favorable conditions for subsequent gold leaching. Comparative thermal treatment at 400-700 °C showed that the sample roasted at 600 °C for 2 h was suitable for further hydrometallurgical processing. At this temperature, partial decomposition of the sulfide matrix, sulfur removal, and formation of iron-containing oxide phases occur, accompanied by an increase in particle porosity and accessibility of gold-bearing sites. These structural changes facilitate penetration of the leaching solution into the modified mineral matrix and improve contact between the reagent and gold-bearing surfaces. The general sequence of thermal activation, structural modification, oxidative leaching, and analytical determination of dissolved gold is illustrated in.

The importance of the acidic and oxidizing conditions is further illustrated by the Eh-pH diagram in (*Figure 2*). The leaching solution was maintained at pH 1.5, where the Fe^{3+}/Fe^{2+} redox couple can provide the oxidizing environment required for conversion of Au^0 to Au^+. Under these acidic conditions, the formation of iron hydroxide precipitates is suppressed, helping to maintain Fe^{3+} availability in the solution. As the pH increases, Fe^{3+} becomes increasingly susceptible to hydrolysis and $Fe(OH)_3$ formation, accompanied by a decrease in the effective oxidizing potential. Therefore, maintaining a strongly acidic medium is important for sustaining the redox conditions favorable for gold dissolution.

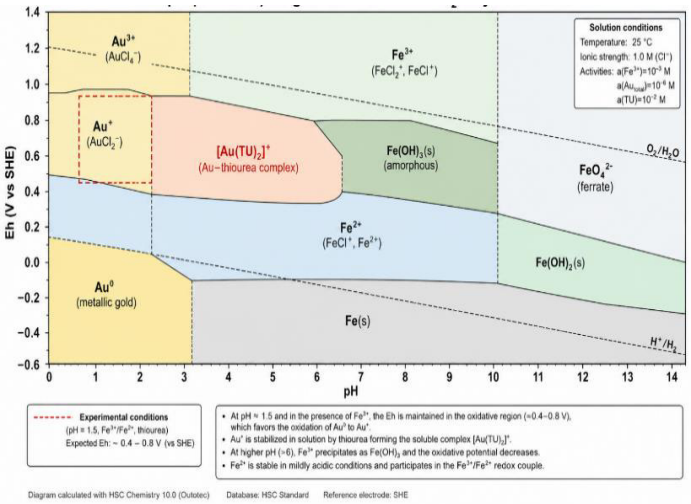


Figure 2. Eh-pH diagram of the Au-Fe-Cl-H_2O system at 25 °C under acidic thiourea leaching conditions.

Thermal activation was investigated in the temperature range of 400-700 °C. Increasing the roasting temperature caused progressive structural modification of the pyrite matrix, including partial sulfide decomposition, sulfur removal, formation of iron-containing oxide phases, and development of a more porous structure. Based on the comparative treatment, the pyrite sample roasted at **600 °C for 2 h** was selected for subsequent hydrometallurgical leaching because the modified structure provided better accessibility of gold-bearing sites to the leaching solution.(Table 1.)

Table 1.

Effect of Thermal Activation Conditions on the Pyrite Concentrate

Roasting temperature, °C	Treatment time, h	Selection for leaching	Main observed changes
400	1.5-2.0	Not selected	Initial thermal decomposition and oxidation of the pyrite matrix
500	1.5-2.0	Not selected	Partial decomposition of the sulfide matrix and structural modification
600	**1.5-2.0**	**Selected**	**Sulfur removal, formation of iron oxide phases, increased porosity, and improved accessibility of gold-bearing sites**
700	1.5-2.0	Not selected	Intensive thermal oxidation; no separate quantitative result was reported

The subsequent leaching experiments were based on an oxidative-complexation mechanism. In the acidic $FeCl_3$-thiourea system, metallic gold is initially oxidized from Au^0 to Au^+ by the Fe^{3+}/Fe^{2+} redox couple, while thiourea (TU) acts as a complexing ligand and stabilizes the oxidized gold species in solution. The process can be represented by the following reactions: Thus, $FeCl_3$ provides the oxidative conditions required for gold dissolution, whereas thiourea promotes the formation of the soluble $[Au(TU)_2]^+$ complex. The mechanism shown demonstrates that efficient gold transfer into solution depends on the simultaneous occurrence of gold oxidation and subsequent complex formation.

The dissolution of gold from roasted pyrite in the acidic $FeCl_3$-thiourea system can be described as a sequential oxidation-complexation process. During thermal activation, the pyrite matrix undergoes partial decomposition and oxidation, accompanied by sulfur removal and structural modification. These changes increase the accessibility of gold-bearing sites to the subsequent leaching solution. In the first stage, metallic gold (Au^0) is oxidized by Fe^{3+} to monovalent gold (Au^+), while Fe^{3+} is reduced to Fe^{2+}:

$$Au^0 \rightarrow Au^+ + e^-$$

The generated Au^+ is highly reactive and rapidly stabilized through complexation with thiourea (TU). Two thiourea molecules coordinate with one Au^+ ion, resulting in the formation of a soluble gold-thiourea complex:

$$Au^+ + 2TU \rightarrow [Au(TU)_2]^+$$

Thus, thiourea acts as a complex ligand that promotes the transfer and stabilization of oxidized gold in the aqueous phase. The Fe^{3+}/Fe^{2+} redox couple provides the oxidizing capacity required for the initial oxidation of metallic gold. The overall reaction can therefore be represented as: (*Figure 3*)

$$Au^0 + 2TU + Fe^{3+} \rightarrow [Au\,(TU)_2]^+ + Fe^{2+}$$

Consequently, gold dissolution in the $FeCl_3$-thiourea system is governed by two complementary processes: oxidation of metallic gold by Fe^{3+} and subsequent complexation of Au^+ by thiourea. The resulting $[Au\,(TU)_2]^+$ complex remains soluble in the acidic leaching solution, facilitating the transfer of gold from the roasted pyrite matrix into the liquid phase for subsequent quantitative determination by ICP-OES.

The leaching experiments were performed using 0.2 and 0.3 mol/l thiourea solutions at a solid-to-liquid ratio of 1:4 (30 g:120 ml). $FeCl_3$ was added as the oxidizing reagent at 0.24 and 0.32 g for the corresponding thiourea concentrations. The solution was continuously stirred at 600 rpm, while the leaching temperature varied from 25 ± 2 to 45 °C and the reaction time from 8 to 16 h. These conditions were selected to evaluate the combined influence of ligand concentration, temperature, and reaction duration on gold dissolution.

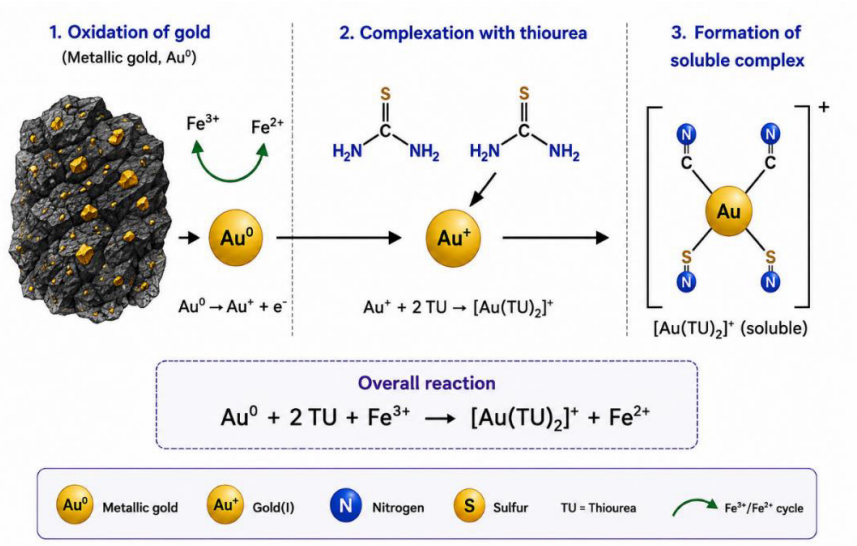


Figure 3. Schematic mechanism of gold dissolution and $[Au\,(TU)_2]^+$ complex formation in the $FeCl_3$-thiourea system.

The results show that gold dissolution was influenced by both thiourea concentration and leaching temperature. At 0.2 M thiourea, the Au concentration ranged from 11.01 to 12.3 ppb, with the highest value of 12.3 ppb at 35 °C. Increasing the thiourea concentration to 0.3 M resulted in higher Au dissolution, reaching a maximum of 41.5 ppb at 35 °C. Under these conditions, the amount of dissolved gold in 120 mL of solution reached 0.004980 mg. Thus, among the presented experiments, the 0.3 M thiourea, 35 °C, 8 h, $FeCl_3$ 0.32 g, and pH 1.5 conditions provided the highest measured Au concentration. (Table 2)

Table 2.

Effect of Thiourea Concentration and Leaching Temperature on Gold Dissolution

Thiourea concentration, M	**Solid-to-liquid ratio**	**Temperature, °C**	**Leaching time, h**	**$FeCl_3$, g**	**pH**	Au concentration, ppb	Au in 120 mL solution, mg
0.2	1:4 (30 g:120 ml)	25 ± 2	8	0.24	1.5	11.01	0.001320
0.2	1:4 (30 g:120 ml)	35	8	0.24	1.5	12.3	0.001476
0.2	1:4 (30 g:120 ml)	45	8	0.24	1.5	12.1	0.001452
0.3	1:4 (30 g:120 ml)	25 ± 2	8	0.32	1.5	22.3	0.002676
0.3	**1:4 (30 g:120 ml)**	**35**	**8**	**0.32**	**1.5**	**41.5**	**0.004980**
0.3	1:4 (30 g:120 ml)	45	8	0.32	1.5	28.1	0.004980

An increase in temperature and leaching time is expected to enhance the kinetics of gold oxidation, thiourea complexation, and diffusion through the porous structure formed during thermal activation. However, excessive oxidative conditions may also accelerate thiourea degradation and reduce the concentration of active ligand in solution. Consequently, the efficiency of the $FeCl_3$-thiourea system is determined by a balance between the oxidation rate of gold and the chemical stability of thiourea. The effect of these parameters was evaluated through quantitative determination of dissolved gold by ICP-OES. Overall, the obtained results support a sequential mechanism in which thermal activation increases the accessibility of gold-bearing sites, Fe^{3+} promotes oxidation of metallic gold, and thiourea stabilizes the dissolved Au(I) species as $[Au(TU)_2]^+$. The combination of the structural changes produced by roasting and the oxidative-complexation mechanism of the $FeCl_3$-thiourea system provides the physicochemical basis for efficient gold transfer from roasted pyrite concentrate into solution. The influence of temperature, thiourea concentration, and leaching time can therefore be interpreted in terms of both mineral accessibility and the redox stability of the leaching system.

The physicochemical changes in pyrite concentrate during thermal activation and leaching were investigated using SEM and ICP-OES. While SEM revealed changes in particle morphology and the development of porous structures after thermal treatment (*Figure 4*). These structural modifications increased the accessibility of gold-bearing sites and facilitated subsequent leaching. Dissolved gold was quantitatively determined by ICP-OES.

The thermal treatment was investigated at 400-700 °C for 1.5-2 h, and the sample treated at 600 °C for 2 h was selected for subsequent leaching. Gold dissolution was evaluated using 0.2-0.3 M thiourea at 25 ± 2-45 °C for 8-16 h. The obtained results were correlated with the phase and morphological changes to evaluate the relationship between thermal activation and gold dissolution in the $FeCl_3$-thiourea system.

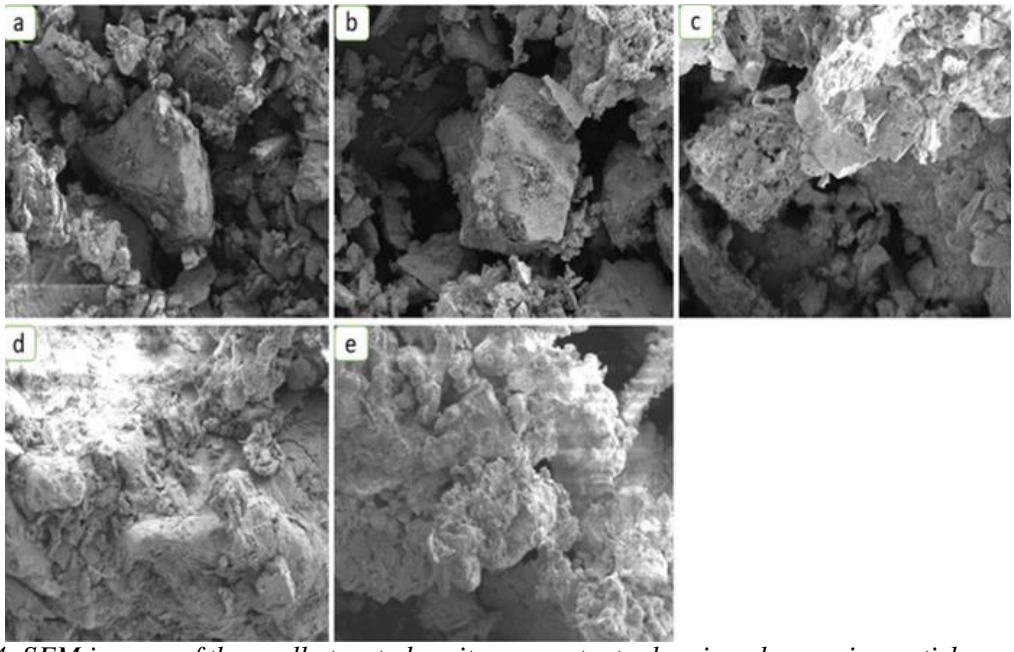


Figure 4. SEM images of thermally treated pyrite concentrate showing changes in particle morphology and surface structure.

Conclusion. Thermal activation of the pyrite concentrates at 600 °C for 2 h was identified as a suitable pretreatment condition, promoting structural modification and increasing the accessibility of gold-bearing sites. Subsequent leaching in the acidic $FeCl_3$-thiourea system proceeded through the oxidation of Au^0 to Au^+ followed by formation of the soluble $[Au(TU)_2]^+$ complex. The gold dissolution process was strongly dependent on thiourea concentration, temperature, and leaching time, while the acidic medium and Fe^{3+}/Fe^{2+} redox couple provided favorable conditions for gold oxidation and complex stabilization. The combined XRD, XRF, SEM, and ICP-OES analyses enabled the relationship between mineralogical and morphological changes and gold dissolution to be evaluated. Overall, the obtained results confirm the potential of thermally activated pyrite concentrate for cyanide-free gold recovery an $FeCl_3$-thiourea leaching system and provide a basis for further optimization of the process

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ГИДРОМЕТТАЛЛУРГИЧЕСКОЕ ИЗВЛЕЧЕНИЕ ЗОЛОТА ИЗ КОНЦЕНТРАТА КАЛЬЦИНИРОВАННОГО ПИРИТА В СИСТЕМЕ С ТИОМОЧЕВИНОЙ

Реферат. *Предпосылки проблемы*. Извлечение золота из упорных сульфидных материалов затруднено его инкапсулированием в пирите, что ограничивает доступ выщелачивающих реагентов к золотоносным компонентам. В связи с этим актуальна разработка безцианидных гидрометаллургических систем на основе тиомочевины, обеспечивающих быстрое растворение золота и потенциальные экологические преимущества.

Цель. Исследовать извлечение золота из термически активированного пиритового концентрата с использованием кислой системы выщелачивания $FeCl_3$-тиомочевина и оценить влияние концентрации тиомочевины, температуры и продолжительности выщелачивания на растворение золота.

Методология. Экспериментальный процесс включал измельчение и гранулирование пиритового концентрата, термическую активацию при 400-700 °C и последующее гидрометаллургическое выщелачивание. Для дальнейших исследований был выбран концентрат, обожжённый при 600 °C. Выщелачивание проводили растворами тиомочевины концентрацией 0,2 и 0,3 моль/л при соотношении твёрдой и жидкой фаз 1:4. $FeCl_3$ использовали в качестве окислителя, а pH 1,5 поддерживали с помощью HCl. Эксперименты проводили при температурах 25±2, 35 и 45 °C в течение 8-16 ч при непрерывном перемешивании со скоростью 600 об/мин. Исходные и обожжённые образцы исследовали методом сканирующей электронной микроскопии (SEM), а концентрацию золота в растворах определяли методом оптической эмиссионной спектрометрии с индуктивно связанной плазмой (ICP-OES).

Научная новизна. Систематически исследовано влияние концентрации тиомочевины, температуры и продолжительности выщелачивания на растворение золота из пиритового концентрата, обожжённого при 600 °C, в системе $FeCl_3$-тиомочевина. Особое внимание уделено роли окислительно-восстановительной пары Fe^{3+}/Fe^{2+} в окислении золота и образовании его растворимых комплексов.

Полученные результаты. Термическая активация способствует окислению сульфидной матрицы, удалению серы, образованию оксидов железа и развитию пористой структуры, повышая доступность золотоносных участков для выщелачивания. В системе $FeCl_3$-тиомочевина золото окисляется и стабилизируется в растворе в виде растворимых комплексов. Эффективность выщелачивания зависит от концентрации тиомочевины, температуры и продолжительности процесса, тогда как чрезмерно окислительные условия могут ускорять её разложение. Содержание растворённого золота определяли методом ICP-OES для оценки эффективности процесса и выбора благоприятных технологических условий.

Ключевые слова: пиритовый концентрат, извлечение золота, тиомочевина, $FeCl_3$, безцианидное выщелачивание, термическая активация, гидрометаллургия, ICP-OES.

Особенности:

- Исследовано извлечение золота из обожжённого пиритового концентрата системой $FeCl_3$-тиомочевина.
- Обоснована термическая активация при 600 °C.
- Изучено влияние концентрации тиомочевины, температуры и времени выщелачивания.
- Применены метод XRD, XRF, SEM и ICP-OES для комплексного анализа.

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KUYDIRILGAN PIRIT KONSENTRATIDAN OLTINNI TIOMOCHEVINA TIZIMIDA GIDROMETALLURGIK AJRATIB OLISH

Referat. *Muammoning dolzarbligi.* Qiyin qayta ishlanadigan sulfidli materiallardan oltinni ajratib olish uning pirit tarkibida kapsulalanganligi va erituvchi reagentlarning oltin saqlovchi komponentlarga kirish imkoniyati cheklanganligi sababli murakkablashadi. Shu munosabat bilan oltinni yuqori tezlikda eritmaga o‘tkazish imkonini beruvchi va ekologik afzalliklarga ega bo‘lishi mumkin bo‘lgan tiomochevina asosidagi sianidsiz gidrometallurgik tizimlarni ishlab chiqish dolzarb hisoblanadi.

Ishning maqsadi. Termik faollashtirilgan pirit konsentratidan $FeCl_3$-tiomochevina kislotali eritish tizimi yordamida oltinni ajratib olishni o‘rganish hamda tiomochevina konsentratsiyasi, harorat va eritish davomiyligining oltinning eritmaga o‘tishiga ta’sirini baholash.

Metodologiya. Tajriba jarayoni pirit konsentratini maydalash va granulalash, 400-700 °C haroratda termik faollashtirish hamda keyingi gidrometallurgik eritish bosqichlarini o‘z ichiga oldi. Keyingi tadqiqotlar uchun 600 °C da kuydirilgan konsentrat tanlandi. Eritish jarayoni 0,2 va 0,3 mol/l konsentratsiyali tiomochevina eritmalarida, qattiq va suyuq fazalar nisbati Q:S=1:4 bo‘lgan sharoitda amalga oshirildi. $FeCl_3$ oksidlovchi sifatida qo‘llanildi, HCl yordamida pH 1,5 darajasida saqlandi. Tajribalar 25±2, 35 va 45 °C haroratlarda, 8-16 soat davomida, 600 ayl/min aralashtirish tezligida o‘tkazildi. Dastlabki va kuydirilgan namunalar SEM usuli bilan tahlil qilindi, eritmalardagi oltin miqdori esa ICP-OES usulida aniqlandi.

*Ilmiy yangiligi.*Tadqiqotda 600 °C da kuydirilgan pirit konsentratidan $FeCl_3$-tiomochevina tizimida oltinning erishiga tiomochevina konsentratsiyasi, harorat va eritish davomiyligining ta’siri tizimli ravishda o‘rganildi. Oltinning oksidlanishi va uning eruvchan kompleksini hosil qilishda Fe^{3+}/Fe^{2+} oksidlanish-qaytarilish juftligining roli alohida ko‘rib chiqildi.

Olingan natijalar. Pirit konsentratini termik faollashtirish sulfidli matritsaning oksidlanishiga, oltingugurtning chiqarilishiga, temir oksidlari hosil bo‘lishiga va g‘ovak tuzilmaning rivojlanishiga yordam beradi. Bu esa oltin saqlovchi qismlarning erituvchi reagentlar uchun ochiqligini oshiradi. $FeCl_3$–tiomochevina tizimida oltin oksidlanib, eritmada eruvchan komplekslar shaklida barqarorlashadi. Jarayon samaradorligi tiomochevina konsentratsiyasi, harorat va eritish davomiyligiga bog‘liq bo‘lib, haddan tashqari oksidlovchi sharoitlar tiomochevinaning parchalanishini tezlashtirishi mumkin. Eritmaga o‘tgan oltin miqdori ICP-OES usulida aniqlanib, jarayon samaradorligi baholandi va maqbul texnologik parametrlarni tanlash ko‘zda tutildi.

Kalit so‘zlar: pirit konsentrati, oltinni ajratib olish, tiomochevina, $FeCl_3$, sianidsiz eritmalash, termik faollashtirish, gidrometallurgiya, ICP.

Xususiyatlari:

- Kuydirilgan pirit konsentratidan $FeCl_3$–tiomochevina tizimida oltinni ajratib olish o‘rganildi.
- Termik faollashtirish uchun 600 °C harorat tanlandi.
- Tiomochevina konsentratsiyasi, harorat va eritish vaqtining ta’siri o‘rganildi.
- Kompleks tahlil uchun ICP-OES usulli qo‘llanildi.

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RECOVERY OF ALUMINUM OXIDE FROM ASH RESIDUE USING SODIUM CARBONATE

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Abstract. *Background*. Recovery of valuable components from industrial ash slag waste attracts attention due to environmental concerns and the potential for domestic resource utilization.

Purpose: Recovery of high-purity aluminum oxide from coal ash slag using sodium carbonate sintering and investigation of its chemical composition, phase transformations, and thermal behavior.

Methodology. The process involved alkaline sintering of ash slag with Na_2CO_3, aqueous leaching of sodium aluminate, seed-assisted precipitation of $Al(OH)_3$, and subsequent calcination. Products were characterized using X-ray fluorescence (XRF) and X-ray diffraction (XRD) methods.

Originality. High-purity alumina (99.7 mass%) was successfully recovered from coal fly ash slag via an optimized seed-precipitation and calcination pathway.

Findings. XRF analysis of initial ash slag revealed an aluminum content of 48.5 mass%, alongside Si (7.32%), Ca (4.87%), Zn (2.30%), and Mg (2.26%) impurities. Alkaline sintering converted insoluble aluminosilicates (mullite) into water-soluble sodium aluminate ($NaAlO_2$). Seed-assisted precipitation yielded a pure hydroxide precursor, which upon calcination produced 99.7 mass% Al_2O_3 with minimal SiO_2 impurity (0.346 mass%). XRD characterization indicated a low-crystallinity structure dominated by transition phases (γ-, δ-, or θ-Al_2O_3) rather than fully ordered α- Al_2O_3.

Keywords*:* ash slag, sodium carbonate, sintering, aluminum oxide, hydroxide, calcination, XRF, XRD.

INORGANIC CHEMISTRY

Atabayev F.B., Begzhanova G.B., Tursunova G.R., Yakubzhanova Z.B. Physicochemical properties of portland cement with a hybrid mineral additive based on local raw materials 48
Jumanov Yu.Q., Eminov A.A., Qodirova Z.R., Xolmurodova S.A., Eminov A.M., Norqulova Z.M. Prospects for using niap 12-05 catalyst waste as an unconventional ceramic raw material 53
B.M. Akhmedov, J.E. Omonkulov, A.A. Zhiyemuratova, J.S. Shukurov Study of the solubility of potassium sulfate salt in monoethanolammonium citrate by the observational polythermic method 57
N.A. Ulashova, M.A. Yuldasheva, Z. To‘rayev, B.X. Kucharov, B.S. Zakirov, A.U. Erkayev Polythermic solubility diagram of the H_3BO_3-K_2SO_4-H_2O system 62
N.D. Maksudova, F.B. Atabayev, G.B. Begjanova, D.D. Mukhitdinov, M.Ch. Abdullaev, A.Sh. Khadjiev, Xudoyberdiyeva.Sh.A Use of kaolin-containing clays of karakalpakstan with elevated Fe_2O_3 content in portland cement clinker production 66
J.E. Omonkulov, B.M. Akhmedov, B.B. Akhmedov, J.S. Shukurov Study of the polythermal solubility of the K_2SO_4 - HOOC-$COONH_3C_2H_4OH$ - H_2O system 72
Eshpulatova M.B. Preparation of complex-action liquid fertilizers based on potassium sulfate 78
N.Z. Ergashev,A.S. Togasharov, M.X. Ikramov, A.A. Sidikov, S.U.Tillayev Study of salt composition of soil samples taken from irrigated fields of sirdaryo district 83
Kuldoshov Sh.M., Adinaev Kh.F., Soatboyeva M.O., Rasulova S.N., Yuldashev Sh.U. Erkinboyeva Sh.S Hydrometallurgical Extraction of Gold from Roasted Pyrite Concentrate in a Thiourea System 89
Soatboyeva M.O., Adinaev Kh.F., Kuldoshov Sh.M., Rasulova S.N., Yuldashev Sh.U. Erkinboyeva Sh.S Extraction of aluminum oxide from ash residue using sodium carbonate 98

ORGANIC CHEMISTRY

O.Yu. Ismailov, T.M. Jurayev, Y.Yu. Yakubov, Z.M. Sattorov Recovery of used motor oils using aluminosilicate and acid reagents 104
G.I. Khamraeva, A.U. Berdiev, U.M. Yakubov, B.Zh. Elmuradov. Thieno[2,3-d]pyrimidine-6-carbohydrazide synthons: synthesis and bifunctional properties 110
Alimbaeva Sh.B., Rezhepov K.Zh., Esanov R.S. Synthesis and spectral analysis of imine derivatives of 2-hydroxy-1-naphthaldehyde 116

ANALYTICAL CHEMISTRY

Norboyevar.N., Rakhimovs.B., Madatovu.A., Smanovaz.A., Norboyevash.N. Sorption spectrophotometric determination of Fe(III) ions, using methyl thymol blue sodium salt 125
Kholturaev K.B., Turaev Kh.Kh., Ibragimov A.B., , Kasimov Sh.A., Saidov D. Kh., Kuldoshov Sh.M., Ruziyev U.U., Ruziboyeva G. S. Synthesis, UV-Vis spectroscopic characterization and adsorption properties of a Cu(II)-isophthalate coordination polymer 131
Ruziyev U.U., Turaev Kh.Kh., Ibragimov A.B., B.A.Kholnazarov., Saidov D. Kh., Kuldoshov Sh.M., Kholturaev K.B., Ruziboyeva G. S. Crystal structure, morphology prediction, and topological analysis of a novel 2d heterometallic [Ni(II)-Na(I)] coordination polymer driven by h-edta linker 137
Nazarov Y.E., Turayev Kh. Kh. Synthesis and crystal structure of the [Fe(2,6-PDCA)$(NO_3)(H_2O)_2$] complex compound 144
Karimova N.J, Muqumova G.J, Turaev Kh. Kh, Adinaev Kh. F., Rakhmonberdiyeva S.B. Synthesis, crystal structure, IR-spectral and thermal properties of a new cadmium(II) complex based on 3-nitrophthalic acid and pyridine 150
Saidov D. Kh., Adinaev Kh. F., Kholturaev K. B., Ruziyev U. U., Ruziboyeva G. S. Synthesis, crystal structure, BFDH crystal morphology and molecular docking analysis of a one-dimensional zinc(II) coordination polymer 156
Sh.S. Nazirov, Kh. Kh. Turaev, N. Turabov, Sh.G‘. Khojiev Spectrophotometric determination of Cu(II) ions using 6-chloro-4-hydroxy-3- nitrosonaphthalene-2,7-disulfonic acid 163
SH.S. Nazirov, Kh. Kh. Turaev, N. Turabov, Sh.G‘. Khojiev Spectrophotometric determination of Zn(II) ions using 6-chloro-4-hydroxy-3- nitrosonaphthalene-2,7-disulfonic acid 172
B. Gulyamov, M. Sobitov, G. Xojiyeva, O. Tursunqulov, Sh. Xojiyev. Effect of dopant chemistry on relative density and total ionic conductivity of LLZO solid electrolytes: a concise analytical review 182