

## PHYSICOCHEMICAL CHARACTERIZATION OF CARBONACEOUS MATTER ASSOCIATED WITH REFRACTORY PRECIOUS METALS ORES

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**Abstract:** However, the origin of carbon in mineral deposits, it does not matter if it is organic, inorganic or a combination of both, it remains a highly debatable issue, geologically carbonaceous matter is considered an important reducing agent that contributes to the formation of large gold deposits. Recent Raman spectroscopy studies in orogenic gold deposits have identified two main types of carbonaceous matter: kerogenous graphitic and other rich in aromatic hydrocarbons, which when decomposed can generate areas rich in carbon. The carbonaceous matter (MC) of a polymetallic ore Pb-Cu-Zn-Au; which presents high pre-robbery activity during gold-pyrite cyanidation, was concentrated by flotation and physically and chemically characterized. The concentrate with 4-5.5%  $C_{Total}$  (50 to 65% organic carbon) and fine size  $d_{80} = 10$  microns, it is a macroporous material with high adsorptive activity, 300 g Au/Ton of MC (Activated Carbon 700 g Au/Ton C). The adsorptive activity can be reduced by 95% by chemical oxidation (HClO), the FTIR-chemical analyzes indicate that the carbon is not oxidized to CO<sub>2</sub> but transformed to non-active forms of carbon. The use of blinders is not effective, as a result of the extensive dissemination of CM in the siliceous gangue.

**Keywords:** Adsorbent activity, carbonaceous matter, pre-robbery.

## INTRODUCTION

The cyanidation process has been the most widely used method for extracting gold and silver for the last 100 years. This is mainly due to its efficiency, low operating cost and simple control during the process; however, gold losses during the process are the biggest problem in the mining industry and if their causes are not properly identified, they can lead to significant amounts of gold in the

tailings (Goodall et al., 2005). In the case of gold ores associated with carbonaceous matter, the observed refractoriness is known as preg-robbing, where the carbonaceous constituents adsorb the aurocyanide complexes from the solution. In these gold-silver ores, associated with carbonaceous matter, when recoveries fall below 80%, it is said that the preg-robbing activity is severe. The preg-robbing phenomenon was detected in 1911 by Cowes, who found gold losses in the tailings of the Waihi-Paerola operations in New Zealand due to the presence of natural carbon in the ore (Miller et al., 2005).

The growing demand of metals to satisfy current living conditions and the depletion of base mineral deposits with high grades and easily extractable, has forced the mining industry to develop processes through which it is feasible to take advantage of those deposits that have low grades and/or difficulties during their treatment. In contrast to the higher-grade polymetallic ores of the 1900's, e.g., 19.0% Pb and 18.0% Zn, some of the deposits in operation today do not even reach one percent (1.0%) of base metals, therefore, large tonnages must be treated to make operations profitable. In these high mass flows the fraction of gold from the flotation tailings that can be recovered in pyrite concentrates becomes attractive, see Figure 1. However, the technical feasibility of recovering this fraction of gold is disrupted by its complex mineralogy: occlusion in pyrite sulfides and arsenopyrite, association with preg-robbing carbonaceous matter, and gold in the form of tellurides (petzite, calaverite, etc.). The only alternative proposed for its recovery has been cyanidation, which, of course, can only partially extract gold values, as long as the concentrates are taken to or reground to finer sizes of less than 20 microns.

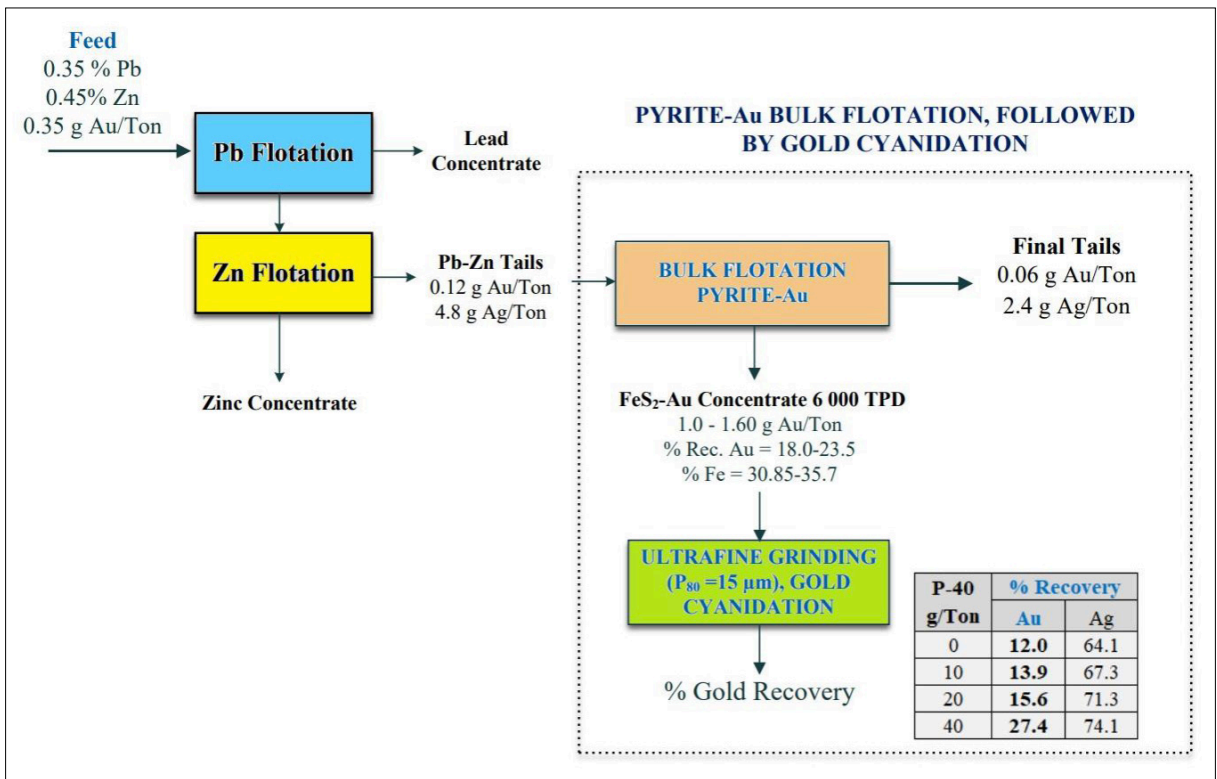
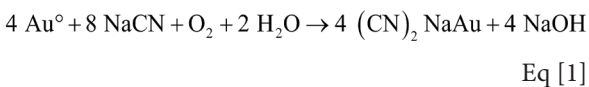


Figure 1. Polymetallic ore flotation flow diagram, including pyrite-Au concentrate flotation (Salazar et al., 2017).

## BACKGROUND

### THE CYANIDE SYSTEM (CN<sup>-</sup>)

Cyanidation is a process that has been applied to the treatment of gold ores for many years. It is based on the fact that native gold, silver or different alloys between these, are soluble in diluted alkaline cyanide solutions, based on the following equation:



Despite its simplicity, the toxicity of cyanide poses serious usage questions. However, in addition to the experience of more than one hundred years of application the system, firstly, provides a reducing medium in which oxygen, with moderate oxidizing power ( $E^\circ = 0.30$  Volts in basic medium) is capable of dissolving the so-called king of metals and, secondly, it is a strong complexing agent, which allows the

stabilization of a high amount of gold and/or silver in solution.

### REFRACTORINESS OF GOLD ORES BY ASSOCIATION WITH CARBONACEOUS MATTER

For some minerals, the recovery of gold by cyanidation is limited by the presence of natural carbonaceous matter that adsorbs metal-cyanide anions from the alkaline cyanide solution, mainly those of gold ( $\text{Au}(\text{CN})_n^{1-n}$ ,  $n = 1 \dots 4$ ). Such minerals are most often referred to as preg-robbing minerals. Although they can be called refractory carbonaceous minerals, being refractory in the sense that *the recovery of gold is hindered by the adsorption losses* that occur. Smith first used the term “robbing” in 1968 and it was used by others later (Hausen and Bucknam, 1984; Stenebråten et al., 1999). Nowadays, it is commonly used

in the industry. The robbing of a pregnant solution or *preg-robbing*, is an important phenomenon preventing gold recovery due to the presence of this natural carbonaceous matter (Miller et al., 2005). There are other minerals with similar conditions, including copper-sulfide minerals, clays, and silicates, which can adsorb gold depending on the area and characteristics of the contact surface. Conceptualizing the term, we could say that *refractoriness* is the resistance that certain ores expose to being processed by conventional methods under standard conditions for minerals with simpler mineralogy.

## ADSORPTION

Adsorption has been defined by IUPAC as the enrichment (i.e., positive adsorption or simply adsorption) or depletion (negative adsorption) of one or more components in an interface.

**Langmuir model.** This model was originally developed to describe gas-solid adsorption on activated carbon and has been used to contrast the performance of different bio-adsorbents. In its formulation this empirical model assumes:

- 1.- Monolayer adsorption, that is, the adsorbed layer is one molecule thick,
- 2.- Adsorption occurs in finite and specific places, which are identical and equivalent.
- 3.- There is no lateral interaction.

The mathematical expressions of this model in its original and linear forms have the following equation:

$$\frac{C_e}{q_e} = \frac{1}{bQ_o} + \frac{C_e}{Q_o} \quad \text{Eq. [2]}$$

Where:

$q_e$  = amount of adsorbate in the adsorbent at equilibrium (mg/g).

$Q_o$  = maximum coating capacity as a monolayer (mg/g).

$C_e$  = equilibrium concentration (mg/L).

$b$  = Langmuir constant (dm<sup>3</sup>/mg).

Graphically, the model is characterized by a *plateau*, which indicates the point of saturation or occupation by a monomolecular layer in which there can be no more adsorption. In addition to the above, there is another dimensionless constant, known as the separation factor ( $R_L$ ), represented by:

$$R_L = \frac{1}{1 + K_L C_o} \quad \text{Eq. [3]}$$

Where  $K_L$  (L/mg) refers to the Langmuir constant and  $C_o$  denotes the initial adsorbate concentration (mg/L). The  $R_L$  value is indicative of the adsorption nature, if  $R_L > 1$  the adsorption is not favorable, if  $R_L = 1$  the adsorption is linear, if  $0 < R_L < 1$  is a favorable adsorption or, if  $R_L = 0$  the adsorption is irreversible.

## METHODOLOGY

### FLOTATION OF CARBONACEOUS MATTER

The test material for this investigation was constituted by a representative sample of approximately 1200 grams of carbonaceous matter concentrate obtained from a mining unit in the state of Zacatecas. The coal flotation stage in the plant has been considered in order to have a more controlled selective flotation and to facilitate the gold fraction cyanidation to be recovered in the pyrite concentrate. An important goal of this characterization study is elucidating the inhibition mechanism of the *preg-robbing* activity using chemical oxidation (HOCl) (Gómez, 2016). The carbonaceous matter was floated using a collector reagent that increases the natural hydrophobicity of carbon. In addition to the “collector” and

to keep the precious metals depressed, it's necessary to add sodium cyanide (10-30 g/Ton) and lime. If not added, the recovery or distribution of these in the carbonaceous matter will be high, greater than 25%.

### **THERMOGRAVIMETRIC ANALYSIS (TGA)**

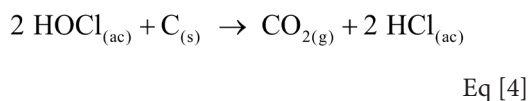
The Thermogravimetric Analysis technique, (from the English acronym TGA, Thermal Gravimetric Analysis), measures the amount and speed of change in weight of a sample as a function of temperature and/or time in a controlled atmosphere. In general, it allows measurements to determine the composition of materials and predict their stability at temperatures of up to 1500°C. This technique can, therefore, characterize materials that exhibit weight loss or gain due to decomposition, oxidation, or dehydration.

### **AU ADSORPTION TESTS ON CARBONACEOUS MATTER**

This procedure helps quantify the carbonaceous matter characteristics of the sample, specifically, we will be able to assess the preg-robbing activity from the sample we are treating. It will make possible to establish a comparative parameter to assess the final results as favorable or null when applying this technique again to oxidized carbonaceous matter.

### **CHEMICAL OXIDATION OF CARBONACEOUS MATTER**

The mechanism of deactivation, or passivation, with chlorine is not fully understood. Direct oxidation of organic carbon to carbon dioxide is theoretically possible:



Chlorine is highly soluble in water and dissolves to form hydrochloric acid and hypochlorous acid (Marsden and House, 2006). Nonetheless, deactivation efficiency, as assessed by the ore's response to cyanide leaching, has been found to be unrelated to any change in the organic carbon content of the material being oxidized. That is, the deactivation of the carbonaceous matter by hypochlorous acid or hypochlorite ion may be the result of the formation of a layer of chlorinated hydrocarbons or the formation of carbonyl structures, composed mainly of carboxyl groups (COOH). These surface groups passivate carbon by blocking active adsorption sites. It has also been suggested that ionization of surface groups (such as COOH) in alkaline solutions results in a negatively charged surface of organic material, thus repelling the negatively charged Au(I) cyanide ions. In short, this would indicate that Eq [4] is not responsible for the deactivation.

## **PROCEDURES**

### **EQUIPMENT AND REAGENTS.**

The equipment for the adsorption tests was implemented with a glass reactor and a stirring head, both mounted on a universal lab stand. Sample analysis was performed via atomic absorption, using a Perkin-Elmer AAnalyst-200 kit.

Synthetic Au-CN solutions were used for the adsorption tests, which involved the use of sodium cyanide (NaCN), a 1000 ppm Au standard at 10% HCl, and sodium hydroxide (NaOH) to regulate the pH required for the preparation of the solution. In all cases, the synthetic solutions were prepared with distilled water, enough milliliters of the standard to give a specific concentration of gold, then the pH of the solution was adjusted to 10.5, and finally the cyanide was added to have a strength of 1000mg NaCN/L. All the

reagents used were analytical grade and are summarized in Table 1.

Reagent	Formula	Function
Sodium hypochlorite	NaClO	HOCl production
Hydrochloric acid	HCl	pH regulator
Sodium hydroxide	NaOH	Regulate pH
Sodium cyanide	NaCN	Solution preparation
Blinder	Unknown	Blinder
Gold standard	1 000 mg Au/L	Synthetic solutions

Table 1. Reagents used during the experiments.

For the chemical oxidation tests, a larger reactor system (700 mL) was implemented and then mounted on a special support. Additionally, the system was complemented with a *jacket* to keep constant temperature. For the extraction of any gases, a vacuum pump and a trap were used to neutralize the acid gases produced in the reactor.

### AU ADSORPTION TESTS ON CARBONACEOUS MATTER

Eight gold-cyanide adsorption tests on carbonaceous matter were carried out, six of them for characterization and two to verify the chemical oxidation results (with pre-treated carbonaceous matter). The first ones used Au-CN solutions with concentrations of 5, 10, 15, 20 and 30 mg Au/L with a pH of 11. The tests to assess the efficacy of the pre-robbing inhibitor pretreatment were carried out with solutions of 15 ppm concentration and 10.5-11 pH.

#### Procedure

For each test, 400 mL of distilled water were poured in a one-liter beaker, enough amount of gold standard to give the desired gold concentration was added. The pH test

tube was immersed in the solution and the solution pH adjusted at 10.5-11.0. Finally, 500 mg of cyanide were added, keeping the solution stirring until all the cyanide dissolved. Then, the solution was poured into a 500 mL volumetric flask, gauged and stirred to ensure homogeneity.

Once the solution was prepared, 400 mL of it were emptied into a baffled container. Likewise, 10 grams of carbonaceous material were weighed and added to the reactor and stirred ( $300 \text{ min}^{-1}$ ). At this moment, the clock was started and later, at defined intervals of time: 1, 2, 4, 8 and 24 hours, the agitation was stopped and samples of ten milliliters of the supernatant solution taken, replenishing the same amount of the remaining prepared solution. The collected samples were left to decant, then the clear decanted solution passed to a clean vial to be analyzed for gold via atomic absorption. Figure 2 shows the system for adsorption tests.

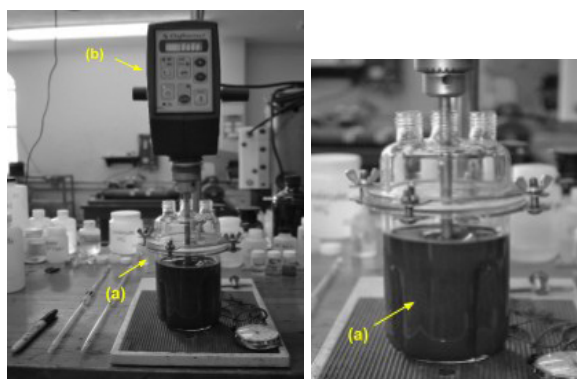


Figure 2. Implemented system for adsorption tests: (a) baffled reactor (400 mL) and (b) Cafrano stirring head.

### CARBONACEOUS MATTER CHEMICAL OXIDATION WITH HOCL

Three oxidation tests were carried out with sodium hypochlorite (NaClO) and the oxidation efficiency was confirmed by performing adsorption tests with synthetic solutions of 15 mg Au/L-oxidized carbonaceous

matter. The sodium hypochlorite added in tests was calculated based on the chemical analysis of organic carbon in the carbonaceous matter sample (Corg = 2.58%).

Thus, and based on the stoichiometry of reaction 3.1, the first test was carried out with 25 g of NaClO, 75% of the stoichiometric; the second with the stoichiometric quantity; and the third with a 10% in excess of the stoichiometric.

### Procedure

First, the reactor and the agitator were mounted on the support structure, then the former was covered and secured with screws. The *jacket* was inserted in the lower part, then the hoses that will recirculate the water to keep the system temperature constant (25 °C) were connected. All the cover orifices were blocked with plugs, and the orifice with a connector was connected to a hose through which the acidic gas was extracted towards the neutralization trap. See Figure 3.

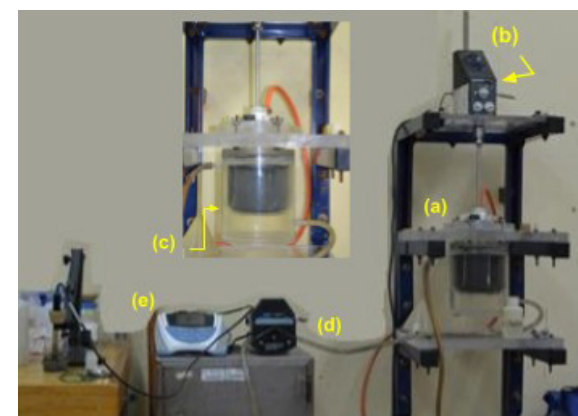


Figure 3. System implemented for chemical oxidation tests: (a) reactor, (b) agitation head, (c) jacket, (d) peristaltic-bath and (e) pH meter.

Once the system was assembled-fixed, 600 mL of distilled water and 100 grams of carbonaceous matter were added to the reactor. The contents were stirred until integration and the temperature of the medium was measured. The pH was then

adjusted to 5; at this pH, hypochlorous acid HOCl predominates. System stabilization takes approximately one hour and then NaClO was added. At this moment, pH began to vary, so it was necessary to stabilize it periodically with HCl additions up to no more than 25 mL of HCl. The oxidation test lasted two hours, then the agitation was turned off, the reactor disassembled and its content filtered. During filtration, 50 mL of filtrate were recovered, necessary for elemental analysis of cations. Recovered solids were filtered and dried, then weighed to record if there was a change in mass and then set aside for further adsorption tests and other determinations, e.g., X-rays.

### Adsorption tests in the presence of blinding agent

The passivation or blinding of the carbonaceous matter was possible by adding organic reagents. In this case, the blinding agent used was PROL-40 from the manufacturer Pro-Ambiente.

### Procedure

The procedure of these tests was very similar to that of the oxidation. That is, once the system was assembled, 550 ml of distilled water were added and pH adjusted to 10.5. Then, 100 grams of carbonaceous matter were added, along with enough blinding agent as well; based on the manufacturer's suggestions and in the estimated area of organic carbon to block-blind.

Pretreatment time with the blinding was extended up to twelve hours, at the end of which 50 mL of solution with gold and cyanide were added, resulting in 15 mg Au/L. The efficacy of the blinder was determined by taking samples of the reactor contents at 1, 2-, 4-, 8- and 24-hours intervals. Each sample taken was filtered and then the recovered filtered matter analyzed for gold via atomic absorption.

## RESULTS

### CHEMICAL CHARACTERIZATION

As part of the coal flotation tests carried out in the unit, approximately 1,200 grams of carbonaceous matter were obtained. This quantity represented the accumulated mass of coal concentrates from three flotation tests, each carried out from twelve (12) kilograms of sample, but with different amounts of coal collector. The elemental chemical analyzes of this carbonaceous matter, both by concentrate and by composite, are summarized in Table 2.

### THERMOGRAVIMETRIC ANALYSIS (TGA)

A representative portion of carbonaceous matter was sent for thermogravimetric analysis. Figure 4 shows a weight loss against temperature graph and Figure 5 shows weight loss against time.

Based on slope or peaks changes, the first one would correspond to the organic carbon oxidation, while the second would be the conversion of inorganic carbon into oxide. In this case, the peak would possibly correspond to the presence of magnesite, although it's also possible there's presence of altered plagioclases. The latter tend to produce the peculiar dirty color observed on carbonaceous matter, in addition to the fact that their decomposition temperature ranges between 650 to 700 °C.

### PORE SIZE

As in the previous case, a representative portion of the carbonaceous material was sent to determine its pore size. Figure 6 shows the isotherm of this determination, which, according to its shape and the IUPAC classification, would correspond to that of a macroporous material, similar to activated carbon, with pore sizes greater than 50 nm.

### PARTICLE SIZE DETERMINATION

A portion of the carbonaceous matter concentrate was washed on the 325 mesh (45 µm), however, only 5% of the material showed sizes greater than the 325 mesh. Given this, we requested in one of the Institution's Academic Units, support to carry out this determination via microscopy or some alternative way to sieving or screening.

The results of this determination provided not only the size of the carbonaceous matter, but also, and since it was necessary to define a diffraction index for the material, the microphotographs and chemical analyzes showed that the carbonaceous matter, in addition to having a fine size, is found disseminated-associated with silica. Figure 8 shows the size graphs and Figure 9 some photomicrographs-analysis of the carbonaceous matter.

No.	SAMPLE ID	g/Ton		Metal percentage								
		Au	Ag	Pb	Zn	Cupppm	Fe	As	Sbppm	Corg	CTot	S
1	1820R37MS5BP-1CPC	0.46	29.7	0.73	0.39	920	1.23	0.087	776	3.46	5.40	2.34
10	1820R37MS5BP-2CPC	0.41	27.1	0.56	0.35	851	1.34	0.083	300	2.48	4.38	2.32
19	1820R37MS5BP-3CPC	0.28	23.5	0.53	0.36	879	1.73	0.107	637	2.04	3.95	2.29
28	1820R37MS5BCOMCPC	0.30	25.7	0.53	0.36	622	1.62	0.117	567	2.59	4.42	2.20

Table 2. Carbonaceous matter concentrates chemical analysis.



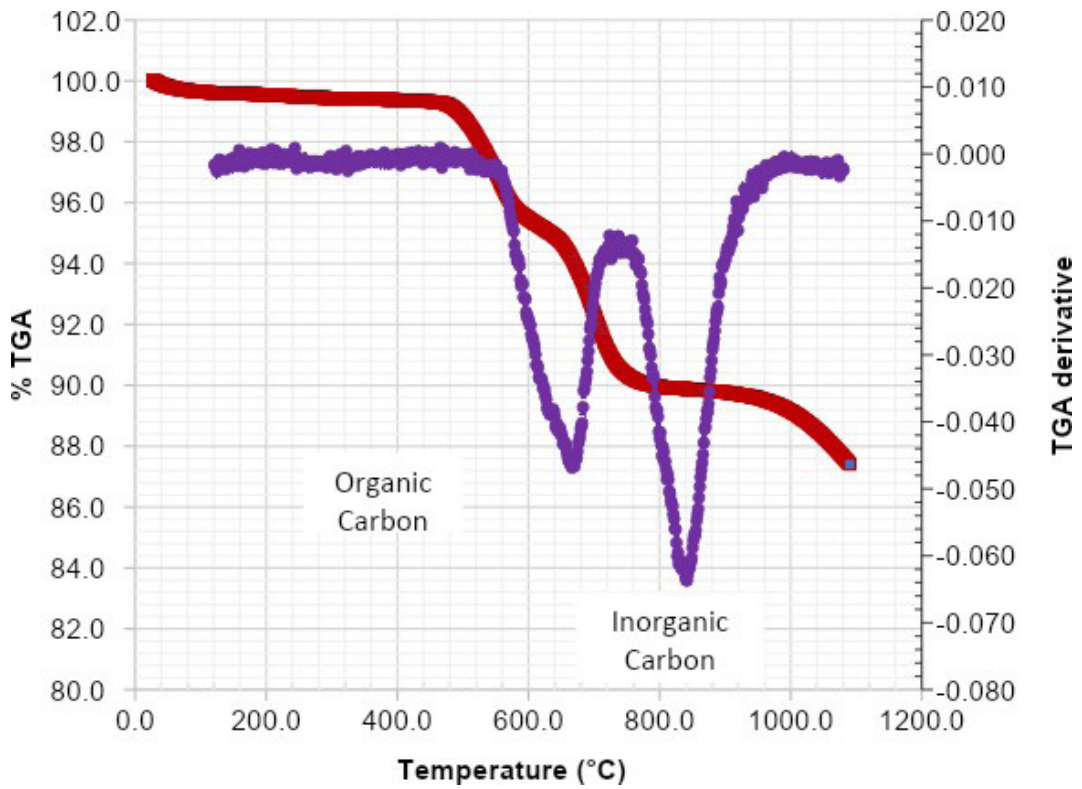


Figure 4.- Carbonaceous matter thermogravimetric analysis: TGA % vs. Temperature and TGA derivative.

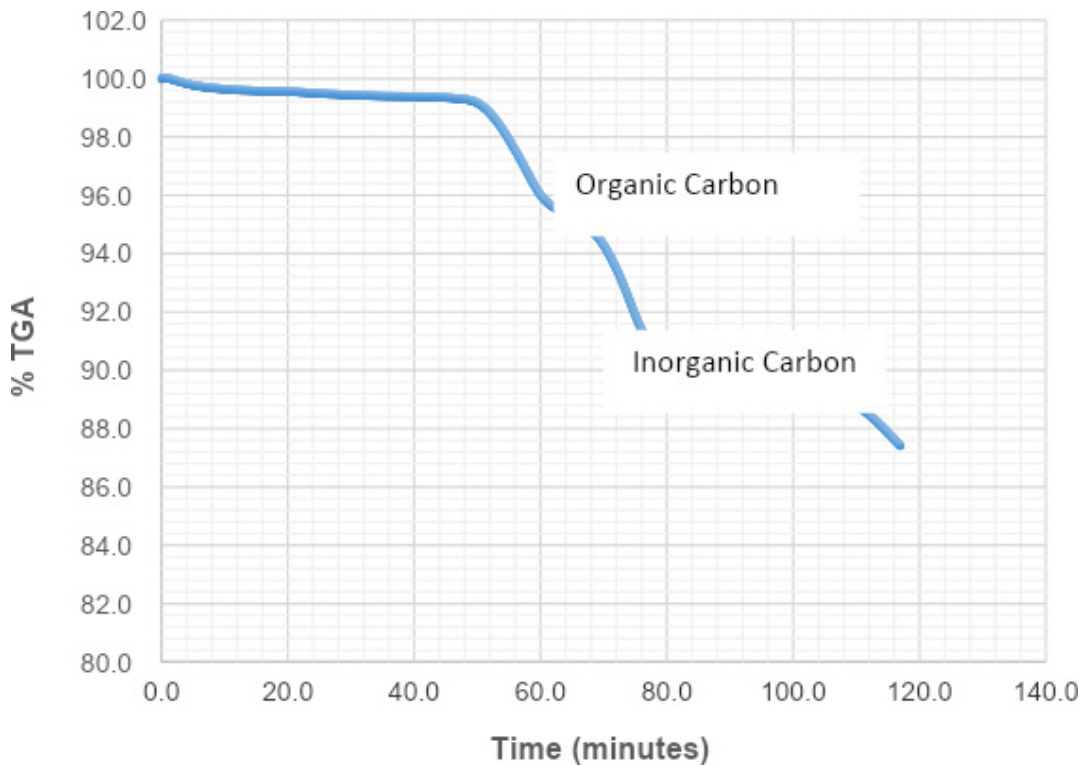


Figure 5.- Carbonaceous matter thermogravimetric analysis: TGA % vs. Time.

Material	Pore Diameter ( $\mu\text{m}$ )	Type of Isotherm according to IUPAC	Example
Microporous	< 2.0	I	Zeolite
Mesoporous	2 - 50	IV and V	MCM-41, SBA-15
Macroporous	> 50	II, III and VI	Activated carbon

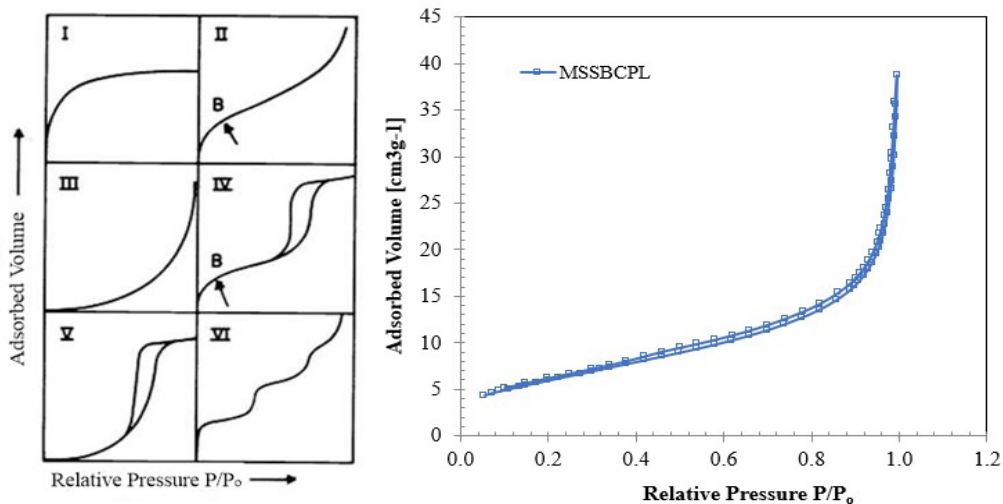


Figure 6.- Adsorption isotherm, carbonaceous test material.

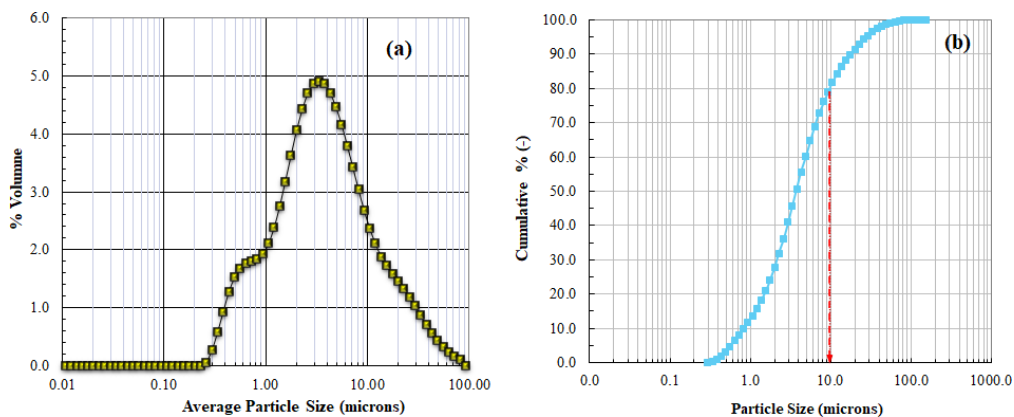


Figure 8.- Particle size distribution of the carbonaceous matter concentrate: (a) % volume against particle size (microns) and (b) Cumulative % (-) against particle size (microns).

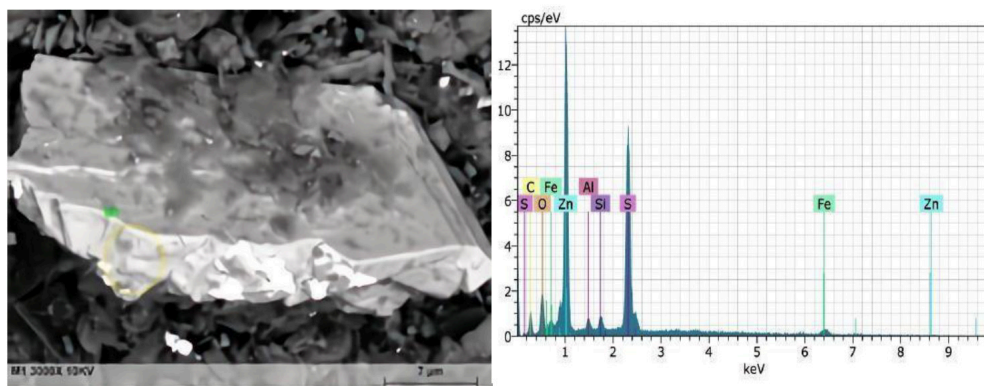


Figure 9.- Photomicrograph showing details of one particle of the carbonaceous matter, (b) chemical analysis of the yellow circle.

## AU ADSORPTION BY CARBONACEOUS MATTER

The activity of the carbonaceous matter, or adsorption capacity for precious metals in solution, can be determined by means of established procedures (Rees and Deventer, 2000; Miller et al., 2005). However, in this work, and given that the industrial process contemplates the flotation of the carbonaceous matter, and that it was possible to have enough material from this carbon concentrate, it was used as an adsorber material.

Thus, the results of adsorption tests, carried out using synthetic solutions of 5, 10, 15, 20 and 30 mg Au/L, and ten (10) grams of carbonaceous matter, indicate that the latter has an activity comparable to that of an activated carbon. Figure 10 shows one of the gold loading curves in mg/g against contact time.

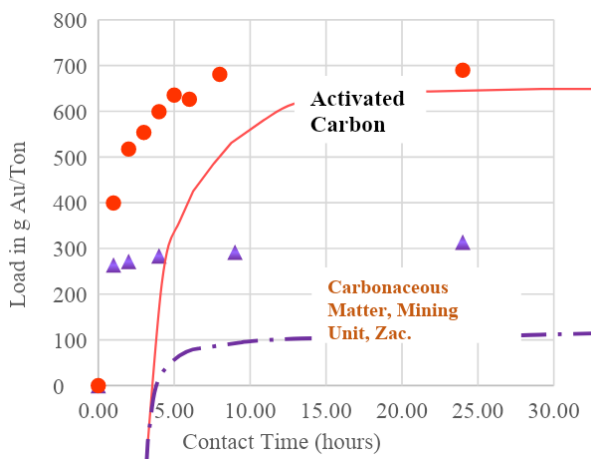


Figure 10.- Gold loading curve on carbonaceous matter: 400 mL synthetic solution (15 mg Au/l), ten (10) grams of carbonaceous matter.

From the rest of the loading curves obtained, once graphed, the necessary values to draw the Langmuir isotherm were obtained. Figure 11 illustrates the isotherm.

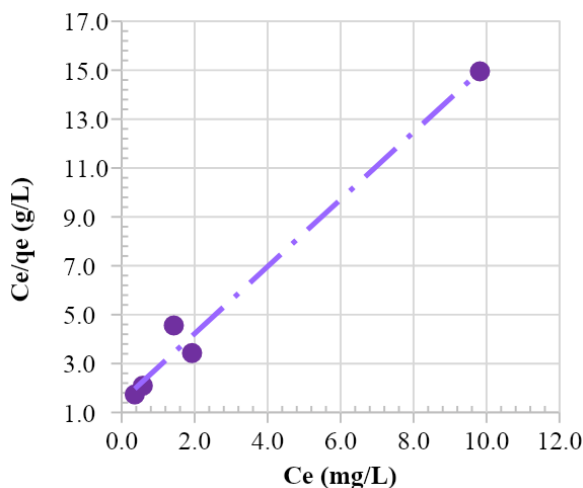


Figure 11.- Langmuir isotherm for carbonaceous matter using synthetic gold solutions.

From the Langmuir isotherm we get that  $Q_o=0.719$  mg/g and  $b= 1.10$  dm<sup>3</sup>/mg ( $K_L \equiv b$ ). On the other hand,  $R_L$  values are calculated with the next equation:

$$R_L = \frac{1}{1 + K_L C_o} \quad \text{Ec. [5]}$$

They range between 0.177 and 0.035, indicating a favorable adsorption.

## CHEMICAL OXIDATION WITH NACLO AND INHIBITION EFFICIENCY

After the oxidation pretreatment was performed on the carbonaceous matter, a portion of it (10 grams) was taken and put in contact with a synthetic solution of 15 mg Au/L. Figure 12 shows the results of gold adsorption by the oxidized carbonaceous matter with stoichiometric quantities and 10% excess of NaClO.

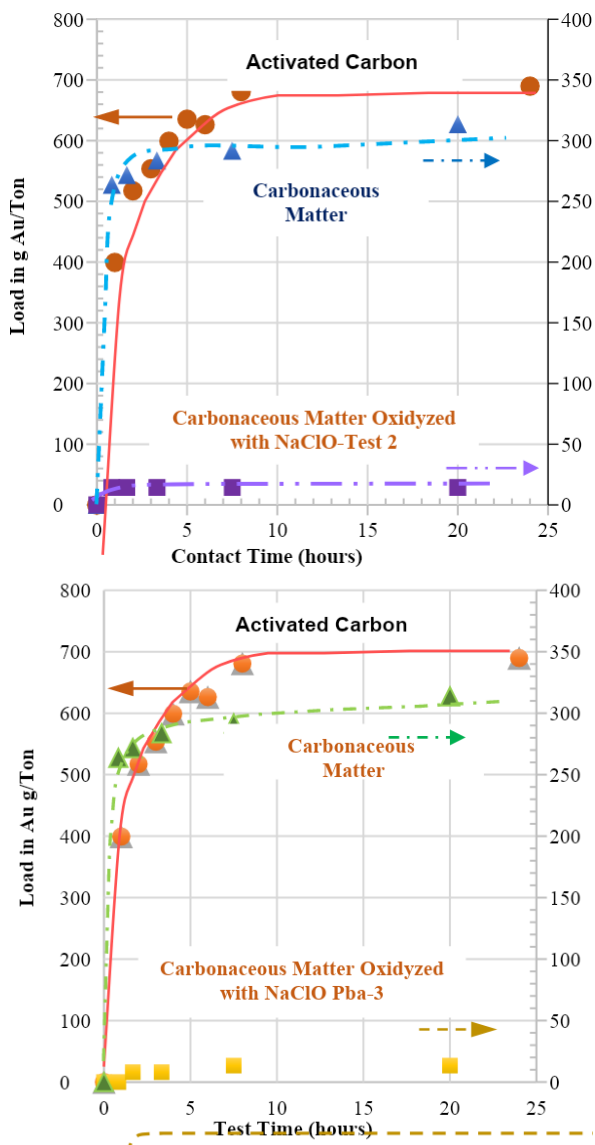


Figure 12.- Adsorption curves on carbonaceous material oxidized with NaClO.

The adsorption inhibition by the carbonaceous matter, after oxidizing it, both with the stoichiometric amount and with 10% excess, is 95%. Table 4 summarizes the gold loadings in g Au/Ton vs. contact time.

Table 5 summarizes the elemental chemical analyzes of the carbonaceous matter before and after oxidation, while Figure 13 shows the reduction in the percentage of organic carbon.

The FTIR characterization of the floated carbonaceous matter (FloatedCM) shows a silica composition that is observed in the elongation vibrations of the  $\nu$ Si-O-Si and  $\delta$ Si-O lattice at 1029 and 911  $\text{cm}^{-1}$ ; the presence of hydrating water is observed at 3426  $\text{cm}^{-1}$  ( $\nu$ OH), as well as the presence of isolated silanols at 3609 $\text{cm}^{-1}$ . These bands show a sample with major silica composition, the presence of organic matter is evidenced by weak signals corresponding to  $\nu$ C-H between 2900-2500  $\text{cm}^{-1}$ , bands corresponding to acid-type carbonyl groups were observed at 1700  $\text{cm}^{-1}$ . 1; while the oxidized matter shows essentially the same silica composition with a higher intensity of vibrations corresponding to acids that shift to 1802  $\text{cm}^{-1}$ . This suggests the condensation of these groups to anhydrides. The presence of alkene groups is evidenced in the oxidized matter with the vibration of  $\nu$ C=C at 1584

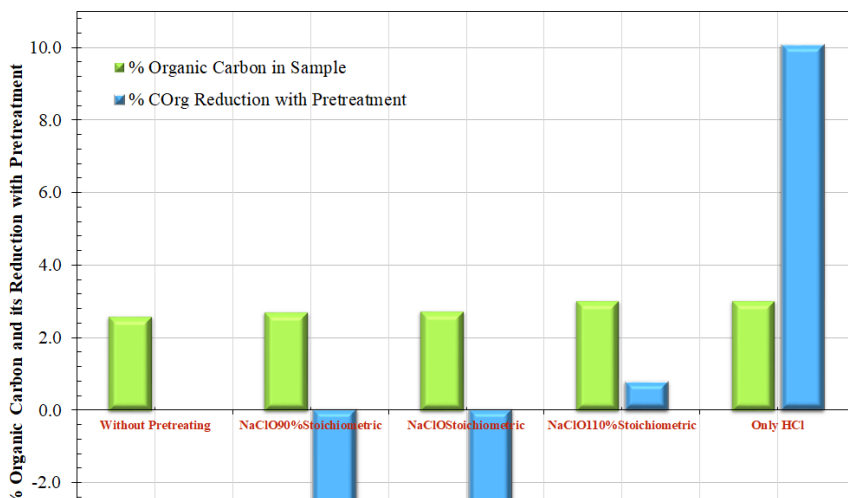
Sample	Sampling time (hour)	Conc. mg Au/L	mg of Au in sol.	mg of adsorbedAu	mg of adsorbedAu accumulated	Loadingmg Au/gCM*	Loading g Au / Ton CM
1	0.00	14.45	5.78	0.00	0.00	0.000	0.00
3	1.00	14.52	5.81	0.00	0.00	0.000	0.00
4	2.00	14.32	5.73	0.08	0.08	0.008	8.10
5	4.00	14.39	5.75	0.00	0.08	0.008	8.10
6	9.00	14.25	5.70	0.05	0.13	0.013	13.49
7	24.00	14.32	5.73	0.00	0.13	0.013	13.49

Table 4.- Results of loading carbonaceous matter after being oxidized under: (a) pH of 5, adjusted with hydrochloric acid (HCl), (b) 100 g of carbonaceous matter with 2.58% Corg, (c) 600 mL of solution and (d) 32.5 grams of NaClO.

SAMPLE DESCRIPTION	Essay %								
	Ag,g/T	Zn	Cu,ppm	Fe	As	Sb,ppm	Corg,	CTot,	S
Initial composite of carbonaceous material, without pretreatment	25.70 0	0.35 6	622	1.62	0.12	567	2.59	4.42	2.20
Pba.1-Oxidation Chemistry: T=35°C, NaClO=25 g, M <sub>o</sub> =100 g, M <sub>f</sub> = 92.4 g	22.08 4	0.09 0	51	1.97	0.08	274	2.49	3.87	1.71
Pba.2-Oxidation Chemistry: T=35°C, NaClO= 32 g, M <sub>o</sub> =100 g, M <sub>f</sub> = 80.6 g	15.54 8	0.07 6	52	2.04	0.09	258	2.49	3.44	1.76
Pba.3-Oxidation Chemistry: (10% stoichiometric excess), M <sub>o</sub> = 100 g, M <sub>f</sub> = 87 g, pH <sub>f</sub> = 4.66	13.05 0	0.07 6	55	2.03	0.09	283	2.61	3.11	1.66
Carbonaceous Matter Sample: 6 mL HCl + 300 mL H <sub>2</sub> O+ 100 g M.C. pH=5, M <sub>f</sub> =94.4 g	21.14 6	0.33 8	49	2.06	0.09	251	2.85	4.50	2.11

Table 5.- Elemental chemical analysis of the carbonaceous matter before and after oxidative pretreatment with NaCl.

Test No	% Corg	% ReductionCOrg
Without Pretreatment	2.59	0.00
NaClO75%Stoich	2.69	-4.03
NaClOStoich	2.71	-3.74
NaClO110%Stoich	3.00	0.77
Only HCl	3.02	10.07



(\*) CM: Carbonaceous matter.

Figure 13.- Percentage of organic carbon and its reduction, before and after oxidative pretreatment with NaClO in acidic medium.

cm-1; both materials showed the presence of C-S groups with the vibration at 692 cm-1 corresponding to the  $\nu$ SCSSCS. See Figure 14.

## **BLINDING OF CARBONACEOUS MATTER**

The blinder tests began with amounts of 60 and 250 g of PROL/Ton, typical dosages of ore concentration processes, e.g., flotation. However, and since a blinder is intended to adsorb and block the surface of the carbonaceous matter, the area of the amount of organic carbon contained in 100 grams of carbonaceous matter was estimated and the blinder dosage was increased to 80 kg/Ton. Even under these dosages, the inhibition of carbonaceous matter does not appear to be efficient. Table 5 summarizes the concentrations of the solutions contacted with one hundred grams of carbonaceous matter, which was pretreated with blinder for 12 hours.

## **CONCLUSIONS**

This study has focused mainly on determining the essential characteristics of the carbonaceous matter associated with precious metals, as well as the preg-robbing potential or activity that it may exhibit. The former is with the purpose of deepening in the mechanism of gold adsorption by this material, and also establishing pretreatment conditions that allowed obtaining favorable results in the inhibition of the activity of the carbonaceous matter during the precious metal recovery process.

Having a considerable amount of carbonaceous matter concentrate made possible defining the size of its pores, a size that would classify it as a macroporous material, similar to activated carbon. Regarding its activity or adsorption capacity for gold cyanides, it is also high, being approximately

half that of activated carbon. Of the pretreatments studied, chemical oxidation with hypochlorous acid (HClO) proved to be the most efficient, reducing the adsorption capacity by 95%. Due to the basic nature of these gold ores, it would be important to consider the possibility of oxidizing them in a basic medium, the hypochlorite ion (ClO<sup>-</sup>) and the hypochlorous ion (HClO) have similar oxidation potentials, which would make it possible to manage without an acid. The chemical and FTIR analyzes of the chemically pretreated carbonaceous matter indicate that the coal is not consumed at CO<sub>2</sub>; as established in the literature, the inhibition of its activity would be the result of its transformation to other forms of non-activated carbon. Regarding the blocking of active sites through the use of a blinder, the large areas associated with carbonaceous matter could be one of the reasons why, even at the high dosages of blinder used (25 kg/ton), we were unable to inhibit adsorption. Regarding this observation, it is possible that not only the organic carbon shows preg-robbing activity, but that the total material is showing this preg-robbing activity.

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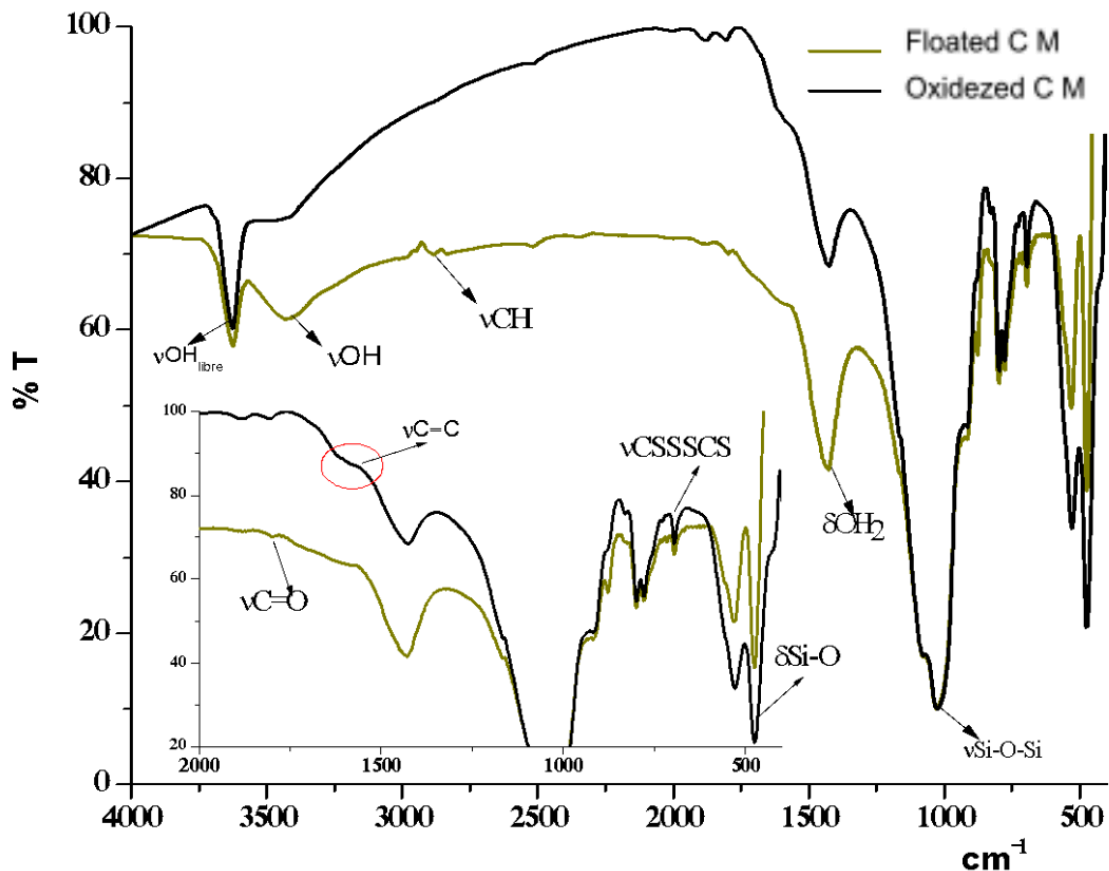


Figure 14.- FTIR characterization of the floated and oxidized carbonaceous matter.

Test No	PROL-40 Dosagekg/Ton	AbsorbanceSol. 24 hours	Conc. Sol.mg Au/L	Initial Conc. mg Au/L	Adsorbed Au mg	% Adsorbed
1	0.06	0.080	0.15	14.45	14.30	98.98
2	0.25	0.090	0.51	14.45	13.94	96.37
3	25.00	0.095	0.69	14.45	13.76	95.02
4	80.00	0.106	1.08	14.45	13.37	91.91

Table 5.- Results of gold adsorption on carbonaceous matter pretreated for twelve hours with different amounts of PRO-40 blinder.

## REFERENCES

- Gómez, A. A. V. (2016). Evaluación de la oxidación química (HOCl) de la materia carbonosa como pretratamiento para recuperar los metales preciosos asociados Departamento de Ingeniería en Minas, Metalurgia y Geología. Guanajuato, México, Universidad de Guanajuato. **Licenciatura:** pág.: -1-98.
- Goodall, W. R., J. D. Leatham, et al. (2005). "A new method for determination of preg-robbing in gold ores." *Minerals Engineering* **18**(12): 1135-1141.
- Hausen, D. M. yC. H. Bucknam (1984). Proceedings of the Second International Congress on Applied Mineralogy in the Minerals Industry. Study of preg robbing in the cyanidation of carbonaceous gold ores from Carlin, Nevada, Los Angeles, California, Metallurgical Society of AIME.
- Marsden, J. yI. House (2006). Oxidative Pretreatment. The Chemistry of Gold Extraction. Colorado, USA, Society for Mining, Metallurgy, and Exploration: 185 - 188.
- Miller, J. D., R. Y. Wan, et al. (2005). Preg-robbing gold ores. *Developments in Mineral Processing*. D. A. Mike yB. A. Wills, Elsevier. **Volume 15:** 937-972.
- Salazar, M. M., A. M. A. Corona, et al. (2017). Reporte Técnico: Evaluar el pro-40r en molienda previo a la flotación selectiva de la mena polimetálica de Saucito, Zac. Guanajuato, Universidad de Guanajuato, Departamento de Minas: pág.: 1-11.
- Stenebråten, J. F., W. P. Johnson, et al. (1999). "Characterisation of Goldstrike Ore Carbonaceous Material, Part 1: Chemical Characteristics." *Minerals and Metallurgical Processing* **16**(3): pág. : 37-43.