Total flotation and backfill

Carlos Villachica León [1]

Kolektívna flotácia a zavážanie

Kolektívna flotácia a zavážanie (TFB) boli navrhnuté ako veľmi výhodný technologický postup pre dosiahnutie trvalého rozvoja pri podzemnej ťažbe polymetalických rúd v Peru. Táto technológia zlepšuje ekonomiku, značne znižuje väčšinu environmentálnych problémov, ktoré súvisia s prevádzkovaním jemných odpadov, kyslými vodami a nadmerným používaním chemikálií v úpravniach.

Kolektívna flotácia (TF) je založená na mimoriadne hrubom mletí a flotácii sulfidov neželezných kovov s výnimkou pyritu. Získaný produkt je kolektívny koncentrát s hmotnosťou 15-25 % hmotnosti vyťaženej rudy. Postup umožňuje veľmi jednoduchú schému aplikácie flotačného režimu a flotačného okruhu bez stupňov triedenia, zahusťovania a filtrácie. Úpravne pracujúce v TF režime sú tak malé, že ich je možné inštalovať v podzemí, čím sa značne znížia náklady a infraštruktúra potrebné pre manipuláciu s rudou a jej dopravou na povrch.

Odpady z TF prevádzkovanej v podzemí sú hrubozrné takže je možné ich zavážanie bez predchádzajúceho triedenia za účelom odstránenia jemných podielov. Tým sa znižuje množstvo odpadu, ktoré sa má čerpať na povrch až na 5-10 % hmotnosti vyťaženej rudy. Kolektívny koncentrát sa čerpá na povrch, kde sa premieľa a separuje na koncentráty Cu, Pb a Zn a pyritový koncentrát. V prípade Peru táto separačná jednotka (SP) môže byť vzdialená od miesta ťažby.

V prípade novej baníckej technológie TFB dochádza k dramatickým zmenám pri návrhu a projektovaní banského diela. Technológiu TFB je možné tiež úspešne aplikovať v jestvujúcich baniach, kde je nutné ťažiť hlboko uložené ložiská. V tejto práci sa popisujú skúšky s TFB technológiou pre Zn-Pb ložisko veľkej hĺbky. V týchto skúškach sa dosiahli výťažnosti pre Zn a Pb do 90 % pre koncentrát tvoriaci 15 % vyťaženej rudy pri hrubom mletí (25 % - 200 mesh) pri porovnaní s jemným mletím (57-60 % - 200 mesh) , ktoré sa aplikuje na štandardných úpravniach s produkciou selektívnych koncentrátov. Výsledky flotačných testov pri jemnosti mletia 18 % - 200 mesh je potrebné zlepšiť doplňujúcou gravitačnou úpravou. Testy perlokácie ukázali, že odpady z TF procesu je možné priamo použiť pre zavážanie banského diela.

Pri štúdiu kinetiky flotácie sa zistilo, že v porovnaní so štandardným flotačným okruhom je tiež výhodná a že pre TFB proces sa vyžadovali maximálne 2 flotačné cely s časom zdržania 10 minút. Stupeň kondiciovania sa vylúčil prípravou zmesi umožňujúcej simultánnu aktiváciu a nakoncentrovanie sulfidov Zn v rámci stupňa mletia. Vďaka tomuto postupu bolo možné uvažovať o TFB ako o technologickom postupe.

Key words: *flotation, concentrate, backfill.*

Introduction

Environmental management of tailings decisively affects the profitability of the Small Scale Mining (SSM) and also the Medium Scale Mining (MSM), due to peculiar geographic and mineralogical characteristics of Peruvian Mining. This document proposes the reengineering of polymetallic ores treatment taking into account new environmental demands, highly competitiveness of global market and the fact that this process has not suffered from important changes of its strategy or philosophy since froth flotation was invented at the beginning of past century.

Tailings management is probably the greatest environmental problem that the Polymetallic Mining (PM) faces but engineers exert the greatest control here because tailings are the result of an operation with parameters selected by to achieve a definite economic objective. In the past this objective was maximizing them profitability of mining operations. Now the same objective has to be achieved by minimizing environmental impacts. Therefore it is worthwhile to consider the reengineering of former strategies in order to accomplish the new objectives.

Mining history shows that changes in mineral processing, along the past century, have been aimed to improve the metal recovery, reduce the energy consumption, increase the treatment capacity, introduce the automation to reduce labor and improve process control, improve the product quality and so on. These changes have resulted in larger and more efficient equipments and processes that nevertheless perform the same function as before (crushing, grinding, flotation, thickening, filtering, etc.); there has not been, so far, an important change in the flotation strategy as to face with greater success the environmental demands.

Many underground PM mines have been converted to open pit mines in order to reduce operation cost through the mechanization and greater mining and processing throughput. Changes also involved wider galleries and trackless operations using trucks for mineral transportation. This practice resulted in the less selective mining and a greater usage of energy, water, chemicals and steel in the treatment plant, and the generation of greater amount of coarse (waste rock) and fine (tailings) solid residues along with larger volume of liquid effluents.

Larger and massive ore bodies are suitable to these methods while relatively thin orebodies are not. To achieve the profitability, SSM and MSM need a great technological change that reduces consederably the production cost and keeps the contamination within acceptable levels.

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During the last century, flotation technology has not been addressed to solve environmental problems caused by tailings they produce, and tailings storing and management has generally been in charge of civil and geotechnical engineers. We know that tailings physical stability depends strongly on the particle size and its capacity to retain water, but few metallurgists have taken the advantage of the high degree of control they have on this parameter. On the contrary, the particle size of tailings has decreased progressively since the introduction of gravimetric concentration to the modern flotation.

Technology can be easily transferred from one to another country as far as equipments, chemicals and processes refer. However mining and processing strategy depend on the geography, geology and mineralogy, climate, ecology, economy, population and social and cultural characteristics of each country. Thus TFB technology suits very much to Peruvian reality but could not be suitable to developed countries mining.

Flotation processing background

Froth flotation is a process based on surface chemistry, where particles of metallic sulfides are collected by air bubbles to become the concentrate while gangue minerals remaining in the pulp become the tailings (Gaudin, 1957).

Conventional flotation of polymetallic ores has three circuits to obtain individual concentrates of Cu, Pb and Zn. Flowsheet is complex and chemicals are added along the circuit in order to counteract the effect of chemicals added before (Figure 1). Thus Zn sulfides that were depressed in the Cu-Pb circuit by NaCN, $ZnSO_4$ and $NaHSO_3$ at pH 8.0, are reactivated with $CuSO_4$ and CaO, at pH 11.0; thereafter we acidify the pulp down to pH 6.0 to float pyrite. NaCN or K_2CrO_7 is added in the Cu-Pb separation circuit to depress Cu or Pb minerals. Average reagents (CaO included) consumption is 3.5 kg/t . Finally most of these chemicals go to final tailings.

Environmental disadvantages of this flotation strategy are:

- Usage of a great variety and significant concentration of polluting chemicals that finally are discharged into natural streams.
- Large volume of effluents, usually three times the weight of treated ore, that contains these chemicals.
- Technical difficulty to recycle tailings solutions due to the adverse effect of some of the chemicals and solution pH differences in final tailings (11.0) and first flotation circuit (8.0).
- Intensive usage of fresh water, that thereafter degrades and can hardly be used in agriculture or fishery.
- Since PM operations locate in high Andean regions, water impacts are more severe and the contamination extends many kilometers down stream before it is diluted by larger streams.
- Once mining is closed down most of tailings and wastes dumps remains stored at the surface, and their polluting and esthetical effects, and safety risks, last forever affecting the natural environmental and the life of local population.

Good liberation is indispensable to obtain an efficient separation of sulfides and the ore should be ground until each sulfide particle becomes almost monomineral. Thus, Cu ores are not associated to significant amounts of Zn nor Pb or gangue minerals and vice-versa. Conventional Selective Flotation (SF) implies grinding of all the ore down to very fine size (Figure 2). As a consequence, final tailings result as fine as 50 to 70 % -200 mesh in conventional polymetallic flotation plants.

Industrial grinding systems do not make difference among minerals and therefore a great proportion of gangue is unnecessarily ground. Also, valuable metallic sulfides are unnecessarily overground due to the density effect and hardeness.

Environmental and safety problems related to the tailings grain size are greater as this becomes finer and finer. Other issues related to grain size of tailings are:

- Decisively affects coarse tailings recovery and their drainage behavior. This in turn determines the weight of tailings placed as a hydraulic backfill and what has to be stored in the surface.
- Affects the physical stability of tailings dams since it establishes the amount of fines and its capacity to retain water
- Fine tailings also occupy greater space on a unit weight basis, and therefore affect a larger surface area.
- Fine grain size limits the proportion of coarse tailings that can be recovered to build the dike in tailings dams. Down stream type tailings dams for seismic areas like Peru, require much coarse tailings. Plants operating below 50% -200 mesh grinds cannot provide enough volume of coarse tailings to build these dams.
- New technologies as dry tailings storing require thickening and filtering operationm that are hindered by fine particles.
- Water Process Recycling is also hindered by fine particles.

Tailings amount from 75 to 95% of treated ore weight, depending on the head grade. Ground ore occupies up to 60% greater space that fresh ore, and this differences increases as grain size decreases. Thus tailings volume ranges between 110 to 160% of the mined volume.

In general, simple flotation systems that uses little variety of chemicals and pH values. Coarse grinding provides greater advantages in respect to tailings and plant effluents handling.

Particle size determines the metal recovery and concentrates quality. Also it determines the main equipment investment, energy and steel consumption, and therefore affects the operating costs. Coarsening the grinding decreases the investment and operating cost but also lowers markedly the metal recovery.

Therefore a new simple flotation system with very coarse grinding would have many environmental and economic advantages but requires a careful control to achieve an acceptable metal recovery and concentrate quality.

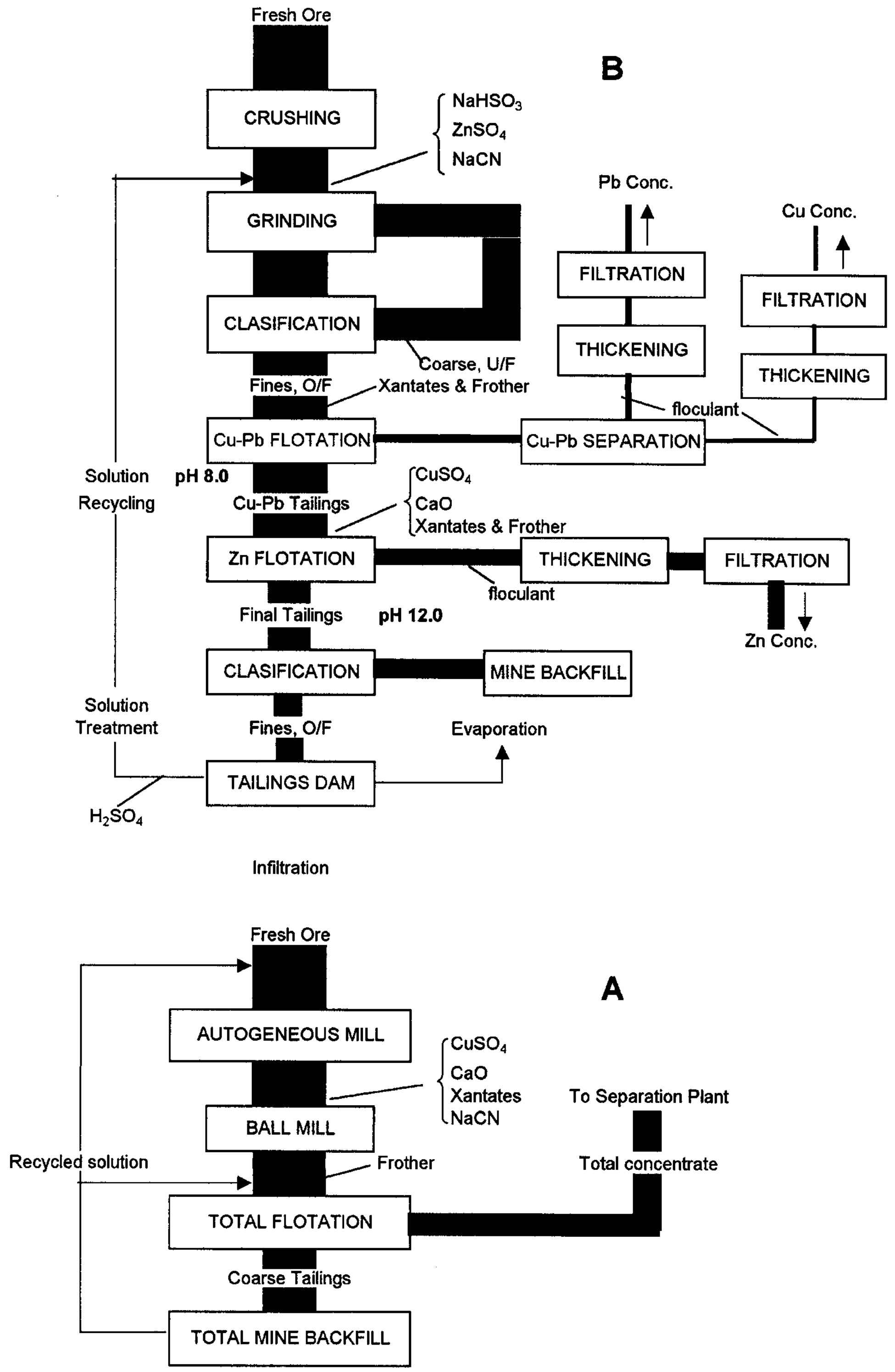

Fig.1. Principal regimes of flotation: A – Total flotation, B – selective flotation.
Obr.1. Základné režimy flotácie: A – kolektívna flotácia, B – selektívna flotácia.

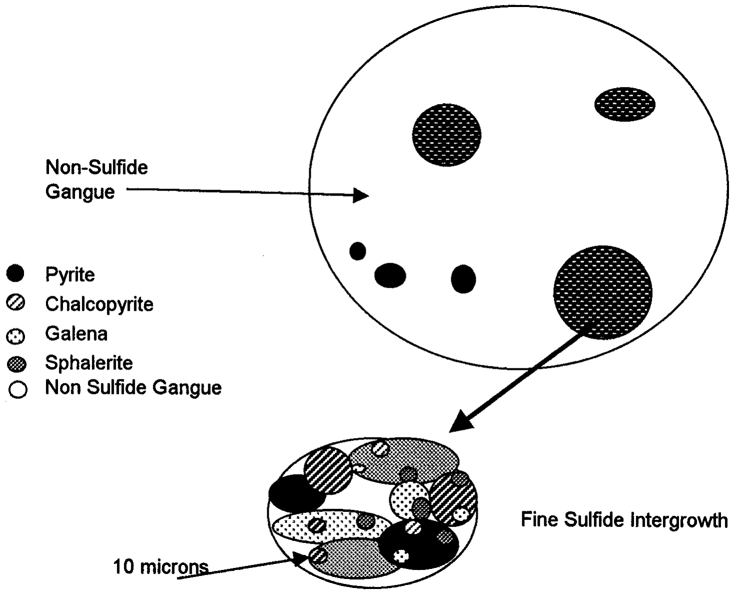

Fig.2. Fine intergrowth and liberation of minerals. Obr 2. Jemné prerastanie a uvoľňovanie minerálov.

Reengineering of polymetallic ores concentration

In Peru PM ores are processed to obtain individual concentrates of Cu, Pb and Zn, which are dewatered and transported either to La Oroya Smelter or to the port for exportation. Figure 3A represents the logistics of materials movement in present Selective Flotation Strategy (SF). Figure 3B on the other hand shows the logistic of the proposed "Total Flotation" Strategy (TF) the comparison of both diagrams suggests that there is not a sound reason for obtaining the individual Cu, Pb and Zn concentrates at the mine site if they are not marketed but far away (Villachica, Manzuneda, 1997).

The proposed TF gets similar or greater metal recoveries along with much coarser tailings than SF because liberation on intergrowth sulfides is not necessary to produce a Total Concentrate of sulfides (TC) (see Figure 1). Thus Total Flotation (TF) flow sheet and reagents scheme results are much simpler than SF even though we consider the Separation Plant (SP) in the TF case.

In selective flotation (SF), individual concentrates are the first final products obtained, on the contrary tailings are the first final product in total flotation (TF). TC obtained is an intermediate product that is further processed in a complementary Separation Plant (SP) in order to obtain commercial concentrates of Cu, Pb and Zn. Chemical characteristics of individual circuit preclude the process water recycling in SF while the simple reagent scheme facilitates the high recycling of process water in TF and SP plants. As a consequence, the fresh water usage and contaminated effluents are minimized in TF (zero discharge operation).

The separation plant is not only physically separated from the total flotation plant. It can also be located at other place, far away but closer to the final destinaton of commercial concentrates (see Figure 3). TC weight could be from 25 to 35% higher than the total weight of individual Cu, Pb and Zn concentrates obtained by SF.

Relevant metallurgical and economical factors

Most convenient location for the complementary SP depends not only on the distance to TF plant but also on environmental aspects of the site. In Peru the best location could be a dry climate area close to concentrates shipping port instead of the mining site itself. Higher transportation costs due to the larger weight of TC would increase the cost by about of 0.8 US$/mt of fresh ore, but could be balanced by the following:

- A great reduction in the energy and steel consumption in grinding due to the coarser grind (20-30 % instead of 50-70% - 200 mesh). Energy consumption in TF is less than 50% of SF. Steel consumption is also 40% lower. These savings (about 2 US$/mt) overcome the higher transportation costs of TC.
- A great increase in particle size of final tailings that provides a larger proportion of suitable backfill material. About 90% of this coarse tailings can be directly backfilled (without classification), whereas no more than 50% of conventional SF tailings can be backfilled after classification and surface storing of remaining 50%

of fines. Sometimes TF will not require surface disposal systems (tailings dams) while in other ones their size will be quite small. Coarse tailings management involves large savings, in the investment and operating costs compared to the conventional SF approach; savings costs averages are 2 and 8 US$/mt, respectively. Costs of tailings management increase as the size of operation decreases and the geographic difficulties increase, this being a common case in Peru.

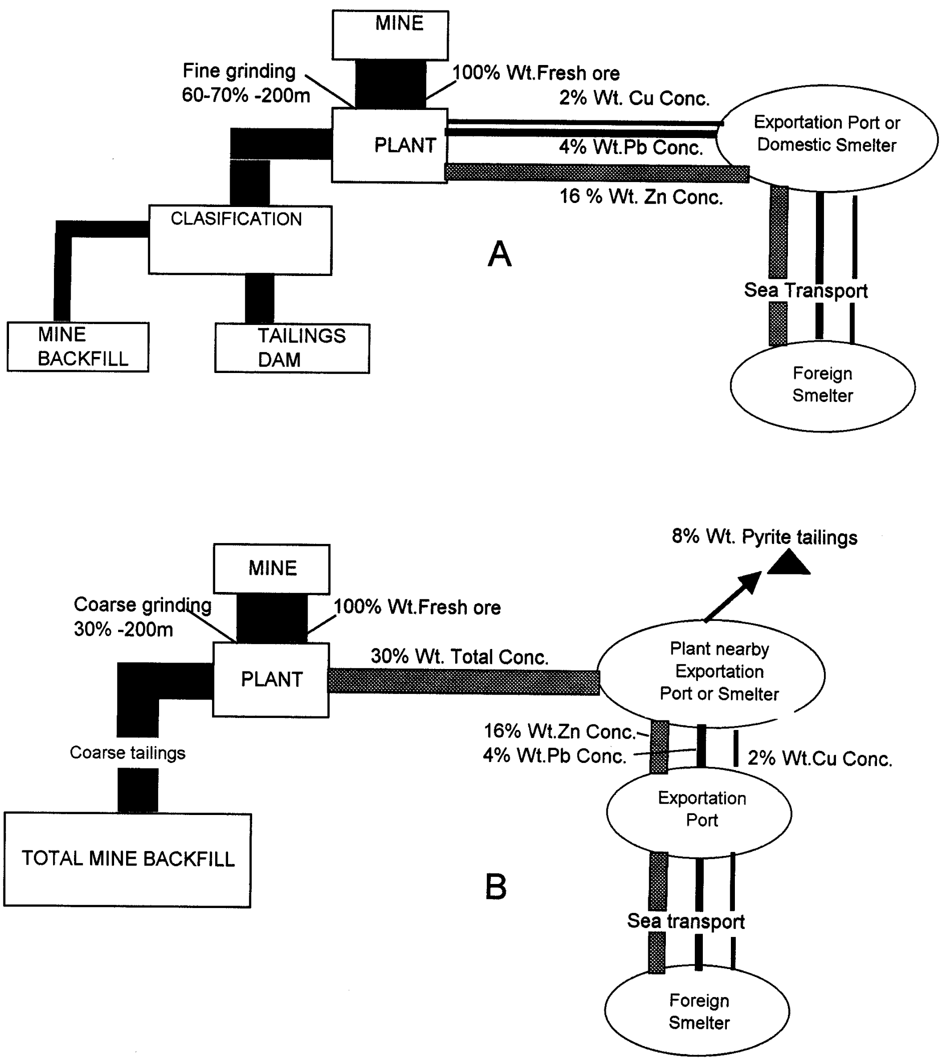

Fig.3. Schematic representation of selective flotation (A) and total flotation (B) strategies for treatment of polymetalic ores.
Obr.3. Schematické zobrazenie postupu selektívnej flotácie (A) a kolektívnej flotácie (B) pre spracovanie polymetalických rúd.

- A very simple and flexible circuit, having only one stage instead of three stages of each of the following processes: grinding, flotation, thickening and filtration. Control is made easier and the operation is more efficient and cheaper due to the flexibility against the common grade variation that occur in SSM and MMS operations. Flotation efficiency depends upon the sum of individual concentration of floatable sulfides rather than on the individual sulfides concentration, and we know that this sum varies much less than the later. These differences are also greater in small plants like SSM´s.
- A very simple reagent scheme, neutral pH and one single activator and depressant agent throughout the circuit. Reagent consumption in mine site plant is reduced from 3.5 to 0.6 kg/MT and the direct water process recycling is much favored; this reduces markedly the fresh water consumption. Coarse particle size of tailings and TC also favors very much the liquid-solid Separation and reduces the water recycling costs. A great part of collector and frother is recovered from TC dewatering while depressant is recovered from tailings dewatering; this cannot be done in conventional SF unless a complex water treatment plant is applied.
- Efficiency of sulfides separation in the complementary SP is higher than in conventional SF plant due t :

- Grinding to liberate sulfides is, metallurgically and energetically, more efficient when we regrind TC instead fresh mineral characterized by a high content of hard non-sulfide gangue, broader range of particle size and variety of minerals hardness.
- Excess of collector in bulk concentrates pulps hinders appreciably the complementary separation in conventional SF plants, while in TF this excess is removed due to dewatering and washing before shipping TC to SP.
- TC grinding creates new surfaces which become exposed to a suitable chemical environment (activators, depressants, modifiers, adsorbers, etc.) to the enhance separation efficiency in SP. On the contrary, in SF grinding is mostly done at the beginning and reground of concentrates is rarely done to develop new surfaces.
- Dewatering and exposure of minerals like galena ocurring in the TF practice promotes its oxidation and thus favors its depression to separate it from other sulfides .
- In the present practice, varying characteristics of bulk Cu-Pb concentrates (Cu, Pb, Zn, Fe contents, dilution, pH, liquid phase chemical composition, etc.) during operation hinder the separation efficiency. In TF practice, CT pulp characteristic are much more uniform and can be regulated in advance thanks to dewatering and repulping stages and chemical analysis of TC before it arrives to SP. This also reduces the cost of SP circuit automatation.

- TF Plant operates at a very low unit cost at the mine site. This is a great overall saving since thecost of energy, materials, chemicals, labor and services apply to 100% of the original ore. Thus, TF allows to profitably exploit and treat lower grade ores than SF, without the requirement of high throughput.
- In TF the higher unit cost is transferred to the Separation Plant, where it is on the other hand reduced due to metallurgical and location factors such as: previous S/L separation, sulfides regrind, less energy and reagents consumption, automatic controlled operation, and convenient location according to residues disposal, services and infrastructure. SP location at the mine site is rarely the most convenient option.
- Concentrate quality: metal recovery compromise that characterizes each single circuit within a SF plant causes important metal losses by the misplacement. Table 1 shows that Cu losses by misplacement to Pb or Zn concentrates ranges from 12 to as much as 61% of their content in the original ore. Also Pb and Zn misplacements to other concentrates are as high as 18 and 12%. Misplacement losses are even higher than metal losses in final tailings, and account about 80 million dollars/year. Nevertheless small size SF plants in SSM and MSM do not allow profitable recovering of these values. TF strategy, instead, allows it because SP operation can be optimized and automated thanks to a greater volume and metal value (300 to 400 US$/mt) of the TC as compared with the fresh ore (around 80 US$/mt) treated in SF plants. TF option is even more profitable if TC from several mines are treated in a single SP instead of having several small SP.

Table 1. Metal losses due to misplacement in Conventional Selective Flotation Plants(1995).
Tabuľka 1 Straty kovov v dôsledku znečistenia koncentrátov u klasických úpravní so selektívnou flotáciou (1995).

Mine	Misplacement to the wrong concentrate, % of fresh ore content		
	Cu	Pb	Zn
Casapalca	12	9	10
Yauliyacu	20	9	6
Austria Duvaz	23	14	5
Yauli	23	14	5
Chungar	31	10	3
Huarón	61	7	6
Santa Rita	31	8	7
San Miguel	55	19	12
Atacocha	49	6	3

- There exists a great variety schemes for sulfides separation, and several of them are applied to conventional SF with a relative success. Water steam, nitrogen with activated carbon, SO_2, among other somewhat sophisticated techniques have, not been applied in peruvian polymetallic plants due to the scale economy and technical factors pointed out above.

Cu-Pb separation by activated carbon (Villachica, 1979) gave excellent results (Table 2) for a very refractory bulk concentrate at the Pilot Plant scale; however, results were not as so good at the industrial plant due to a very high variability of bulk concentrate pulp. TF system overcomes this main inconvenience and this technique as well as another innovating ones can now be applied; on the other hand, activated carbon consumption is anticipated to be lower due to previous filtration and washing of TC. Recovery and individual concentrates quality will also be better than those obtained in conventional plants.

Table 2. Results of Cu-Pb separation, using NaCN-ZnO, without and with activated carbon (Yauricocha Mine).
Tabuľka 2. Výsledky separácie Cu-Pb pri aplikácii NaCN-ZnO bez a s použitím aktívneho uhlia (baňa Yauricocha).

Concentrate type	Without activated Carbon Metal content, %		With activated Carbon Metal content, %	
	Cu	Pb	Cu	Pb
Cu	13.5	8.0	21.0	1.0
Pb	5.0	42.0	0.8	62.0
Cu-Pb	6.0	23.0	6.0	23.0

- Flotation rate is directly proportional to the concentration of mineral species to be floated and is adversely affected by other sulfides which could float, while the non-sulfide gangue affects this rate in much less extent. In TF systems the sulfides and non-sulfide concentrations are the highest and lowest, respectively, that one can obtain in a real system. As a consequence, the total sulfide flotation rate is very high (although pyrite is still considered as the gangue).

Another important kinetical variable to be considered is the excessive pulp dilution after first cell in TF circuit, so that we introduce a densification of the pulp for the second cell. In a SF circuit we cannot easily introduce these densification stages. Required flotation time in TF is as short as 5-10 minutes as compared to 40-60 minutes required in the conventional SF.

- FT involves redesigning of some equipment and also few will be required in the new scheme. Second grinding stage will not be required in the TF plant, and regrinding of TC could use pebbles instead of steel balls considering low hardness of sulfides involved. Flotation machines, to efficiently handle coarse particles would probably be complemented with gravimetric concentration or froth column devices to float very coarse sulfides. On the other hand, either thickening or filtration stage would not be required because of TC particle size.

Experimental results of total flotation

I. Polymetallic ores

Table 3 and Figures 4 and 5 summarize results of TF tests carried out with polymetallic ores (Cu, Pb, Zn, Ag) from Cerro de Pasco and Morococha mines in Peru. Results are very promising even though the tests are preliminary.

Table 3. Preliminary Results of Total Flotation tests (recovery is referred to the content of metals in the fresh ore).
Tabuľka 3. Predbežné výsledky testov kolektívnej flotácie (výťažnosť je vzťahovaná k obsahu kovov vo vsádzke).

Parameter	Cerro de Pasco Ore				
Mesh of grinding, %-200m	30	40	50	60	70
Recovery in 3 minutes, %	86.5	92.6	92.1	93.6	90.3
Recovery in 10 minutes, %	94.2	96.3	96.7	96.8	96.5
Concentrate weight, 3 min.,% fresh ore	35.3	35.1	36.5	37.3	33.7
Concentrate weight, 10 min.,% fresh ore	42.3	39.7	42.1	42.2	40.8
Parameter	Morococha Ore				
Mesh of grinding, %-200m	30	40	50	60	70
Recovery in 3 minutes, %	87.7	87.0	89.6	86.5	87.5
Recovery in 10 minutes, %	94.8	95.5	96.0	95.6	95.6
Concentrate weight, 3 min.,% fresh ore	35.3	34.8	35.8	34.6	34.2
Concentrate weight, 10 min.,% fresh ore	42.3	43.9	43.9	43.3	41.4

Cerro de Pasco Ore

Head assay of this ore is : 0.1 %Cu, 4.7 %Pb, 6.6 %Zn, 4.9 oz.Ag/t, 19.1 %Fe

- At grinding as coarse as 30% -200 mesh TF recovers 94% of metallic value, in only 10 minutes of flotation. Recovery in 3 minutes (86.5%) is higher than that obtained with fine grinding and much longer flotation time in the conventional SF.
- At 40% -200 mesh grinding global recovery achieved is 93% in just 3 minutes and TC value is 340 US$/mt, while CT weight amounts as much as 35% of fresh ore.
- Pb that still remains in tailings is too coarse to be lifted by bubbles so that gravimetric or froth concentration, or suitable flotation machine for coarse grains would be necessary.
- Figure 4 shows that neither recovery nor quality is significantly improved with grinds beyond 40% -200 mesh, whereas conventional SF usually requires grinds of 60-70% -200 mesh to achieve maximum recoveries of Cu, Pb, Zn and Ag. Hence the coarse grind corresponds to a non sulfide gangue liberation.

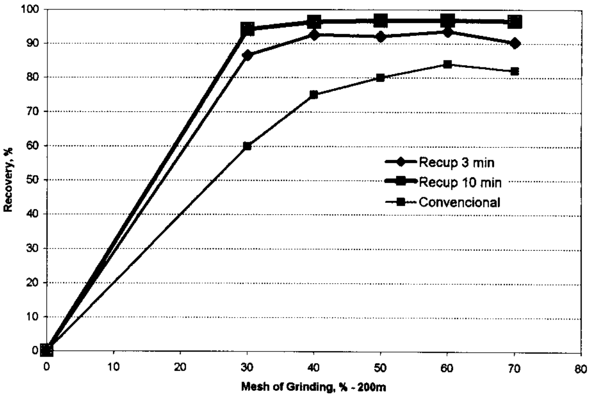

Fig.4. Total flotation of Cerro de Pasco ore .
Obr.4. Kolektívna flotácia rudy z ložiska Cerro de Pasco.

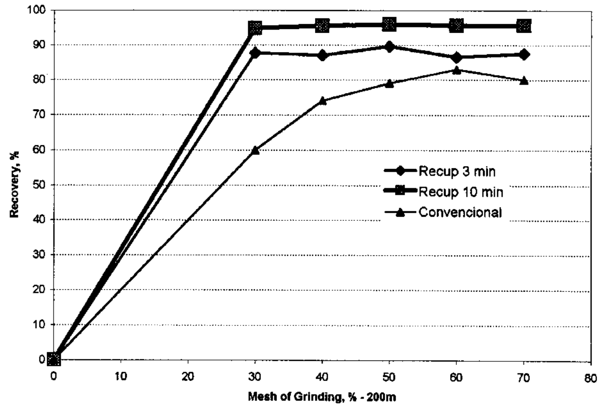

Fig.5. Total flotation of Morococha ore.
Obr.5. Kolektívna flotácia rudy z ložiska Morococha.

Morococha Ore

Head assay of this ore is : 0.6 %Cu, 2.7 %Pb, 6.7 %Zn, 10.4 oz.Ag/t, 19.4 %Fe

- At grinding as coarse as 30% -200 mesh TF recovers 95% of metallic value, in only 10 minutes of flotation. Recovery in 3 minutes (87.7%) is higher than that obtained with fine grinding and much longer flotation time in the conventional SF. CT weight results 35% of fresh ore, and 42% with 10 minutes, suggesting that pyrite depression must be improved. Value of TC is 446 - 403 US$/mt, respectively.
- Figure 5 shows that neither recovery nor quality is significantly improved with grinds beyond 30% -200 mesh, whereas conventional SF usually requires grinds of 60-70% -200 mesh to achieve maximum recoveries of Cu, Pb, Zn and Ag. Hence this coarse grind corresponds to non sulfide gangue liberation.

Results obtained with ores from most important polymetallic regions show that liberation of sulfide from non-sulfide gangue is obtained at grinds as coarse as 30% -200 mesh and corroborate the practical benefit of TF strategy. Therefore, obtaining a coarse worthless tailings can be achieved with a simple, cheap and fast process.

- Final tailings report only 30% of fines (- 200 mesh); this gradation enables a direct placement as hydraulic backfill of almost whole tailings. Also, this gradation allows surface storing as dry compacted tailings without requirement of expensive filtration.
- TC is coarse (below 30% - 325 mesh) as compared to individual Cu, Pb and Zn concentrates obtained with conventional SF (over 80% -325 mesh). This confirm that sulfides overgrinding occurs in SF. The TC concentrate can be dewatered very easily, and retains little water, while individual SF concentrates retain much water and increase the handling and transportation cost.

II. Zinc (lead) ore

TF strategy great advantages are more evident with polymetallics where Cu, Pb, Zn minerals are finely intergrowth. To extend its application we explored TF with Zn ore hosted in dolomitic rock in order to increase tailings particle size as much as possible. San Vicente mine is developing a very deep orebody that has to be trucked a long way to the surface and was proposed to explore the chance of installing a very simple TF plant in the underground; this TF plant would pump TC and excess of tailings to the surface through independent pipelines while most of TF tailings would be directly placed as the backfill.

Head assay of this ore is : 0.26 %Pb, 7.53 %Zn, 0.1 oz.Ag/t, 0.72 %Fe. This shows that the main value is Zn and it has a very low pyrite content. In the SF Plant the ore is actually ground to around 60% -200 mesh to produce a Pb concentrate and Zn concentrate and tailings are used for the backfill and Dam construction. As expected, they have problems to get coarse tailings. Zn recovery is about 90%.

TF test results, shown in Figures 6, 7 and 8, indicate that a good Zn recovery can be obtained at grinds as coarse as 23% - 200 mesh, with a very good Zn grade in TC. This grade (40 %Zn) results from a very low pyrite content in the fresh ore, so that TC weight only amounts 15% of fresh ore.

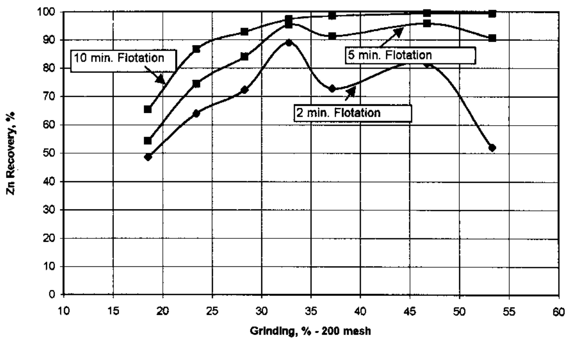

Fig.6. Total flotation of San Vicente zinc ore: recovery of Zn vs. particle size.
Obr.6. Kolektívna flotácia zinkovej rudy z ložiska San Vicente: výťažnosť Zn vs. veľkosť častíc.

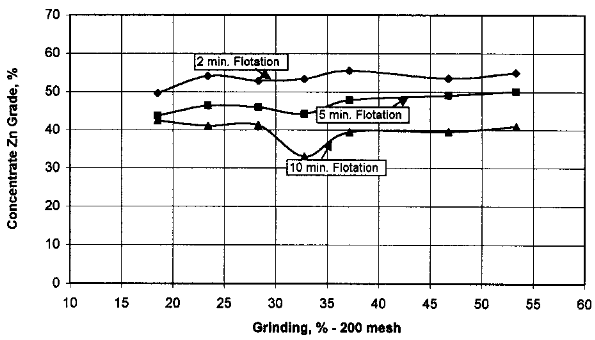

Fig.7. Total flotation of San Vicente zinc. Ore: concentrate Zn grade vs. particle size.
Obr.7. Kolektívna flotácia zinkovej rudy z ložiska San Vicente: kovnatosť Zn koncentrátu vs. veľkosť častíc.

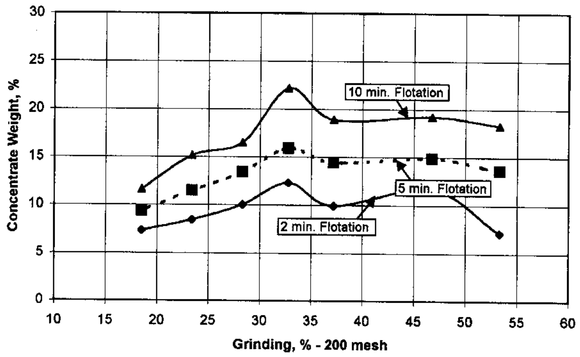

Fig.8. Total flotation of San Vicente zinc ore: concentrate weight vs. particle size.
Obr.8. Kolektívna flotácia zinkovej rudy z ložiska San Vicente: hmotnosť koncentrátu vs. veľkosť častíc.

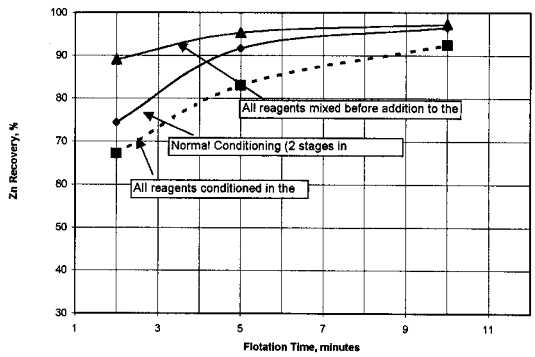

Fig.9. Total flotation of San Vicente zinc ore: different types of conditioning.
Obr.9. Kolektívna flotácia zinkovej rudy z ložiska San Vicente: rôzne spôsoby kondiciovania Zn.

Percolation tests carried out with TF tailings show that it can be either directly placed as the backfill or used for the dam construction. These results allow to solve coarse tailings demand and support the replacement of actual SF Plant.

To reduce the size of TF Plant we evaluated a different scheme for conditioning Zn-Pb ores since the conventional Zn conditioning would require twice as much volume as the whole flotation circuit. Results shown in Figure 9 indicated that the standard conditioning can be successfully replaced by preparing a mix of activator, lime and xantate and add it to the mill. Zn recovery obtained is even higher than using the conventional method, and the underground TF plant can operate with no conditioning stage.

Thanks to this, the TF plant becomes so simple and compact that it can be installed in a short space underground. Underground TF Plant will then consist of:

4 stages crushing and screening circuit (1 stage crushing if the SAG mill is considered)
1 stage ball mill grinding circuit
1 (2) large volume flotation cells
3 pumping lines for the total concentrate, excess of tailings and backfill each

Relevant environmental factors

TF offers several environmental advantages against environmental problems:

Acid Drainage

- Polymetallic tailings are highly pyritic. In SF most of tailings have to be stored at the surface because its fine gradation restricts the mine backfilling. TF leaves very little tailings for surface storing thanks to its coarse gradation; acid drainage is restricted in underground storing and can be definitely avoided after the mine is flooded and sealed.

- In SF, most pyrite is displaced to tailings and generates acid at the surface of mine site due to climatic factors. In TF an important part of pyrite is taken by the TC and will be discarded as tailings at the SP site. This site can be selected to restrict or avoid the acid drainage.
- Higher TC transportation costs due to pyrite content can be balanced by the lower investment and operating costs to control acid drainage during the operation and after mine closure.

Tailings Dam Physical Stability

- Physical stability of tailings dams depends very much on its content, and this depends on fine tailings content . TF tailings have the coarsest gradation obtainable in flotation schemes, so that the drainage and physical stability achievable are at maximum.
- TF places most of tailings in the underground. Therefore, the maximum stability is achieved due to the confinement within rock structures. Volume of remaining tailings stored at the surface is greatly reduced, and lowers the investment required to construct a safe structure. Smaller tailings volume have a better chance to be stored in available areas near the mine site.
- When using tailings as a material for the dam construction, TF provides the largest volume of coarse material obtainable in flotation schemes. This means a great saving and lower usage of earth for the same purpose.
- Tough topography, seismicity and hydrological characteristics of peruvian mining demand for very high safety factors for conventional tailings dams. Required down stream dams with flat slopes demand very large volumes of coarse tailings that conventional SF cannot provide. TF provides large volumes of coarse tailings while reduces the volumes of fine tailings to be stored.
- Using TF coarse tailings instead of earth for the dam construction precludes the excavation of the surface land, and doubles the dam storing capacity. Also, the surface area occupied and impacted by the tailings dam is reduced to a half.
- When a tailings dam fails, the extent magnitude is directly related to its size. By maximizing the underground placement, TF minimizes the risk and magnitude of damage in case of extreme events like earthquakes and floods.

Process Water Recycle

- TF achieves the greatest recycling of process water obtainable in flotation systems because of its very simple scheme and coarse tailings. Highest water recycling reduces very much the use of fresh water in the high Andes while in the SP high recycling is achieved by several filtration stages. Conventional SF pollutes water streams due to the complex reagent schemes and finer tailings that restrict dewatering and water process recycling.
- S/L separation of TF coarse tailings requires a simple equipment and low operating cost.

Relevant mining characteristics

Polymetallic mining is mainly done underground and creates empty spaces that are not filled completely. TF matches very well to underground mining:

- Empty mined spaces develop the underground instability that also affects surface lands and infrastructure. Conventional SF do not provide enough coarse tailings to fill up this spaces while some methods formely used suitable to completely fill mined areas require expensive amounts of cement. TF can provide all the tailings the backfill systems demands (Villachica, 1997).
- Tailings required for the mine backfilling should have good a drainage to shorten the mining cycle; TF coarse tailings involves a very short time for the placement, drainage and the consolidation.
- Using the hydraulic backfilling instead of earth or rock backfilling improves the underground air quality since no trucks are required to place the fill.
- TF can preferentially place acid-generating fraction of its tailings within underground areas and thus reduce the closure cost of tailings deposits.

Relevant economical and financial aspects

In Peru Cu, Pb and Zn concentrates are transported from the mine site to the port or domestic smelter in order to sell them (see Figure 3A). Conventional SF requires 3 to 5 kg/t of reagents and the steel consumption is

1.2 kg/t. Most of these materials are manufactured in the coast. Energy consumption is in the range of 30 kwh/t, and this figure varies according to the plant size, ore hardness, grind, and also the type and size of equipment. About 50% of total energy is spent in crushing and grinding circuits, while 30% is taken by the flotation circuit. Remaining energy is used in dewatering, and tailings disposal.

Most of MSM companies take the energy from the National Electrical System while others have their own hydroelectric one. SSM companies use expensive diesel generators. TF demands very little energy and means a better option than SF for SSM and MMS. In Peru almost all SSM mines do not operate since more than 15 years due to high operating costs rather than low metal prices. Environmental restrictions increase even more the operating cost and preclude the reactivation unless we introduce a great change that simultaneously reduces operating and environmental costs (Villachica, 1999). Advantages of TF strategy for reactivating SSM are listed below:

- Support financing for reopening closed operations, thanks to profitable and clean operation
- Lower operating costs enables exploiting lower grade ores and therefore increases economic mineral reserves without the requirement of additional exploration.
- Provides enough quantity of good quality tailings for mine hydraulic backfill, thus reducing the mining cost wherever the cut and fill method is used.
- Provides tailings with the excellent drainage index, so reducing the mining cycle time and increasing productivity.
- High flotation rate, simple flowsheet and low energy requirement of TF plant makes it very small and compact. Therefore, this type of plant can be installed underground to process fresh ore, pump out the TC pulp while most of coarse tailings is directly placed in empty areas.
- TF underground plant (TFUP), would reduce dramatically the mining operating costs (transport, labor, backfill, energy, ventilation, and environmental). On the other hand, TFUP would reduce dramatically the time and investment required to develop the mine and start to operate continuously. So far mining has been modernized by the progressively incorporated large drilling and haulage equipment. TFUP offers a new approach, that uses much less equipment to achieve the same capacity of production at a lower cost. Actual mining practice requires a long time consuming stage of construction of long and wide tunnels for the trucks to displace and transport ore to the SF plant; in the future we expect that the installation of TFUP derives in a narrow and short gallery for the TC and tailings pipeline, most of solids being handled by pumping.
- TF plant is much less expensive than a SF plant of similar capacity, therefore SSM companies can rise their treatment capacity from 100 to 800 t/day with a moderate investment.
- In this case, operating cost will be reduced very much due to the scale of operation, and lower unit consumption of energy, steel, chemicals, labor and services.
- The great environmental restriction that threatened SSM before, would no longer be a worry thanks to the adoption of this clean technology.
- Acid drainage would be minimized because pyrite backfilling besides total tailings backfilling.
- SP will produce high quality concentrates thanks to a highly automated and controlled operation that incorporates the most advanced separation technology.
- If SSM reactivation takes place as a consequence of TF strategy, then TC obtained in several TF plants can be processed by pressure leaching (PL) and electrowinning to obtain, directly, most metals. Hydrometallurgy route instead conventional smelting practice guarantees a much cleaner, simpler and more profitable operation. The PL plant coupled with the TF plant and Total Backfill mining would certainly be a highly competitive strategy for the treatment of polymetallic ores.

Conclusions

The proposed Total Flotation-Total Backfill (Figure 10) coupled with the treatment of total concentrate in an independent separation plant to obtain individual concentrates of Cu, Pb and Zn is a radical change of strategy to treat polymetallic ores. This option simultaneously provides great environmental and economic advantages as we basically change the conventional objective of liberating sulfides from each other to that of liberating the non sulfide gangue from all sulfides.

The TF plant is very simple and can be installed underground to operate there. This allows to handle TC, and tailings as a slurry and makes unnecessary the use of large haulage equipments and related infrastructure (tunnels). Low operating cost resulting from this innovation is also coupled with a much more rapid mine development.

TF is most suitable for challenges that peruvian mineralogy, geography, weather, ecology, infrastructure and economy poses but could be hardly suitable for other countries.

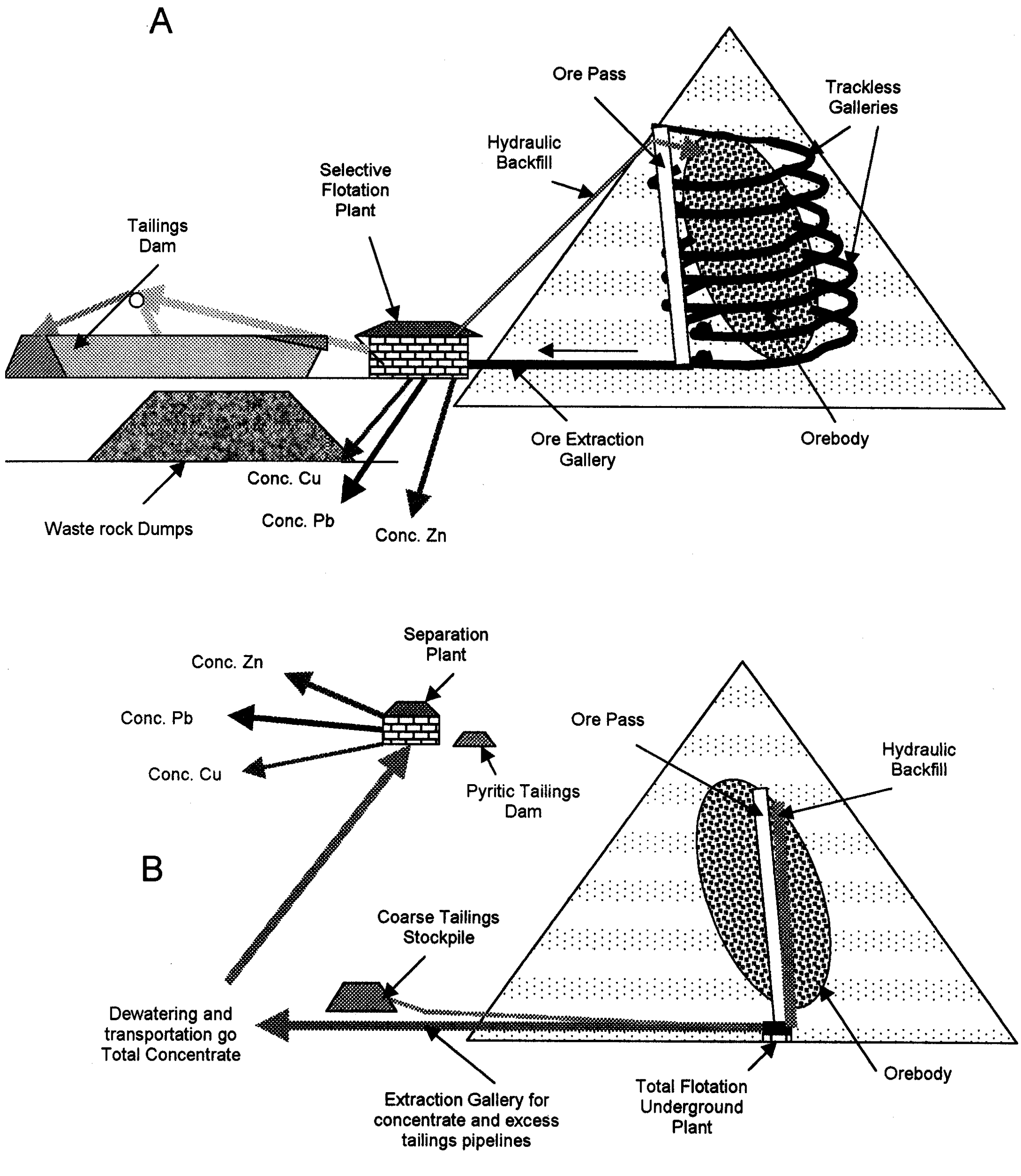

Fig.10. The principle schema of conventional mining and processing (A) and the total flotation and backfill (B) of polymetalic ores.
Obr.10. Základná schéma klasickej ťažby a spracovania (A) a postupu kolektívnej flotácie a zavážanie (B) polymetalických rúd.

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