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TITLE : IMPROVEMENT AND EXTENSION OF THE USE OF FLUTATION COLUMNS - FLOWSHEET OPTIMIZATION

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INTRODucTtON

The present project focused on the **improvement of the flotation process, a basic** process to concentrate the vaiuable metal bearing minerals which are present in ores. The grade of metals contained in ores are usually to low to aHow their direct feeding into industrial metallurgical circuits. The grade of copper ores, for exampIe, is generally in the range of 0.4 to 3 '??o and the minimum grade of the concentrates accepted in Cu metallurgy is about 20°/0. Flotation is therefore an industrial process able to concentrate the Cu bearers present in the ores in the form of chalcopyrite crystals ($CuFeS^2$), for example, and to produce a chalcopyrite concentrate with a Cu grading of between 200/0 and 340/0 (the grade of Cu in a chalcopyrite cristal varies very little hound 34% Cu). The principle of flotation is to provoke, in a suspension of ground ore particles in water, **the attachment of bubbles to certain species of minerals.** The bubble-mineral aggregates then float and can be recovered at the top of the flotation tank. By acting on the **physico-chemical properties** of the water-ore particle mixture, we can selectively govern the attachment of bubbles, for example, to chalcopyrite particles in the case of Cu flotation.

It is estimated that, at the present time, the world tonnage of ores treated by flotation is at least 2000 **Mt/year.** There are also applications of flotation in the paper industry, in environmental protection (soil decontamination) and potential applications in the chemical industry.

Mechanical cells have usually been used to carry out the flotation processes, but during the eighties, a new concept appeared-column flotation which claimed to have the advantages of better selectivity, lower energy consumption, an ability to simplifi circuits thanks to the elimination of mechanical agitation and to the existence of a double counter-current (one in the collection zone, the other in the groth) enabIing a reduction of treatment stages and the production of a purer concentrate (Fig. 1).

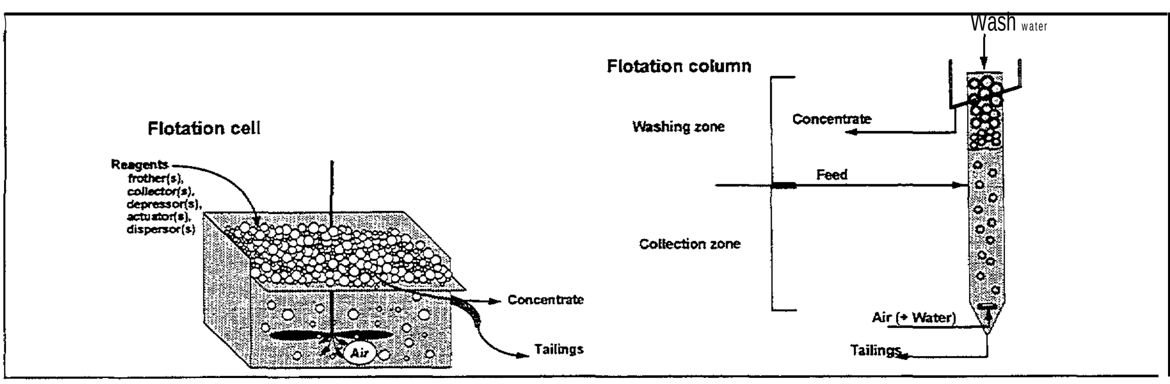


Fig. 1- Ceil and cohmm jlotation,

When the project started in 1992, column flotation was being used in commercial operations in several industrial sites for various ores, mainly in AustraIia, Canada, Chile, and USA. In Europe also, columns were installed in several industrial plants but, in general, they were not producing the results which had initially been expected and, afier a period of great enthusiasm, **operators became suspicious of their real practical advantages.**

1. STATE OF THE ART

The state **of the art** in this field, at the time, can be summarized as follows.
The use of flotation columns was thought to improve the flotation process through:

better **metallurgical** results (mainly concentrate quality);
better separation of **fine** particles (thanks to the counter current washing of the froth);
decreased **energy** consumption (thanks to flowsheet simplification and elimination of agitation)

In countries like Canada, the USA, Australia and Chile column flotation has very often been considered either for the final stages of the flotation process, called the **cleaning stage** in new operations, or in existing circuits to replace mechanical cells, and **industrial research** has focused on comparison between mecha.nical cells and flotation columns for the production of final concentrates. In some rare cases, the use of columns for the first stage of the flotation process (called the roughing stage) has also been suggested.

Academic research was focused mainly on modelling, process control and bubble behaviour rather than cm the process itself or its integration within a plant, or with the association of new equipment such as agitated mills. This is probably because it is difilcult to carry out laboratory scale column flotation tests with actual ores.

In various industrial cases, the use of columns has been disappointing when actual performance is compared to expected pefiorrnance and also when considering their flexibili& in industrial operation.

Ionic flotation was considered to be of interest at laboratory scale, in spite of the fact that it is difficult to develop at industrial scale for technological reasons, and the potential of agitated mills needed to be confirmed within up-to-date flotation circuit configurations.

2. OBJECTIVES OF THE PROJECT

The targets **of this project** were:

- to improve the **economics** (revenues and operating costs) of treatment operations through a rationally conceived use of columns and agitated mills in flotation circuits;
- to define the possibility to extend the use of columns from cleaning stage to **roughing stage;**
- to take advantage of the specificity of the columns to reduce the use of **environment** polluting reagents;
- to evaluate and develop improved **bubble generators;**
- to make **possible separations** diff]cult to carry out in mechanical cells as ionic flotation

To achieve these goals the project was divided into five tasks with the following objectives:

Task 1: Take advantage of the lower air consumption of columns to act on the physico-chemistry of the pulp by addition of gases such as 0_2, N_7, $C0_7$ to the gas used for column flotation and thereby reduce or eliminate the use of **env~ron-ment** ~olluting reagents,

Task 2: Find methods for characterizing tioth properties, establish correlation between **froth characteristics,** wash water chemistry and metallurgical resuks.

Task 3: Evaluate and develop improved **bubble generators** using no water.

Task 4: Demons&ate the possibility of **flowsheet simplification** by reducing the treatment stages from 5 to 2 or 3, possibly using new agitated mills for regrinding stage; extend the use of columns at the roughing stage to fine-grained ores.

Task 5: Make possible separations that are very difllcult to carry out in mechanical cells such as **ionic flotation.**

3. IVIEANs usED TO ACHIEVE THE OBJECTiVES

Various means were used during this project:

Some of them already existed: **Laboratory** equipment of the different partners (flotation cells, grinding mills, analytical apparatuses, etc.), and **pilot-scale** equipment (grinding mills, screens, flotation cells and columns, etc.). The APIRSA **industrial site** was used to run pilot and industrial tests. A Jameson cell was temporarily instalIed in the plant.

Other means were **developed** specifically for the project. BRGM developed new tools to study the froth. Control International S.A. designed and manufactured **a mobile pilot cohmn (30** cm x 10 m) integrating two different types of spargers (Turbo Air and Microcel) in order to compare their performances. Within task 4, MITU developed and buih a **mobile pilot plant** to compare various flowsheets including **columns, conventional cells and an agitated grinding** mill. This pilot device also included sensors to allow efficient process control.

4. MAIN RESULTS

Regarding **task 1,** laboratory tests were carried out by MITU and APIRSA, and piIot scale tests by BRGM. In spite of poor reproducibility, results obtained on the pilot plant showed that the **nature of the gas** used for **flotation** has an effect on the process, but lab work proved that the previous treatment of the pulp (i.e., **grinding conditions,** pre-conditioning, existence of an oxidation phase before flotation) are **more important. The** best flotation results were obtained with grinding conditions typical of those existing in autogenous grinding, a size reduction method which is more and more widely used. The use of gases other than air in flotation after balI miH grinding led, in the best cases, to metallurgical results similar to those obtained when air was used after autogenous grinding.

Alternative gases to air may still play a role in flotation, but their impact is less significant than expected, and in particular, less significant than the impact on flotation results of the physioc-hemical conditions existing during the grinding stage.

Therefore, after the first half of the project had been completed, the partners decided to halt work on task 1.

Most of the work on **task 2, froth control,** *was* carried out by BRGM. The activities were divided into two fields and the results are the following:

- the study of physico-chemical parameters and their influence on metallurgical results:
  - . **froth dosage,** distribution of frother between wash water and bubble generator water are important parameters,
  - . the **addition** of collector or **electrolytes in** wash water have an effect on flotation results,
  - . distribution of collector between normal conditioning point and wash water improves selectivity,
  - mineral-bubble attachment becomes stronger in the presence of frothers.

tools development for fi-oth study at lab and pilot scales. In addition to the adaptation of existing equipment such as the Bikerman frothability measurement apparatus and the use of existing tools (such as the LEM induction time measurrnent device existing) various tools were developed:

at lab *scale: an* apparatus enabling **coalescence** study on water-fiother mixtures, a device aIlowing the study of solid **particle detachment** during coalescence (Figs. 2 to 5),

at pilot piant scahz a device to **sample** the **froth** zone in a column which enables collection of superposed samples, to determine their air, water and solid contents and to provide solid samples for analysis (Fig. 6); a **sensor,** based on capacity measurement, installed on a column at BRGM, enabling to estimate **froth characteristics** (percentages of water, gas and solid, Fig. 7).

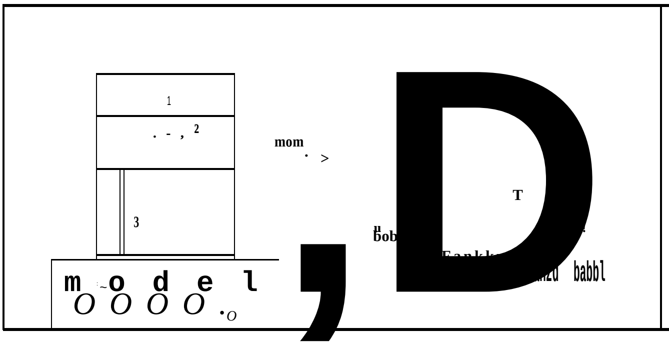


Fig-we 2- Induction time apparatus.

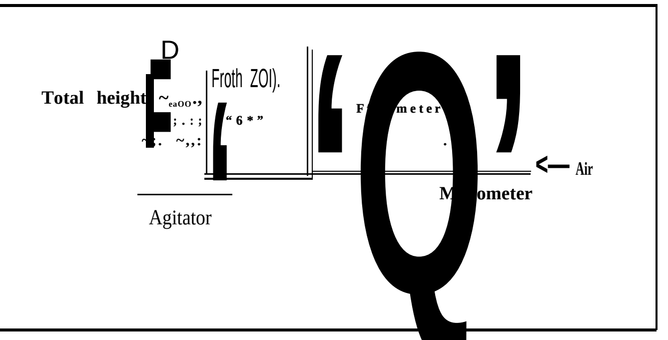
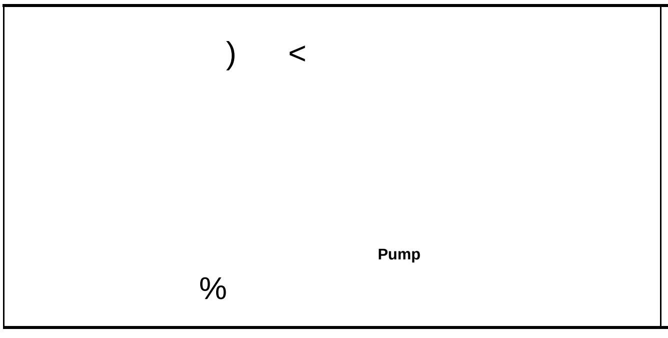


Figure 3- Frothabih@ measurement set up.



F&-ure 4- Coalescence study equipment.

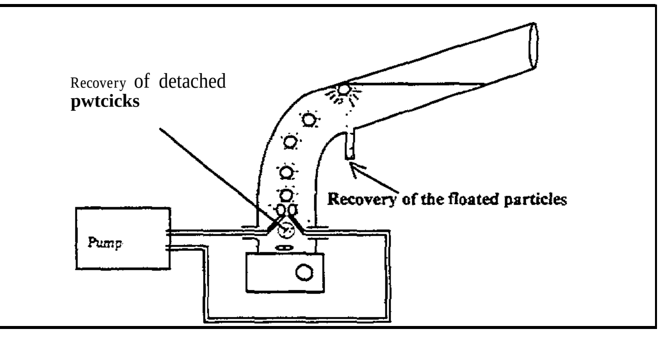


Figure 5- Selective coalescence stuaj equipment

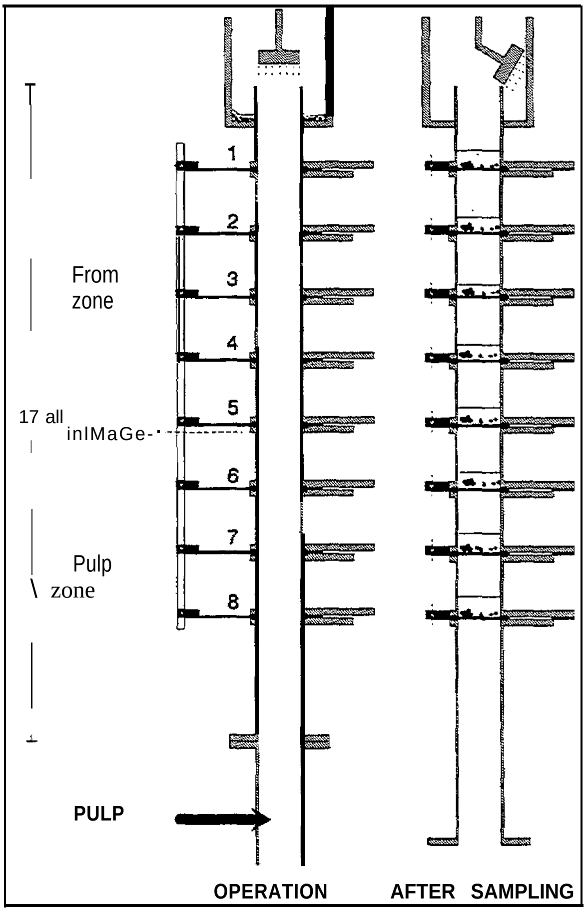


Figure 6- Froth sampling system

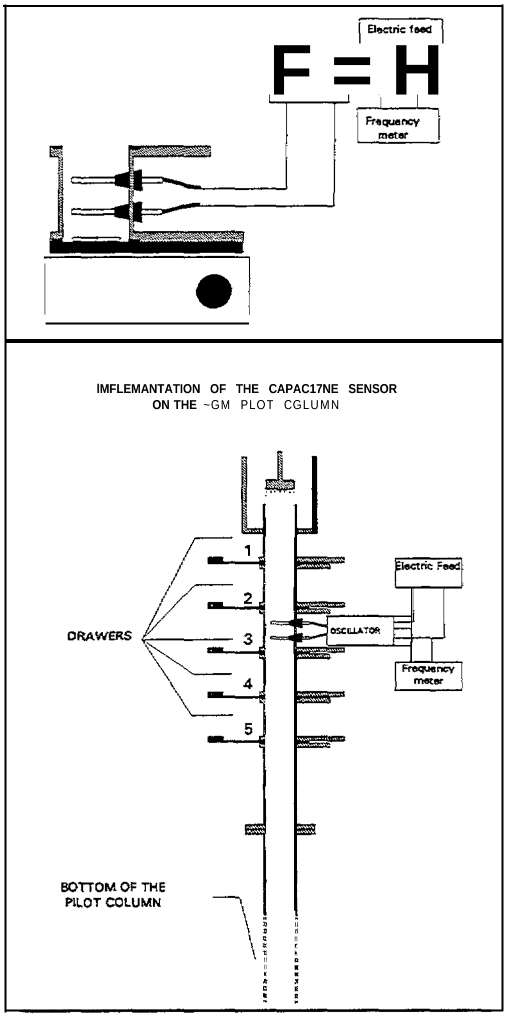


Figure 7- Froth characterisation devic. e

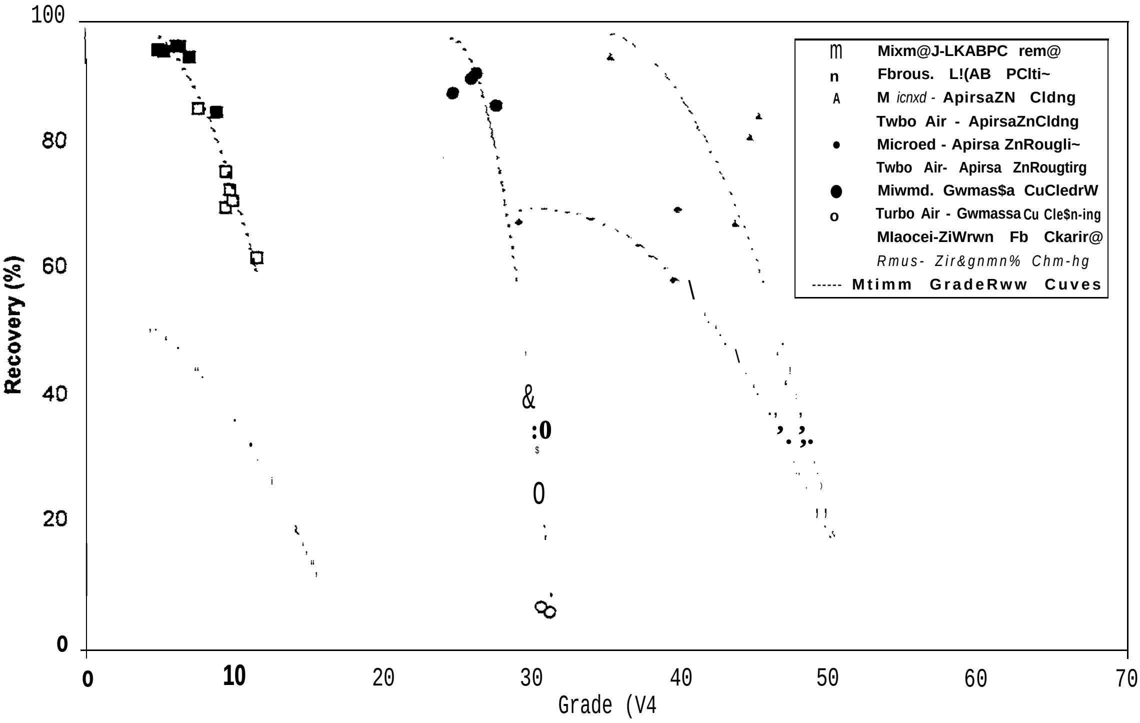


Figure 8- Grade-recovery curves obtained during the pilot plant campai~s with comparison of bubble generation systems.

Task 3 proved the **superiority of the Microcel** system over the Turbo Air system. Several series of comparative tests were carried out by Control International, MITU and BRGM at piIot scale on various ores. The Microcel system always gave **higher recoveries than the** other systems with very little loss of selectivity (Fig. 8). An industrial application in the lead circuit of APIRSA confirmed at the plant level the performance expected following the pilot plant tests. The better metallurgical results are associated with lower maintenance requirements and **increased operational flexibility.**

Task 4 was divided into **three main sub-tasks.** The first sub-task dealt with fine-grained ore processing and focused specifically on the APIRSA ore. Coarse-grained ores were studied in the second sub-task. The third sub-task consisted of an economic evaluation of column flotation technology and a comparison of column technology with that of conventional cells from an economical point of view.

Within sub-task 4.1, lab, pilot and industrial tests were carried out by APIRSA and BRGM in the 13RGM's facilities and at the APIRSA plant. Modelling was also done. Tests showed that:

- a Jarneson cell, used as flash flotation equipment, can produce, in the Apirsa plan~ a rich roughing concentrate on a fraction of the Zn content
- when mineral liberation is good, Zn roughing is feasibie in columns, and produces a commercial concentrate with a good recovery;

very good metallurgical results are obtained on the first Cu cleaning, producing a very good commercial concentrate, with a very good selectivity against Pb, Zn and Sb.

ModeHing and **simulation** work produced a very efficient model of the **SALA Agitated Mill** which can predict product size distribution and energy consumption. A **coiuiimi flotation model** which takes into account the **froth zone** as well as the **collection zone was** also developed. These two models are included in the **USIM PAC** process simulator.

Sub task 4.2 on coarse-grained ore was carried out mainly by MITU. Numerous tests were run on the different industrial sites of the consortium:

- on the **complex sulphide** ore of Petikn&s (Bo}iden Mineral);
- on the **iron ore of Kiruna** (LKAB), to float apatite or silicate minerals from the ore or to float the apatite from the iron tailings;
- on the **Pb-Zn ore** of Zinkgruvan (Ammeberg Mining Corporation).

These consisted in testing different circuit configurations with the mobile pilot plant. The main conclusions of this sub-task are, for column-based circuits, a circuit simplification, an improvement of metallurgical results **and an improvement of selectivity compared to conventional circuits.**

Concerning the economic evaluation, procedures were established to design circuits, evaluate their **metallurgical** performance, estimate related costs, and calculate robust synthetic indicators of profitability. The method includes the maximisation of the profitability of a beneficiation system into an aigorithm for designing flotation circuits that integrate both conventional with column technologies.

Task 5 was dedicated to ionic flotation. Lab and pilot work was carried out on two main targets: flotation of **Mo** from uraniferous leach solutions, and Cr^{vl} flotation from effluent solutions. The project proved the feasibility of such flotations with very high recoveries (> 90%). Industrial applications could be possible for purification of contaminated liquid effluents or recovery of specific ions from solutions.

5. CONCLUSIONS

The programme was almost totally carried out, except for Task 1 which was suspended when partners realised after the first half of the programme had been completed that there was a lack of corresponding industrial perspective within the framework of the present project. To compensate for this, a greater effort than initially planned was devoted to Task 2.

The halting of industrial activity at APIRSA for one year-and the refusal of the Commission to consider this as a @-cc majeure and extend the length of the contract-forced the partners working in close relationship with APIRSA (mainly Control International S. A., BRGM and Trieste University) to condense and accelerate the interpretation work and the economical evaluation.

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Of the results obtained within the framework of the project, we can distinguish between process principle results and industrial results.

5.1. PROCESS PRINCIPLE RESULTS

The nature of the gas used to carry out the flotation of sulphide ores plays only a minor roIe compared to others parameters such as grinding conditions, bubble size, and froth characteristics. Furthermore, the magnitude of experimental error generally encountered in flotation tests (in pilot plants as well as industrial plants) masks the effect of the nature of gases.

Froth characteristics play an important role on **selectivity** and **recovery** occurring in the **froth** layer. The froth plays a dual role in the flotation:

- It must carry hydrophobic particles up to the overflow, a function which requires a well structured froth.
- It must also eliminate any mechanical transport of hydrophilic particles, a fimction which requires a froth with a low water content and low viscosip (therefore fragile)

During this project, tools were developed to study in depth the phenomena occurring in the froth layer. These include:

- Pilot column **sampling** equipment which is, as far as we know, the only sampling device which enables us to obtain representative samples coming from different depths of the froth.
- A sensor system principle enabling determination of froth **composition** (water, gas and solid content) in pilot plants or commercial operations.
- Laboratory ‘scale equipment enabling to study the effect of the dosage and nature of various frothers on bubble **coalescence** and solid particle detachment.

The effect of the addition of frothed, collectors and electrolytes was studied at different points in the pilot scale circuit. Some effects on froth characteristics and metallurgical balance were noticed, but the phenomenon needs to be studied in greater depth before industrial application.

The importance of the **wash water distribution** system and of the **froth extraction** system has been also demonstrated (Aprisa-Boliden).

The task on bubble generators demonstrated the advantages of the Microcel[m] bubble generator for the following reasons:

- **improved flexibility of the industrial operation,** making the acceptance of a coIumn-based circuit easier for the plant operators;
- better concentrate **recovery** (at the cost of a loss in grade if compared to columns with classic spargers);
- possibility of **finer bubble** production and, therefore, obtention of a better recovery of fine particles or flocks;
- **no use of water** for bubble generation: the applications of column flotation could therefore be extended to suspensions which are not water-based or to water-based suspensions to which more water cannot be added. The water savings should be mentioned since classic air sparger systems consume significant quantities of water.

Concerning the controversy existing as to the **best roIe of a column in a flotation circuit** (is a column best adapted to the cleaning stage or should it be used for the roughing stage since it is able to produce a final concentrate directly, making tie cleaning stage useless?), the present programme provided an answer which might reconciliate the two positions: A major specificity of columns is their **ability to be** very **selective** and to float only particles whose physioc-hemical characteristics vary within a narrow range. Consequently, columns can produce a relatively pure concentrate composed of the minerals to be floated and not polluted by other species. It will hardly float particles composed of different locked minerals, the characteristics of these particles being different from those of a particle composed only of one mineral. Columns are therefore **well adapted to the cleaning function and even more to the roughing function if, and only if, the particks to be floated are ahnost completely liberated** in the pulp feeding the flotation roughing stage.

The advantage of the improved selectivity could, however, become a drawback if the particles are not well liberated, as it ofien the case in the roughing circuits of large scale operations. Locked particles would then remain in the flotation tailings and would be lost. Mechanical cells are, therefore, better adapted to the roughing stage when the objective is to collect a maximum of the particles bearing the values of interest and when the minerals to be floated are not well liberated. Even under those conditions, however, columns could be of interest in a roughing circuit to produce a high grade concentrate composed of the fraction of liberated particles. It could be concluded that an ideal flowsheet should include, as a geral rule conventional cells for roughing, agitated mills for regrinding and columns for cleaning.

A **good knowledge of the mineralogy** and texture of the ground ore appears once again to be a **prerequisite for the proper design** of a flotation circuit.

Concerning ionic flotation, it has been demonstrated that columns **open the way to industrial applications of ionic flotation** in two fields:

- **purification of contaminated liquid effluents,**
- **recovery of specific ions from solutions.**

Models for column flotation and SAM grinding were developed and **procedures** were established to **design circuits, evaluate** their **metallurgical performances,** estimate related costs and calculate robust synthetic **indicators of profitability. The** method which includes the maximisation of profitability of a beneficiation system could also be adapted to processes other than flotation.

5.2. INDUSTRIAL APPLICATIONS

5.2.1. Boliden Apirsa

The R & D projects are of two-fold interest for Boliden Apirsa because it wil enable them to:

- improve **current** operations (about 2 Mt /year of ore);
- design a **new plant** corresponding to the "Los Frailes" ore body which has characteristics similar to those of the presently exploited ore body, but with a **capacity twice** as great.

An industrial application of the project was the installation 5 months ago of a **new bubble generator** at the last cleaning stage of the **lead** flotation. Its association with the **internal launder system** and the **improved wash water** system have produced a direct increase in revenue. The same installation will be considered for the **"Los Frailes"** plant.

The impact is important for the whole economy of the operation, in spite of the minor importance of Pb in the revenues of the operation: less than 20°/0.

Industrial tests will also be carried out in the **zinc** and **copper** circuits **(Zn** sales account for more than 50 °/o of Apirsa **revenues).** A grade increase of the corresponding concentrates for the same recovery is expected.

In spite of the fact that no prediction can be made at the present time on the impact of the improvement of the column operation on copper and zinc concentrates, it appears that in Andalusia, which is one of the least favoured regions of Europe, the economical impact of the project is yet very significant.

5.2.2. BRGM

The benefits for BRGM of the R & D project are the following:

.*Industrial application*

For the BRGM group, one major industrial target of the project was the Chessy project were 4 different column-based circuits were studied (Cu, Zn, Ba, Pyrite). The use of columns for the industrial operation seemed to be very attractive, not only in order to increase the commercial value of the concentrates, but also for the improvement of investments and operating costs. Because of a lack of mineable reserves, the operation has been delayed and is presently suspended until new reserves are found.

Nevertheless, BRGMs mining subsidiary, LaSource, is involved through its fully owned daughter company SEIEMSA, in an extensive geological prospecting programme in Andalusia and it is highly probable that the orebodies which could be developed will be finely mineralised like the Aznalcollar orebody. The knowledge acquired during the present project will be filly applied during the feasibilifiy study. Some tests are scheduled for the beginning of 1996. The length of time needed to develop the corresponding orebodies make the opening of any industrial exploitation unlikely before a period of 4 years. In the case of a positive conclusion and on the basis of the savings corresponding to Aznalcollar operation, we may anticipate very significant savings.

The knowledge gained concerning the obtention of high purity concentrates could also be used for the production of base metal concentrates in mines located in Afric~ fm from harbours: the decrease in weight of concentrates to be trucked could be very significant from an economic point of view, but here also the main advantage would probably be the improvement of the commercial value of the concentrates.

• ***Technological development***

BRGM has developed tools which can be considered to be applications of the project. These include:

- A sensor enabling characterisation of the pulp and froth zones (solid, gas and liquid contents).

- The design of a prototype and its inclusion in a control system, outside of the scope of the present projecL is under consideration. An application for patent protection is presently under consideration.

- A device allowing the study of the effect of coalescence on flotation selectivity. Such a device could be used to improve flotation selectivity through a better choice of fiother.

• ***Improvement of know-how***

BRGM has greatly increased its know-how in the field of possible column flotation applications and could expect an increase in sales of services and royalties.

It is presently defining a marketing strategy, in association with Control International S.A., to difise know-how, in particular in the countries of the former Comecon.

• ***Sof2ware development***

BRGM has developed steady-state models for column flotation and vertical mill design which will be incorporated into its USIM PAC 2.1. software, sold directly by BRGM or through its subsidiary, CISA and through a representative network.

The column flotation model still requires a more complete validation stage before it can be considered to be completely operational.

The SAM verticaI mill model, which has proved to be very efficient for predicting energy consumption and size distribution, also needs further development to predict mineral liberation, an important parameter for the simulation of a complete regrinding-flotation circuit.

5.2.3 Control International S.A.

The test work carried out within the sub-task 3 has resulted in the following:

- ***Comparison of bubble generation systems***

CornparativeIy, the Microcel™ bubble generation system always performs in a significantly higher recovery zone than the porous and Turbo Air bubble generation systems for the same grade recovery curve.

These results led Control International S.A. to select the MicrocelTM system as the leading product for bubble generation systems for al} column flotation applications. This decision could not have been taken without the results from the research programme.

- ***Industrial application of the MicroceP system***

One industrial application of the Microcel™ system in the Iead circuit of Boliden Apirsa has produced, at the plant level, the petiormance expected from the pilot plant testing campaign. The application results are presented in detail in the Boliden Apirsa sub-task. After the bubble generator was replaced, there was a large improvement in the column operation. The same replacement in the zinc circuit should take place in the near future.

No investment capital cost comparison was carried out within the Ilamework of the project. It is anticipated that the Microcel™ system has a higher cost mainly due to the recycled slurry pump required. However, the operating cost comparison showed that there is no significant difference between the two systems.

The two major advantages of the MicroceF™ sparger are that the system allows much better metallurgical results linked with lower maintenance requirements. The technology is therefore perceived as a major breakthrough in the field of column flotation.

- ***Expectations for industrial MicroceP applications***

Control International S.A. will very actively market the MicroceI~ technology for industrial operations.

New mining projects are scarce in Europe. Consequently, the main potential market for the Microcel system in Europe will be the retrofitting of bubble generators in existing plants. It is also important that pilot plant and laboratory columns be equipped with the system in order for the product to be well accepted by the industry. Identified applications linked with the pilot plant tests of the research programme are at LKAB and Ammeberg Mining Corporation, as described in the MITU sub-task and also in Spain, Portugal, and Morocco.

5.2.4. MITU

Test work with a mobile pilot plant carried out by the Swedish companies resulted in the following:

- **LKAB will invest in a new cleaning circuit with columns** in the dephosphorization flotation circuit in their Kiruna plant. This improvement definitely falls into the category of improved metallurgical results.

- Test work with apatite flotation has given **excellent metallurgical results and a very simplified flowsheet.** In recent years, LKAB had stopped recovering apatite tlom tailings because it was not economically advantageous, especially at low phosphor contents in the ore. Up until now, there has been no direct exploitation of the results. However, the results are so interesting that it is likely that finther pilot-plant test work will be carried out to verify and optimise the results. This might lead LKAB to reconsider the possibility of producing an apatite concentrate. The results fall into the categories of lower investment and operating costs for the plant, better metallurgical results, and especially that of more controllable circuits.

- The results from the test work at Boliden AB are more difilcult to quantifi since no investments are programmed and no changes have yet been made in the plant circuits. The results fall mainly into the category of **improved know-how in the future operation of existing flotation coIumns** and future flowsheet development. Since the latest results will take some time to evaluate, the economic potential of the last test campaign cannot yet be estimated. The achieved results fall into the category of more controllable circuits and possibly also into that of better metallurgical results.

- Results from the test work at Ammeberg Mining Corporation will lead to the **installation of a Microcel air sparger in the existing flotation column,** and further test work will be carried out in order to determine whether columns should be included in the future design of the flotation circuit. If pilot plant results are confirmed and columns are included in the flowsheet, the results will fall into the category of better metallurgical results.

Furthermore, for BoIiden and Ammeberg Mining Corporation, the project provided the opportunity to pay more attention to metallurgical operations, and therefore to indirectly improve the metallurgical balance. Since 1992, an increase of 1 ‘Yo in the zinc concentrate grade, **and** a **2°/0** increase in Pb and a 10/0 decrease in zinc in the lead concentrate have been obtained at Ammeberg.

5.2.5. LEM

LEM has demonstrated the **feasibility of floating ions or precipitates in columns.** Two major development schemes could be considered:

- Purification of effluents. The work on sulphuric solutions containing Mo or Cr has been successful and has proved that recovery can be higher than 90°/0.

- Recovery of specific ions. Ionic flotation has been studied since 1962, but up until now, due to the lack of well-adapted flotation equipment, there were no commercial applications. The present study makes commercial applications feasible.

LEM plans to exploit the results in the following way:

- At the present time, LEM is discussing with various commercial organisations the **development of ionic flotition in the field of solution purification.**

- Reagent recycling must be studied because the reagent represents a major element in the operating cost.

- The “Value” programme could be a means of further developing industrial ionic flotation applications.

5.2.6. Trieste University

Trieste University has increased its knowledge of economic evaluation of flotation circuits and developed a **tool allowing the economical evaluation of different flowsheets:**

The procedures developed by UTS-DINMA for evaluating and comparing flotation technologies and designing plants according to maximum profit (= revenues - costs) could easily be extended. They can be used for other processing networks other than those using flotation: flowsheets that employ different physical separation principles or hydrometallurgical routes. These analytical methods can be included in intelligent simulators capable of assisting the process designer rather than merely documenting a process decision. This spin-off of the Impexfiocol project will be an area of fi.u-ther studying by UTS and a CNR financial support has been given to UTS to continue these studies.

5.3. NEEDS FOR FURTHER R8LD WORK

If the work carried out within the fi-amework of the present project has demonstrated the potential of column flotation in specific applications, an ;mmedia~e generalisation of the results to other ores, mainly sulfides, does not yet appear to be evident and the application to other types of ore will require additional experimental investigations. **Models can and must stiII be improved,** making it easier to predict industrial results on other kinds of ore. This should be based on an increased knowledge of the behaviour of particles in relationship with their nature, shape and **Liberation.** Such predictive tools should also include the effect of regrinding equipment (for example, SAM mill) on liberation.

Using modeis taking into consideration the effect of particle composition, a simulator (using the existing shell of USIM PAC, for example) will be able to simulate and compare various fill flowsheets: the **extensive recycling** in a grinding-flotation circuit decreases efllciency, for the **gIobal evaluation** of the fill circuit, of a comparison based on the performance of **a single-unit** operation.

Research work to understand the **phenomena** occurring in the **froth** must continue and should also take into consideration the **nature,** shape and the mixity of the **particles** as well as the effect of any modification of the physico-chemical parameters (for example, through the addition of chemicals in the wash water), and the effects of the froth water content on the metallurgical results.

The development and demonstration of **sensors** able to characterise froth on-line, mainly in terms of water, gas and solid content, wiH enable us, on the one hand, to define models describing the effect of the froth phase composition on the metallurgical results and, on the other han~, to use such models for he optimis-ation of metallurgical res;lts.

In the field of ionic flotation, the results of greatest interest should be extended to **industrial cases in the fields of hydrometallurgy and environment protection.**

5.4. ENVIRONMENTAL IMPACT, WORKING CONDITIONS AND IMPACT ON LESS FAVOURED EUROPEAN REGIONS

The exploitation of the R & D project has positive impacts on the following areas:

5.4.1. Environment

Column-based circuits **consume less energy than** totally mechanical cell-based circuits. (A Thermie grant has been awarded to the Chessy project for energy savings associated with the use of columns but has not been spent because of the postponement of the industrial project. The target was a savings of 6.6kwhA of ore treated for the flotation section which corresponds to a savings of 60% of the energy consumed by a traditional fiowsheet.).

The increase in metal recovery when columns are used decreases the heavy metal content in tailings and therefore lowers the impact on the environment directly at the mining site.

The increase of concentrate quaIity also has a very positive impact on the environment through:

- lower energy consumption for the transportation of the concentrates;
- lower smelting costs for the same metal production;
- **less pollution linked to impurities at the metalh.mgical site.**

Another aspect, not very highlighted but important, is the absence of watir injection in the Microcel^T~ bubble generator. The USBM type of bubble generator consumed large quantities of fresh water.

5.4.2. Working conditions

The links between column **use** and an improved control system (columns require stricter control and therefore improve process control) lead to a significant improvement of working conditions.

5.4.3. Impact on less favoured european regions

The IWO principal industrial plants studied in the projects are mines located in less favoured European regions:

Kiruna in northern Sweden, inside the polar circle.
Aznalcollar in Seville, Spain. The present boom in the Iberian sulfide belt will provide an excellent opportunity to introduce the know-how obtained during the project.

LIST OF PUBLICATIONS AND COMMUNICATIONS

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2. **To be presented after the the end of the project**

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