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Abstract: The improvement of the flotation of acanthite fines from a finely disseminated ore through the addition of sodium hexametaphosphate (SHMP) as the dispersant has been studied in this work. This study was carried out on the silver scavenger concentrate from the Fresnillo concentration plant in Mexico. The experimental results have shown that the dispersion processing by adding SHMP as the dispersant greatly increased the separation efficiency and the flotation rate of acanthite fines from the ore. This increase was much more remarkable for smaller mineral particles. It has been found that the improvement might be attributed to the fact that SHMP increased simultaneously the electric double layer repulsion and steric repulsion between minerals (valuable and gangue) particles in aqueous suspensions upon the adsorption of polymetaphosphate anions on the mineral surfaces, and thus eliminated the hetero-coagulation of the fine mineral particles in the aqueous ore suspension.

Keywords: Acanthite, fine mineral particles, froth flotations, sodium hexametaphosphates

INTRODUCTION

The mineral industry today is facing an increasing amount of finely disseminated metallic ore, which requires fine grinding to liberate valuable

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minerals before any beneficiating process can commence. This grinding would produce a large amount of fine mineral particles, leading to a hetero-coagulation of fine particles of valuable and gangue minerals in aqueous suspensions in the most of cases (1,2). The hetero-coagulation not only applies to fine mineral particles, but also to between fine and coarse particles. The latter is termed as slime coating (3,4).

Hetero-coagulation of valuable and gangue mineral fine particles in aqueous suspensions is very detrimental to the separation efficiency (concentrate grade and recovery) of any beneficiation process. If the hetero-coagulates are collected into the concentrate, the grade of the concentrates would be lowered; if the reverse is true, the recovery would be reduced. Accordingly, an effective dispersion processing is really needed to apply to prevent mineral particles from hetero-coagulation in case there are a large amount of fine mineral particles in ore suspensions. The dispersion processing is just like grinding to liberate valuable minerals from gangue minerals, and thus might greatly improve the following beneficiation processes.

The dispersion of mineral fines in aqueous suspensions is usually realized through the addition of specialized dispersants and the adjustment of the pH value. The mechanisms of the dispersion are through the adsorption of the dispersants on mineral surfaces to increase the repulsive interaction between particles in aqueous suspensions. The interaction could be electrical double layer repulsion, steric repulsion, and hydration repulsion. Based on the repulsion between particles, dispersion processing can be classified as electrostatic dispersion, steric dispersion, and dispersion by hydration forces (5,6). For example, sodium silicate increases the absolute value of zeta potential of apatite and hematite particles upon its adsorption and thus the electrical double layer repulsion between the particles, producing an electrostatic dispersion in the aqueous mineral suspension (7).

The Fresnillo concentration plant, which is located in the Zacateca state of Mexico, is the most important producer of silver concentrate in Mexico. In this plant, froth flotation with dithiophosphates as the collector is used to concentrate silver sulfide (majority of acanthite) and galena together. The silver flotation circuit consists of a one-step rougher flotation, a one-step scavenger flotation, and a three-step cleaner flotation, in which the scavenger concentrate was recirculated to the rougher flotation without any treatment. The final concentrate assays about 36 kg/ton Ag. The SEM (Scanning Electronic Microscope) study has found that acanthite in the scavenger concentrate are highly and finely disseminated with gangue minerals (8). This recirculation would be detrimental to the flotation circuit due to reduction of the concentrate grades, silver recovery and the capacity of the circuit. In order to improve the flotation circuit, the scavenger concentrate has to be reground to liberate the acanthite particles. In our previous paper (8), we have presented a new process, regrinding and floc-flotation, to beneficiate the silver scavenger concentrate. The experimental results have shown that this process was effective to concentrate acanthite fines from the scavenger concentrate, and thus could greatly improve the flotation circuit of the silver sulphide minerals.

The regrinding of the silver scavenger concentrate would produce a large amount of fine particles. As already stated, in fine particle ore slurries there is often a hetero-coagulation of valuable and gangue mineral particles. Accordingly, the flotation of the reground scavenger concentrate might be improved by applying a dispersion processing.

Although there is a great deal of information on the dispersion processing of mineral fines in aqueous suspensions, few reports have concerned the role of dispersion processing in the flotation of silver sulfide minerals. In this work, we first studied the hetro-coagulation of mineral fines in the aqueous ore slurry of the reground scavenger concentrate by means of a Scanning Electronic Microscopy (SEM). Then, we attempted to use sodium hexametaphosphate (SHMP) as the dispersant to eliminate the hetero-coagulation before the floc-flotation of acanthite fines from the reground scavenger concentrate. The objective of this work is to improve the flotation of the acanthite fines from reground scavenger concentrate through adding SHMP to eliminate the hetero-coagulation of mineral fines in the ore suspension.

EXPERIMENTAL

Materials

The silver scavenger concentrate sample used in this work was collected from the silver flotation circuit of the Fresnillo flotation plant. After being filtrated and dried at 45°C, the sample was divided and then reserved in a nitrogen atmosphere to prevent from being oxidized. It assayed 3.56 kg/ton Ag, 4.26 g/ton Au, 1.45% Pb, 8.05% Zn, 0.36% Cu, and 6.25% Fe. The particle size distribution was determined by using a Shimadzu SALD-1100 laser diffraction particle size analyzer, having the d_{80} (diameter at 80% cumulative undersize) of 82 μm.

The pure acanthite used for electrokinetic measurement was collected from the Fresnillo mine. The chunk acanthite was crushed by a hand hammer, and then was purified by hand sorting by means of an optical microscope. Then, the coarse acanthite particles were finely ground using a vibrating cup mill to be minus 10 μm. The purity of the final acanthite sample was about 97%.

In this work, Aerophine 3418-A (a commercial product of dithiophosphates) from CYTEC industries was used as the collector of silver and lead sulfide minerals. Zinc sulfate ($ZnSO_4$) and sodium cyanide (NaCN) as depressants and SHMP as dispersant were from J. T. Barker with analyzed purity. Kerosene was from Fisher Scientific, which was prepared as an oil emulsion through ultrasonic treatment before use. Sodium hydroxide from J. T. Barker with analyzed purity was used to adjust the slurry pH. Frother IQ-320 used in this work was obtained from Industria Quimica de Mexico.

Tap water was used throughout the flotation tests. The water used for electrokinetic measurements was distilled first, and then treated by passing the resin beds and a 0.2 μm filter.

Experimental Methods

In this work, a stirred mill filled with 2 kg 1/4″ steel balls was employed for the fine regrinding of the scavenger concentrate sample. The regrinding was performed on 500 g solid and 500 ml water at the revolution of 360 rev/min for 5 min in the presence of 100 g/ton NaCN and 1 kg/ton $ZnSO_4$ as the depressants of pyrite and sphalerite particles. In some cases, SHMP was also added as dispersant during the grinding. The reground ore slurry was diluted to 25% solid concentration, and then transferred to a conditioning tank of 20 cm inner diameter with six baffles of 1 cm width. The stirring shaft was equipped with a cross-shape impeller of 6 cm length. The slurry was first adjusted to pH 8 by using a sodium hydroxide solution, and then was strongly conditioned at 900 rev/min for 10 minutes while 20 g/ton Aerophine 3418 (collector) and 200 g/ton kerosene emulsion (promoter) were added, and then was strongly conditioned at 900 rev/min for 10 minutes while 20 g/ton Aerophine 3418 (collector) and 200 g/ton kerosene emulsion (promoter) were added. This treatment led to the formation of hydrophobic flocs of fine acanthite and galena particles in aqueous suspensions. The ore slurry with the hydrophobic flocs was transferred to a 2 liter Denver flotation cell. With 30 g/ton IQ-320 as frother, acanthite and galena fines were floated in the form of flocs, which is termed as floc-flotation. In this work, the dosages of the depressors, the collector and the promoter, and the pH value were selected on the basis of the industrial practices in the Fresnillo plant and the laboratory study for the floc-flotation described in our previous paper (8).

A Philips MICROSPEC WDX electronic scanning microscope was used for the observation of the coagulation and dispersion of fine mineral particles in the ore slurry.

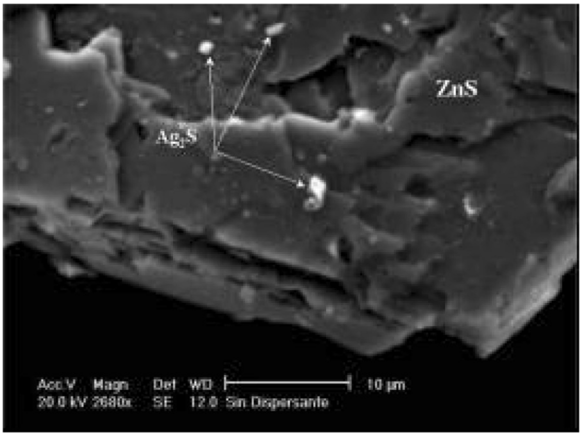
Zeta potentials of acanthite particles in aqueous solutions were determined using a Coulter Delsa 440SX instrument, which is based on the electrophoretic light scattering technique.

RESULTS AND DISCUSSIONS

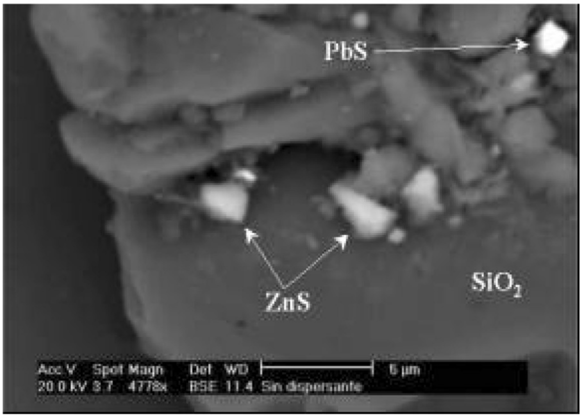
The hetero-coagulation or slime-coating in the slurry of the reground scavenger concentrate has been observed by using SEM in the present work. The samples were prepared by the following procedure: first, 10 ml of the reground scavenger concentrate slurry was collected, followed by a dilution with distilled water to 0.5% solid concentration while the pH value was kept unchanged; then, a drop of the diluted slurry was put on a metallic pin; after drying in air, the sample was covered by carbon to be ready for SEM studying. Figure 1 shows the SEM images of the hetero-coagulation in the reground ore slurry, in which the minerals were identified by using the X-ray fluorescence spectrometer attached to the electronic scanning microscope. As it can be observed in Fig. 1a, acanthite fines (the particle size of 1 to 2 μm) coated a coarse sphalerite particle, which is a typical slime-coating (a specific hetero-coagulation). Figure 1b shows the hetero-coagulation of galena, sphalerite, and quartz particles, in which galena and sphalerite fines (the particle size of 1 to 5 μm) coated a coarse quartz particle. If the percentage of galena fines on the quartz surface or acanthite fines on sphalerite surface is high enough, the hetero-coagulate might be floated and then be collected into the concentrate, leading the silver grade of the concentrate to be reduced. If the percentage is low, the silver mineral particles might loss in the tailing. Therefore, this phenomenon is very harmful for the beneficiation of the acanthite fines.

In order to eliminate the hetero-coagulation in the reground scavenger concentrate slurry, 5 kg/ton SHMP as the dispersant was added while the scavenger concentrate was reground in the stirred ball mill. Figure 2 shows the SEM images of the mineral particles in the reground scavenger concentrate slurry after being treated by the dispersion processing. It can be seen from the graphs that there was no slime-coating on the coarse particles of sphalerite, pyrite, and quartz, and the surfaces were very clean. It indicates that SHMP is a very effective dispersant for the elimination of the hetero-coagulation of the mineral particles in the ore slurry.

The flotation kinetics of the reground scavenger concentrate were carried out in the absence or presence of SHMP (the dosage of 2 kg/ton), in order to study the role of SHMP in the floc-flotation of acanthite fines



(a)



(b)

Figure 1. SEM images of hetero-coagulation of mineral particles in the Fresnillo reground scavenger concentrate slurry.

from ores. The results have been illustrated in Figure 3. As it is noted, the flotation rate was much higher in the presence of SHMP than without any dispersant. At 20 seconds, 30% of silver mineral particles were floated in the presence of SHMP, compared with 15% recovery without any dispersant. Also, the maximum silver recovery was much higher in the presence of SHMP. The difference was about 20%. These results suggest that the addition of an appropriate dosage of SHMP could greatly improve the floc-flotation of acanthite fines from the reground scavenger concentrate through increasing the flotation rate and the maximum

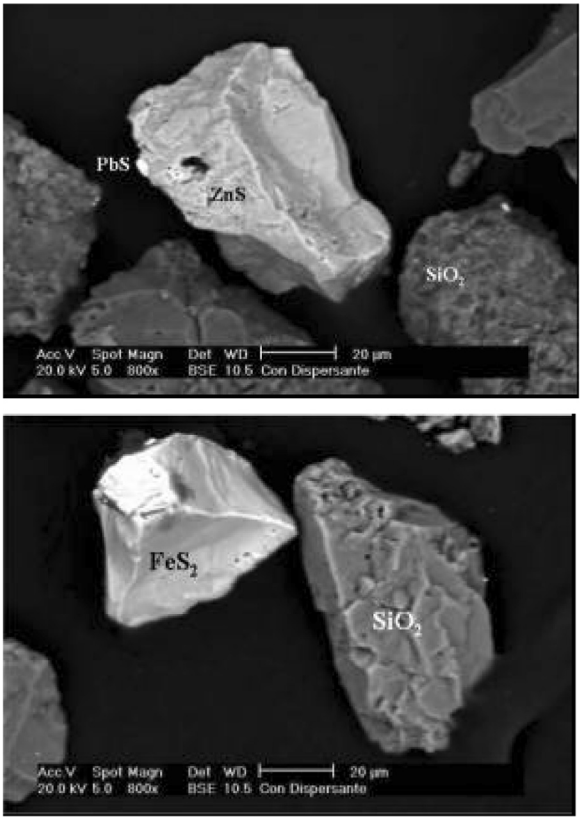


Figure 2. SEM images of mineral particles in the Fresnillo reground scavenger concentrate slurry with dispersion processing by adding SHMP.

recovery. This improvement might be attributed to the elimination of the hetero-coagulation of the mineral particles in the reground scavenger concentrate slurry through the addition of SHMP.

The positive role of SHMP in the floc-flotation of acanthite fines from the reground scavenger concentrate can also be observed from the graphs of Ag grade vs. Ag recovery at a different particle size of the feed ore, which are shown in Figs. 4 and 5. As is noted, the straight lines in the presence of SHMP locate above those in the absence of SHMP. Figure 4 illustrates the results at the feed ore size of 38% minus 10 µm and 49% minus 20 µm. As can be noted, at the same concentrate grade (7 kg/ton Ag), the silver recovery was about 40% and 81% in the absence and presence of SHMP, respectively. The recovery increase was 41% due to the addition of SHMP. At the same silver recovery of

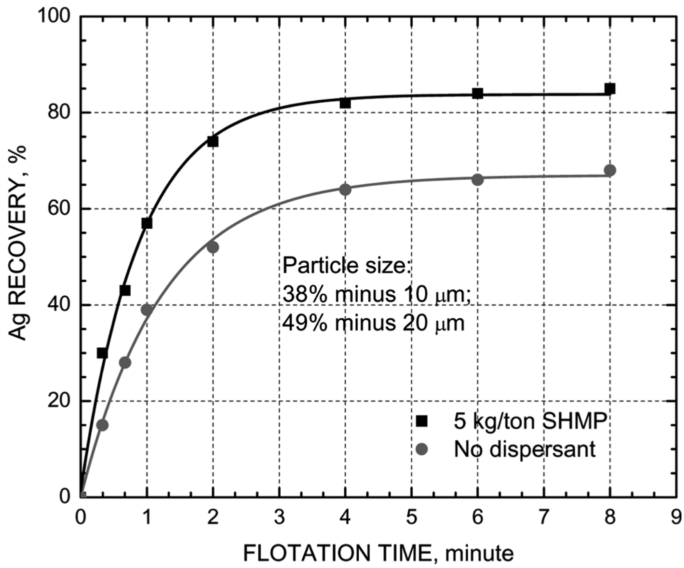


Figure 3. Kinetics of the floc-flotation of acanthite fines from the Fresnillo reground scavenger concentrate in the presence or absence of SHMP.

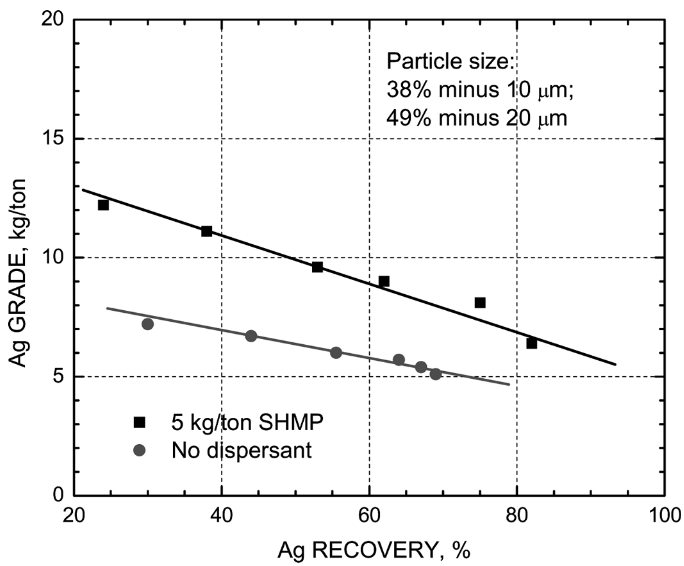


Figure 4. Silver grade vs. recovery curve from concentrates obtained by the floc-flotation of acanthite fines from the Fresnillo reground scavenger concentrate at the feed particle size of 38% minus 10 μm and 49% minus 20 μm in the presence or absence of SHMP.

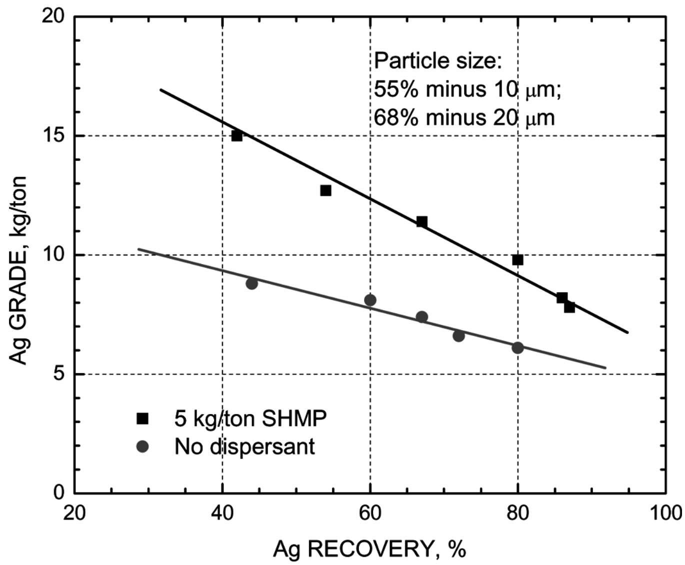


Figure 5. Silver grade vs. recovery curve from concentrates obtained by the floc-flotation of acanthite fines from the Fresnillo reground scavenger concentrate at the feed particle size of 55% minus 10 μm and 68% minus 20 μm in the presence or absence of SHMP.

60%, the presence of SHMP upgraded the concentrate about 3.5 kg/ton Ag. Figure 5 illustrates the results at the feed ore size of 55% minus 10 μm and 68% minus 20 μm. It shows that at the same concentrate grade (10 kg/ton Ag), the recovery was increased about 45% because of the presence of SHMP; at the same silver recovery of 60%, the SHMP addition upgraded the concentrate about 4.5 kg/ton Ag. These results indicate that the SHMP addition greatly improved the floc-flotation of acanthite fines from the reground scavenger concentrate. This improvement was much stronger if a higher grade of concentrate is required. In addition, it can be seen from the two graphs that the positive effect of the dispersion processing on the floc-flotation of the acanthite fines closely correlated with the feed ore size. The finer the feed ore particles, the better was the separation efficiency. This observation might be attributed to the high liberation of acanthite from gangue minerals owing to the size reduction, as well as the high efficiency of the dispersion processing by SHMP. More fine particles in the ore suspension would lead to stronger hetero-coagulation, so that dispersion processing becomes more important for the floc-flotation of the silver mineral particles.

Sodium hexametaphosphate is typically a mixture of polymeric metaphosphates, of which the hexamer $(NaPO_3)_6$ is one, and is usually the compound referred to by this name. It is more correctly termed sodium polymetaphosphate $(NaPO_3)_n$. SHMP is widely used as a dispersant or deflocculant in a wide variety of industries, for example, the clay industry (9,10). It is an acceptable fact that SHMP acts as a dispersant through increasing the negative zeta potential of dispersed particles in media upon its adsorption on the particle surfaces and thus increasing the repulsion of electric double layer between the particles in the media (11).

Figure 6 illustrates the zeta potential of acanthite particles in aqueous solutions as the function of SHMP concentration at pH 8. It can be seen that the negative zeta potential of acanthite particles in aqueous solutions increased sharply with increasing SHMP concentration in the solution until it reached a constant around 6×10^{-4} mol/l SHMP. It indicates the adsorption of hexametaphosphate anions on the acanthite surfaces in aqueous solutions. This adsorption stopped if the SHMP concentration is over 10^{-4} mol/l. This result is in a good correspondence with the reports elsewhere for mineral particles of quartz, pyrite, clay, and sphalerite, etc. (2,12–14). Therefore, in the case of the Fresnillo reground scavenger concentrate slurry, the presence of SHMP could increase the negative

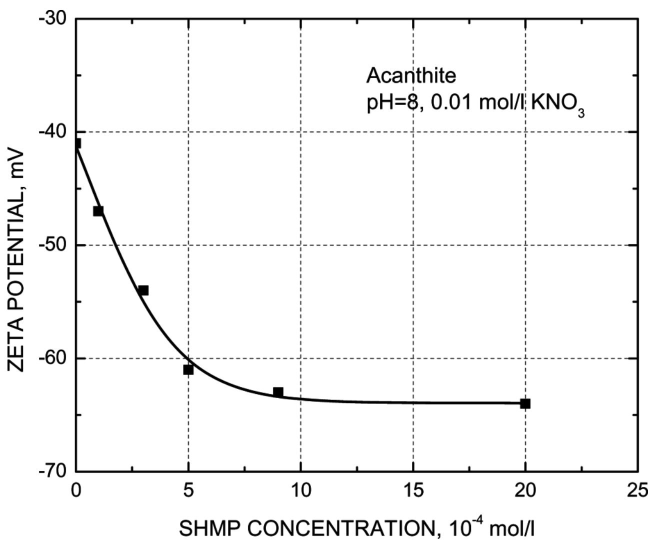


Figure 6. Zeta potential of acanthite particles in aqueous solutions as the function of SHMP concentration at pH 8.

zeta potentials of the particles of the minerals (valuable and gangue) and thus increases the electric double layer repulsion between the particles, leading to a good dispersion in the ore slurry.

The mechanism of SHMP as the dispersant in the Fresnillo reground scavenger concentrate slurry might be also due to the existence of steric repulsion between the mineral particles upon the adsorption of SHMP on the particle surfaces. As already stated, SHMP is a mixture of polymeric metaphosphates. The adsorption of polymetaphosphate on mineral particles would lead to the formation of a brush-like adsorption layer (15,16), resulting in a strong steric repulsion between the particles in aqueous suspensions. This repulsion would certainly help the stabilization or dispersion of the fine mineral suspension. Accordingly, SHMP improving the flotation of acanthite fines from the finely disseminated ore might be attributed to the considerable increases of electric double layer repulsion and steric repulsion between the particles of the minerals (valuable and gangue) in aqueous suspensions upon the adsorption of polymetaphosphate anions on the mineral surfaces.

CONCLUSIONS

1. The experimental results in this work have shown that the dispersion processing by adding SHMP greatly improved the flotation of acanthite fines from reground silver scavenger concentrate. This improvement was more remarkable if the particle size is finer. It might be attributed to the elimination of the hetero-coagulation of fine particles of acanthite and galena with gangue minerals (quartz, pyrite, sphalerite, etc.) in aqueous suspensions.
2. SHMP is an effective dispersant for the flotation of acanthite fines from finely disseminated sulfide ores.
3. The mechanism by which SHMP acted as an effective dispersant in the flotation might be due to that SHMP increased simultaneously the electric double layer repulsion and steric repulsion between minerals (valuable and gangue) particles in aqueous suspensions upon the adsorption of polymetaphosphate anions on the mineral surfaces.

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