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Selective Recovery of Pt, Pd, and Rh from Spent Catalysts by Functionalized Magnetite Nanoparticles

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Abstract

Selective recovery of platinum group metals including Pt, Pd, and Rh from the spent automobile catalysts is investigated by functionalized magnetite nanoparticles as a novel adsorbent. Magnetite nanoparticles are synthesized by co-precipitation of ferrous and ferric salts with ammonium hydroxide, and then coated with a tetraethyl orthosilicate to form well-dispersed silica-coated magnetite nanoparticles. The silica-coated nanoparticles are then functionalized with three different types of organosilane ligands including monoamine (FeSiORA), ethylenediamine (FeSiORDA), and diphenylphosphino (FeSiORP). The effects of initial pH, amount of adsorbent, contact time, and chloride concentration in a multi-component leaching solution are examined in batch tests on [PdCl4]2-, [PtCl4]2-, [PtCl6]2-, and [RhCl6]3-. Among the different types of organosilane ligands examined, the FeSiORA nanoparticles and FeSiORDA, for selective sorption of PGM from the leaching solution, are unsuccessful. It is found that FeSiORPs can effectively adsorb Pt and Pd but exhibit no affinity towards Rh and base metal ions. Under the optimum conditions, the adsorption rates of Pt, Pd, and Rh are estimated 97.5%, 97.0%, and 15.0%, respectively.

1. Introduction

Platinum group metals (PGMs) are six transition metal elements in the periodic table including ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (os), iridium (Ir), and platinum (Pt) [1-3]. PGM, along with silver and gold are called precious metals due to their high price and limited resources in the world [4, 5]. PGMs play an important role in this modern world with application in many products including hard disks, mobile phones, aircraft turbines, drugs, etc. More than 50% of the PGM produced worldwide is used in automobile catalytic converters, a pollution reduction device fitted to cars, trucks, and motorcycles [6-9]. On average, each car produces 15 tonnes of toxic and hazardous gas in a 10-year period, which is reduced by 90% using catalytic converters [10]. Legislations have been adopted for vehicle manufacturers with a requirement to fit catalytic converters to all new petrol cars. It is estimated that the release of 12 million tonnes of toxic and dangerous gases can be prevented by regulating these new requirements [10]. Today, nearly half of the 500 million cars in the world have been equipped with catalytic converters [10]. A catalytic converter prevents emissions of toxic gases such as carbon monoxide, hydrocarbons, and nitrogen oxides by converting them to no or less toxic products [11, 12]. These catalytic converters must be replaced, on average, after five years [13].

The primary sources PGMs are so limited, and exist only in South Africa (more than 95%), Russia, the United States, and Canada. The shortage of platinum mines in the world and holding them as the capital asset are the reasons for the imbalance in the supply and demand of these metals. This has led to significant efforts to recover PGMs from secondary sources [14].

Three different methods have been developed to recover PGMs including pyrometallurgy, hydrometallurgy, and gas-phase evaporation.

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Hydrometallurgy has received more attention due to the low operation cost, selective separation, and less operational complexity [15, 16]. The hydrometallurgical process is typically operated in two different circuits: A: leaching-extraction from the solution by precipitation B: leaching-extraction from the solution with other processes (other than precipitation). The traditional method of precipitation is not recommended due to its lack of selectivity, high operational cost, many operational units, and slow process [17-19]. More sophisticated approaches such as SX and ion exchange are cheaper, more selective, and operationally easier to conduct [20, 21]. Although these processes are advantageous over the precipitation method, they are extremely time-consuming, and leave significant amounts of tailings and chemical wastes. In the recent years, there has been a growing interest toward the application of magnetic nanoparticles (NFe) as adsorbents due to the simplicity of the process, lower cost, and elimination of the need for washing process [22-24].

In the field of extraction of these metals from solution, different functional groups in the form of resin, adsorbent, and solvent extractor (SX) have been introduced. One of the innovations of this research work is the use of functional groups in the form of organosilane. Organosilanes are intermediate compounds that contain a functional group on one side, and are coated on adsorbent nanoparticles on the other. In this way, in addition to using the high adsorption capacity of magnetite nanoparticles, the time-consuming step and the problem of "washing" becomes much easier. Magnetite nanoparticles were synthesized by a co-precipitation process. Then in order to maintain chemical resistance, and prevent the dissolution of magnetite nanoparticles in the acidic solutions, their surface was protected with a silica layer. In the next step, the functional group was coated on the surface of the nanoparticles to allow the platinum group metals to be adsorbed from the solution selectively. This functional group was enclosed with organosilane compounds on the surface of nanoparticles.

Accordingly, two different types of organosilanes were used in this study organosilane, with a) N and NH (amines) functional groups and b) P (phosphines, phosphates, etc.) functional groups for the first time. It should also be noted that these functional groups were selected based on the HSAB theory. The adsorption of platinum, palladium, and rhodium from the leaching solution by two types of adsorbents were examined.

2. Materials and Methods

2.1. Synthesis of magnetite nanoparticles

In this work, the co-precipitation process was used to synthesize magnetite nanoparticles. 0.86 g iron chloride(II) and 2.52 g iron(III) chloride were dissolved in 20 mL of the hydrochloric acid solution. By dipping the gas nozzle into the test chamber (a three-sphero balloon), argon gas was purged into the solution for 4 minutes. While argon purging, the polyethylene glycol was added to the solution for 10 minutes to completely dissolve the polyethylene glycol solution. Then the argon gas was blown off, and the balloon of magnetite nanoparticles was tightly sealed. Then sodium hydroxide solution was slowly dripped from a burette to the solution. Finally, when the pH reached 11, the solution colour changed from yellow to black, indicating the formation of magnetite nanoparticles [25].

2.2. Silica encapsulation of magnetite nanoparticles

A sol-gel process was employed to coat the magnetite nanoparticles with a layer of silica. As a precursor, TEOS alkoxide was used. The amount of 1 g of magnetite nanoparticles synthesized in the previous step was dispersed in 0.5 mL of deionized water. Then 0.3 mL of magnetite nanoparticle suspension was poured into a solution containing 0.14 mL of water, 0.14 mL of ethanol, and 30 mL of ammonium. A 1 mL of TEOS solution dissolved in 15 mL of ethanol was added to the solution and placed on the stirrer for 4 hours at the laboratory temperature. The whole process was carried out under an atmosphere of nitrogen gas. Over time, the precipitate colour changed to almost a deep coffee colour, which was collected by a magnet and dried at 60 $^{\circ}$C [26]. The collected powder was $Fe_3O_4@SiO_2$ core/shell nanoparticles.

2.3 Functionalization of silica magnetite nanoparticles with organosilane functional groups

Three different groups of organosilanes (Merck) were introduced to generate the functional group:amino-propyl trimethoxysilane ($C_6H_{17}NO_3Si$), b) aminoethyl methoxy propylamine ($C_8H_{22}N_2O_3Si$), and c) diphenyl phosphine ethyl diethyl ethoxylan ($C_{18}H_{25}OPSi$). For organosilane surface coating of nanoparticles, the produced FeSi nanoparticles were dumped in a volume of ethanol, and stirred for 15 minutes. The required amounts of organosilane were then added to the solution and stirred for 48 hours. Then the solid was separated by a magnet and washed with an 80% ethanol/water solution. To ensure that the organosilanes did not react, the nanoparticles were placed in an ultrasonic bath for ten minutes and washed again with the ethanol/water solution. Ultimately, the nanoparticles were dried at the ambient temperature. Also Organosilane and nanoparticle weights were obtained using Equation 1 [27].

$$m_S = \frac{K \times S_{Si} \times m_{Si} \times M_S \times OH_{No} \times 10^{18}}{NA} \quad (1)$$

where m_S is the weight of the organosilanes (g), S_{Si}, the surface area of FeSi $(nm)^2$, m_{Si} is the weight of the nanoparticles (g), M_S is the molecular weight of the organosilanes, OH_{No} is the number of hydroxyl groups per square nanometer, K is the ratio of stoichiometric organosilanes to FeSi, and NA is the Avogadro constant.

2.4. Adsorption tests

The leaching solution contained 1904 ppm of the total target metals (platinum, palladium, and rhodium). For the adsorption experiments, the leaching solution was diluted 10 times. Therefore, in all the adsorption tests, the total amount of PGMs was about 200 ppm. Also for the adsorption experiments, the HCl concentration of the initial solution of leaching was not euthanized. Also the range, its concentration was calculated from 1 M to above. The batch adsorption tests were performed using a 250 mL Erlen, containing 100 mL of leaching solution, and the required amounts of nanoparticles. To change the temperature, and to create an agitator round, a shaker convector (a WISD model of butter) was used at the Tarbiat Modarres University. The pH of the solution was adjusted by small amounts of HCl (Junsei chem, 35%) and 1 M NaOH. The magnetite nanoparticles were separated from the solution after adsorption experiments using a strong 4,000 Gauss magnet. The nanoparticles were washed by dipping in water twice. Finally, the liquid phase was sampled at specific time intervals, and the adsorption rate of the metal was calculated based on Equation 2.

$$\frac{C_M - C_i}{C_M} \times 100 \quad (2)$$

The concentration of target phases was analysed by atomic adsorption spectrometry using a Varian model Spect AA 220 apparatus. Infrared spectra were recorded with a Fourier transform infrared spectrometer (FT-IR, Perkin Elmer, spectrum 100). The samples were gently ground and diluted in nonadsorbent KBr matrices to identify the functional groups and chemical bonding of the coated materials. The crystal structure of synthesized materials was determined by an X-ray diffractometer (XRD) (38066 Riva, d/G.Via M. Misone, 11/D (TN) Italy).

3. Results and Discussion

3.1. Characterisation of synthesized magnetite nanoparticles

3.1.1. X-ray diffractometry

The X-ray diffraction diagram (XRD) of the silica coated magnetite nanoparticles is shown in Figure 1. The relative position and intensity of the peaks in both silica coated and uncoated magnetite nanoparticles are consistent with the standard samples of magnetite and pure silica (ICDD 88 – 0866). The uncoated sample mainly consist of magnetite (Fe_3O_4), and to a much lesser extent maghemite (γ-Fe_2O_3). The comparison of the peak sharpness in the two diagrams reveal that the formation of a silica surface coating on the surface of magnetite nanoparticles has reduced the crystallinity. The crystallite size of the uncoated and coated nanoparticles is estimated as 13.28 nm and 8.3 nm, respectively. The reason for amorphisation of the nanoparticles during silica coating can be attributed to the compaction of Fe_3O_4 crystalline structure, and needs to be further investigated.

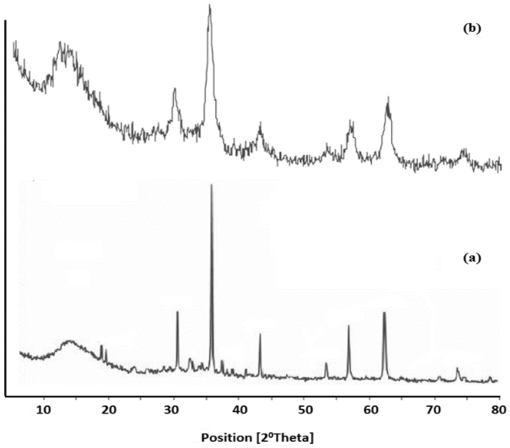

Figure 1. XRD pattern of a) magnetite nanoparticles b) silica-coated magnetite nanoparticles.

3.1.2. FT-IR spectrophotometry

Fourier transform infrared spectrometry was also used to ensure that the appropriate silica layer and organosilane groups were coated on the magnetite nanoparticles (Figure 2). The adsorption band peaks at 1636 cm^{-1} and 474 cm^{-1} are attributed to the magnetite nanoparticles. The band peaks with lower wavenumber than 1700 cm^{-1} arise from the Fe-O bond in the Fe_3O_4 structure. The strong stretching peak at the 1100 cm^{-1} region is related to the siloxane Si-O-Si group on the surface of the magnetite nanoparticles, which clearly indicates the formation of silica surface coating on the magnetite nanoparticles. The observed peak in the range of 1850-800 cm^{-1} is also attributed to the silanol groups [28]. The adsorption band peaks in the 474 cm^{-1} area represent Fe-O bond, which also appeared in the uncoated sample. The peaks of 1320 cm^{-1} in both forms, as well as the adsorption band at 1636 cm^{-1}, relate to the various types of hydroxyl groups, and represent the molecular water physically absorbed on the surface of the particles. In both forms (a) and (b), the adsorption bands of less than 1400 cm^{-1} are attributed to the Fe-O bonds overlapping with Fe-Si-O bands in the same wave number ranges. New peaks that have appeared in the areas from 1280 cm^{-1} to 1300 cm^{-1} belong to the CH groups, which indicate the generation of functional groups on the surface of magnetite nanoparticles by organosilanes. In Figure -a, the peak in the adsorption regions of 1220 cm^{-1} to 1230 cm^{-1} is related to the phenyl phosphine functional groups. Figures (b) and (c) show peaks in the adsorption regions of 11500-1700 cm^{-1} and 1310-1340 cm^{-1}, which are related to the NH and NH_2 groups, and are an indication of the successful surface coating of magnetite nanoparticles with amino-organosilanes. The stretching vibration peak of Si-O-Si siloxane groups in the 1100 cm^{-1} region is still present in Figures (a) and (b) and (c), which reveals that the modification of the nanoparticles surface has not altered the original structure of silica by organosilanes. Also the observation of this peak in both organosilane modified and non-modified samples may be due to the fact that after the surface modification some of the silanol groups on the silica surface have remained unresponsive, and a full organosilane surface coating has not been achieved. In Figure 3, the adsorption mechanism in this study by nanoparticles along with organosilane functional groups is shown schematically.

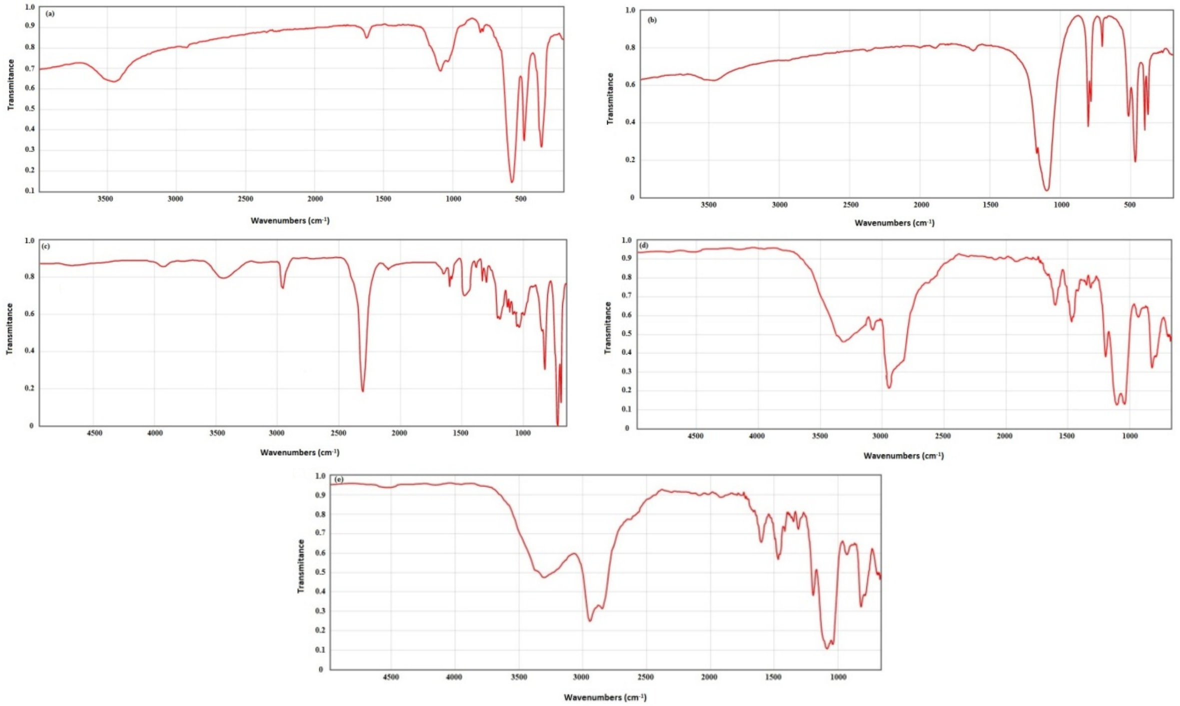

Figure 2. FT-IR spectrophotometry a)NFe b) FeSi c)FeSiORP d) FeSiORA e) FeSiORDA.

3.2. Adsorption test results

Figure 4 shows the adsorption rate of platinum, palladium, and rhodium from the leaching solution by FeSiORA nanoparticles. In a 150 min time period, the adsorption reached 40% for platinum and 48% for palladium, while the adsorption of rhodium was not successful, and at the end of 150 minutes did not exceed 11%.

Figure 5 demonstrates the adsorption results of the ORDA organophosphate nanoparticles. The experiments were conducted in two nanoparticle concentrations of 2 and 4 mg/mL. However, no desirable adsorption was achieved. Figure -c shows that the platinum adsorption rate has increased by over 90% but the concentration of nanoparticles in this experiment is as high as 8 mg/mL. The cause of the need for high amounts of absorbent nanoparticles is to absorb the disturbing metals in the leach solution that occupy the active sites on the surface of adsorbent nanoparticles. In fact, the NH and NH_2 functional groups acting on the surface of these organosilanes play a functional role, lacking the selectivity to absorb platinum group metals compared to the other metals. Certainly, one of the reasons for the attractiveness of amino groups as adsorbents for platinum metals, despite their lack of selectivity, is the simplicity and high kinetics of adsorption. As shown in Figure -c, only about 50% of platinum adsorption was achieved within 60 minutes. Another problem in the adsorption behaviour of the two organosilanes was the difference in the adsorption of platinum and palladium. The organosilane coating nanoparticles containing the ORA functional groups absorbed palladium over high levels of platinum. This was in the case of organosilane-containing nanoparticles containing the ORDA functional group, and platinum had a higher adsorption rate. However, in the case of rhodium adsorption, both organosilanes had the same function and failed to absorb this metal.

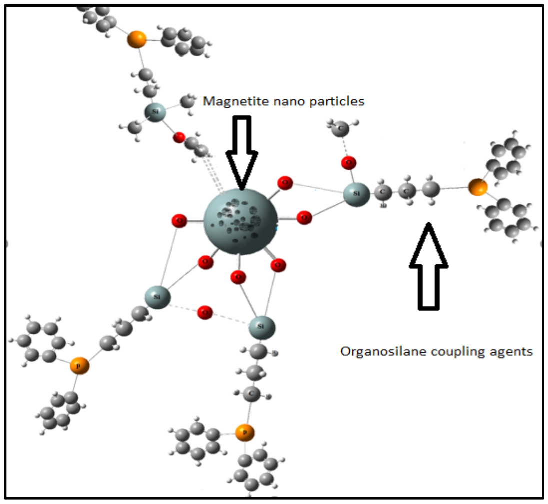

Figure 3. A schematic diagram of magnetic nanoparticle's structure with organosilane coupling agents.

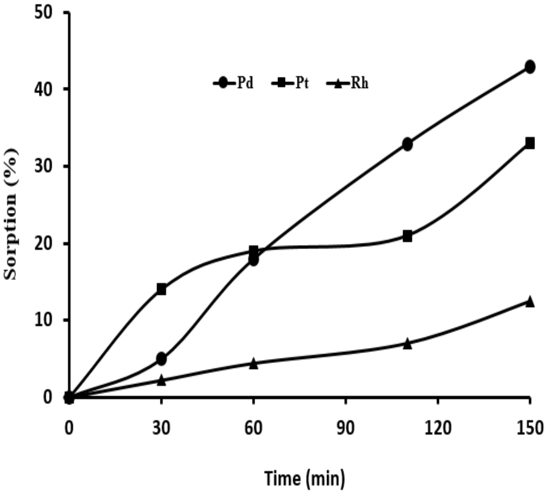

Figure 4. Adsorption rate of platinum, palladium, and rhodium from leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, under laboratory conditions (25 °C), [HCl] = 1 M, rpm = 150 with 4 mg/mL FeSiORA nanoparticles.

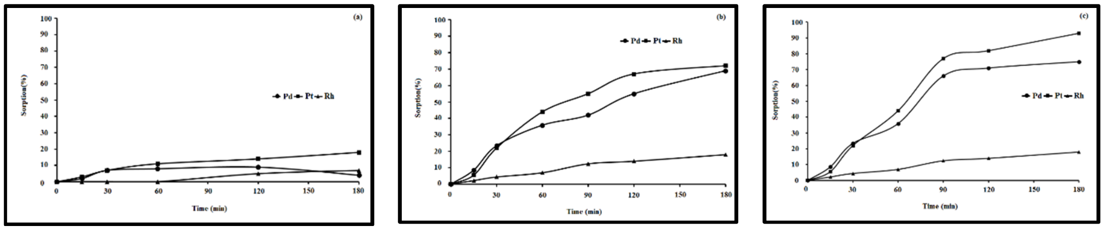

Figure 5. Adsorption rate of platinum, palladium, and rhodium from leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, temperature 25 °C, [HCl] = 1 M, rpm = 150 rpm using FeSiORDA nanoparticles at a concentration of 2, b) 4 , c) 6 mg/mL.

In **Error! Reference source not found.**, the results of platinum, palladium, and rhodium adsorption using a phosphine organosilane adsorbent are shown. Platinum and palladium showed good adsorption with two different kinetic rates. In a period of 60 minutes, about 97% of palladium was collected from the leaching solution, and in the presence of more than 10 competing metals, selectively (with platinum) on phosphine organosilane nanoparticles. Platinum was also adsorbed from the leaching solution after 270 minutes with more than 97% adsorption.

The adsorption of rhodium by the FeSiORP nanoparticles still failed. As a result of very slow kinetics, at least 5% of adsorption was achieved at the end of 5 hours.

3.3. Role of effective factors

Adsorption of platinum group metals (platinum, palladium, and rhodium) from the leaching solution was further investigated by magnetite nanoparticles with organosilane ORP surface coating. The effect of four parameters of Cl^- concentration, temperature, pH, and concentration of adsorbent nanoparticles were examined in details. For this purpose, by maintaining one of the parameters, the effect of other three parameters was investigated.

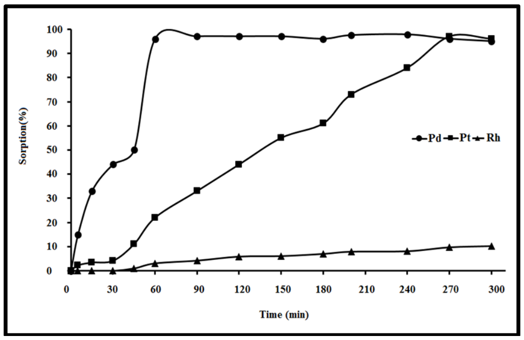

Figure 6. Adsorption rate of platinum, palladium, and rhodium by FeSiORP nanoparticles from leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, temperature 25 °C, $[Cl^-]$ = 2.5 M, rpm = 150 rpm, pH = 2.5.

3.3.2. Effect of Cl^- concentration

The effect of Cl^- concentration on the adsorption of platinum and palladium is shown in Figure . The Cl^- concentration does not seem to affect the adsorption of Pd complexes. At concentrations of 3.5 M, about 95% of palladium adsorption has been achieved, which remains almost constant at concentrations up to 9 M. In the case of platinum, this is not the case, and with increasing the concentrations higher than 2 M, the rate of adsorption declines so that the concentration of 9 M has resulted an adsorption rate as low as 40%.

3.3.3. Effect of pH

The effect of pH on the adsorption rate of platinum and palladium is shown in Figure . At a relatively neutral pH (above 6), the adsorption of both metals shows a sharp drop.

3.3.1. Effect of adsorbent concentration

In order to investigate the role of adsorbent concentration, the adsorption experiments were performed on a leaching solution with a different concentration of FeSiORP nanoparticles (Figure). By increasing the amount of nanoparticles up to 2.5 mg, the adsorption of platinum and palladium increased, and then remained constant afterwards with no more further improvements. In low amounts, palladium is absorbed more than platinum, which suggests that palladium adsorption is faster and more efficient.

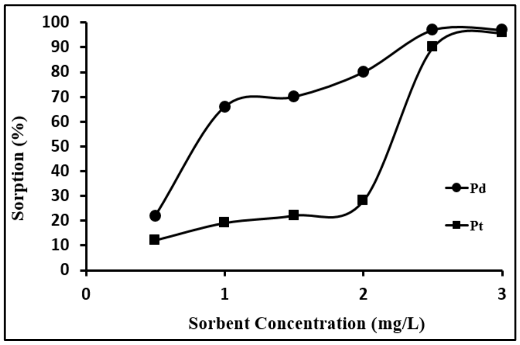

Figure 7. Adsorption rate of platinum and palladium in different concentrations of FeSiORP nanoparticles from leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, and other metals in laboratory conditions. Temperature 25 °C, [Cl-] = 2.5 M, rpm = 150 rpm, pH = 2.5, time =b270 min.

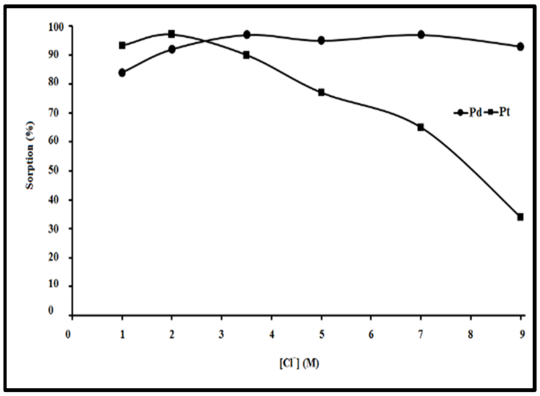

Figure 8. Adsorption rate of platinum and palladium in different concentrations of Cl^- from leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, and other metals in laboratory conditions. Temperature 55 °C, nanoparticle concentration = 2.5 M, rpm = 150 rpm, pH = 2.5, time = 270 min.

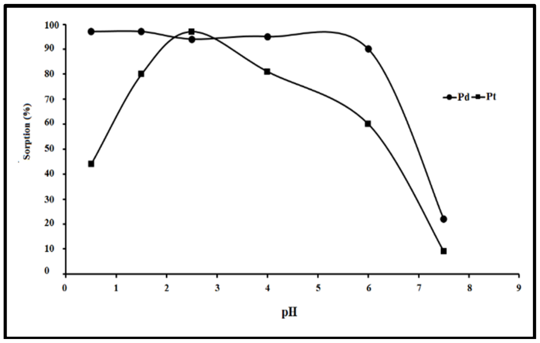

Figure 9. Adsorption rate of platinum and palladium in different pH from the leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, and other metals in laboratory conditions. Temperature 55 °C, nanoparticle concentration = 2.5 M, rpm =150 rpm, [Cl$^-$] = 2.5, time = 270 min.

To further investigate the cause of the adsorption drop at higher pHs, the pourbiax diagrams of Pt, Pd, and Rh were plotted for the M-Cl-H_2O system using the Medusa software package (Figures 10-12). In all acidic pHs and at Eh of 1.5 V, all three platinum, palladium, and rhodium metals form chloride complexes. At pH values above 8, the chloride complexes are not stable, which clearly explain the adsorption drop in high pH observed in Figure 9.

3.3.4. Temperature effect

In order to investigate the effect of temperature on the adsorption of platinum and palladium chloride complexes, a set of adsorption tests were conducted at a temperature higher than ambient and below 75 °C (Figure 13). By increasing the temperature, there is a slight change in the adsorption of platinum and palladium. The higher temperature has improved the palladium adsorption rate slightly.

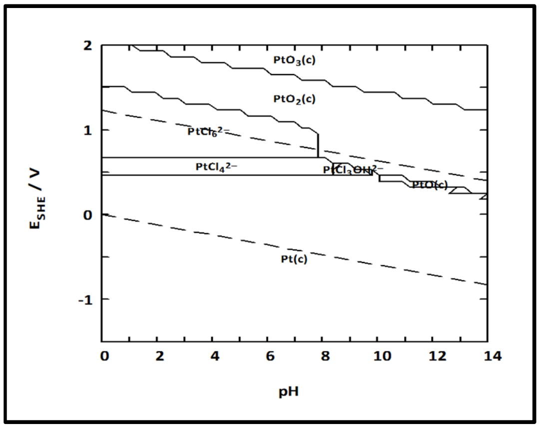

Figure 10. Eh-pH diagram for Pt–Cl–H_2O system with 91 mg/L Pt, 25 °C temperature, [Cl$^-$] = 2.5 M.

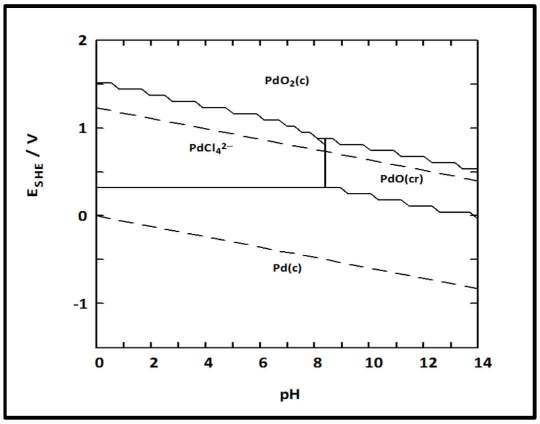

Figure 11. Eh-pH diagram for Pd–Cl–H_2O system with 87 mg/L Pt, 25 °C temperature, [Cl$^-$] = 2.5 M.

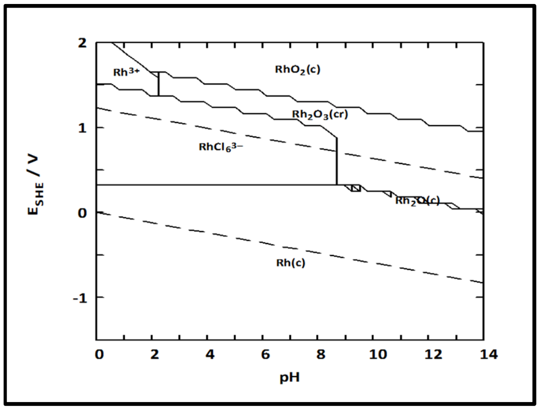

Figure 12. Eh-pH diagram for Rh–Cl–H_2O system with 11 mg/L Pt, 25 °C temperature, [Cl$^-$] = 2.5 M.

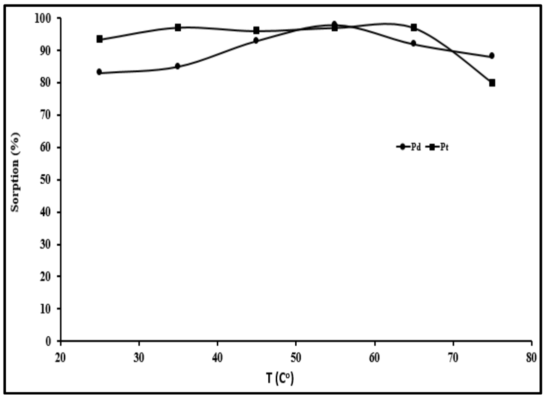

Figure 13. Adsorption rate of platinum and palladium in different temperatures from the leaching solution (100 mL) containing 91, 87, and 11 mg/L Pt, Pd, and Rh, respectively, and other metals in laboratory conditions. Nanoparticle concentration = 2.5 M, rpm = 150 rpm, [Cl$^-$] = 2.5, pH = 2.5, time = 270 min.

3.3.5. Selectivity of adsorbents

In Figures 14-16, the adsorption rates using the FeSiORA, FeSiORDA, and FeSiORP nanoparticles have been compared. The only functional groups with desirable selectivity is diphenyl phosphine, which in the presence of about fifteen invasive elements in the leaching solution (Si, Mg, Al, Zr, Ce, Ti, La, Zn, Ca, Cr, Co, Ni, Fe, Pb, Mn) has still selectively absorbed platinum and palladium only.

The reason for the different behaviour of amino and phosphine functional groups in adsorption should be sought in the structure of the N and P atoms. Both nitrogen and phosphorus atoms have a pair of single electrons. On the one hand, nitrogen is a small atom with high electrostatic repulsion between the valence electrons. The stable electronic arrangement and the symmetric state of the nitrogen atom will completely deteriorate if another electron is added, and therefore, this atom has a negative electron affinity. Unlike nitrogen, phosphorus atom is relatively large (atomic radius is 0.7 for nitrogen and 1.1 for phosphorus). Therefore, the addition of an electron does not create a significant electrostatic repulsion. Therefore, the 3d empty orbitals act as acceptor orbitals through the formation of Pi (π) bonds.

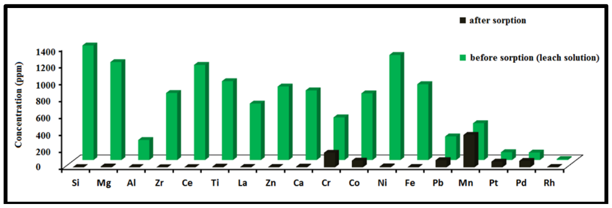

Figure 2. Selective adsorption of platinum and palladium by FeSiORA nanoparticles from leaching solution in presence of 15 metals.

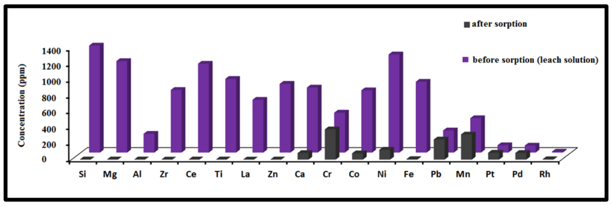

Figure 15. Selective adsorption of platinum and palladium by FeSiORDA nanoparticles from leaching solution in presence of 15 metals.

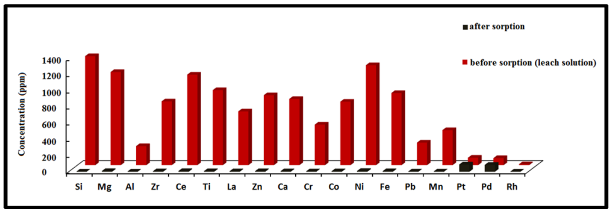

Figure 16. Selective adsorption of platinum and palladium by FeSiORP nanoparticles from leaching solution in presence of 15 metals.

The reason for the selective adsorption of platinum and palladium is expressed by the functional group of phosphine using the hard and soft acid bases (HSAB) theory. The platinum and palladium cations are soft acids, while PR3 phosphine ligand is a soft base. Therefore, according to the HSAB theory, the adsorption of platinum and palladium in a solution containing other metals (hard acids) is preferred by the PR3 ligand.

4. Conclusions

The selective recovery of some platinum group metals including Pt, Pd, and Rh from the spent automobile catalysts was investigated by functionalized magnetite nanoparticles. It was found that FeSiORPs could effectively adsorb Pt and Pd but exhibited no affinity towards the Rh and base metal ions. Under the optimum conditions, the adsorption rates of Pt, Pd, and Rh were estimated 97.5%, 97.0%, and 15.0%, respectively. The reason for the selective adsorption of platinum and palladium is expressed by the functional group of phosphine using the hard and soft acid base (HSAB) theory. Based on this theory, the strongest interactions are expected when HOMO (highest occupied molecular orbital) or LUMO (lowest unoccupied molecular orbital) orbital sets of the reactants are closest in energy. The orbital energy of soft species is close, while HOMO and LUMO differ greatly in hard species. Thus the bond formed between two soft and two hard types is stronger. As a result, soft acids such as platinum group metals are more rapidly and strongly interacted and bonded to the soft bases.

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بازیابی انتخابی پلاتین، پالادیوم و رودیوم از کاتالیست‌های مستعمل توسط نانوذرات مگنتیت دارای پوشش سطحی

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چکیده:

بازیابی انتخابی فلزات گروه پلاتین شامل پلاتین، پالادیم و رودیوم از کاتالیست‌های مستعمل خودرو توسط نانوذرات مگنتیت دارای پوشش سطحی به عنوان یک جاذب جدید مورد بررسی قرار گرفت. نانوذرات مگنتیت به روش هم‌رسوبی توسط نمک‌های کلرید آهن (II) و (III) در حضور هیدروکسید آمونیوم سنتز شده و با ایجاد پوشش سطحی توسط تترا اتیل ارتوسیلیکات دارای یک لایه سیلیکایی شدند. سپس نانوذرات پوشش داده شده با سیلیس با سه نوع مختلف لیگاند ارگانوسیلان شامل مونوآمین (FeSiORA)، اتیلن دی آمین (FeSiORDA) و دی فنیل فسفینو (FeSiORP) دارای گروه عاملی شدند تا قدرت جذب انتخابی فلزات گروه پلاتین را داشته باشند. اثر پارامترهای مختلف نظیر pH، مقدار جاذب، زمان جذب و غلظت کلرید در محلول لیچینگ بر میزان جذب کلروکمپلکس‌های پلاتین، پالادیوم و رودیوم مورد بررسی قرار گرفت. در میان لیگاندهای ارگانوسیلان مورد استفاده، نانوذرات مگنتیت دارای پوشش سطحی FeSiORA و FeSiORDA، برای جذب انتخابی فلزات پلاتین، پالادیوم و رودیوم از محلول لیچینگ، ناموفق بودند. نانوذرات مگنتیت دارای پوشش سطحی دی فنیل فسفین FeSiORP پلاتین و پالادیوم را از محلول لیچینگ به خوبی جذب کردند اما در جذب رودیوم خوب عمل نکردند. نهایتا توسط نانوذرات مگنتیت دارای پوشش سطحی دی فنیل فسفین FeSiORP در شرایط بهینه، میزان جذب پلاتین، پالادیم و رودیوم به ترتیب ۹۷/۵، ۹۷ و ۱۵ درصد بدست آمد.

کلمات کلیدی: فلزات گروه پلاتین، کاتالیست‌های مستعمل، نانوذرات مگنتیت، گروه عاملی ارگانوسیلان.
