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A REAL TIME VISUAL SENSOR FOR SUPERVISION OF FLOTATION CELLS

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ABSTRACT

This paper describes an expert system for the supervision of flotation plants based on ACEFLOT, a real time analyzer of the characteristics of the froth that is formed on the surface of flotation cells. The ACEFLOT analyzer is based on image processing and measures several physical variables of the froth, including colorimetric, geometric and dynamic information. On the other hand, the expert system detects abnormal operation states and suggests corrective actions, supporting operators on the supervision and control of the flotation plant. © 1998 Published by Elsevier Science Ltd. All rights reserved

Keywords
Mineral processing; flotation froths; flotation bubbles; on-line analysis; expert systems

INTRODUCTION

Supervision and control of flotation plants is generally accomplished taking in account the information supplied by expert operators, who observe the froth and bubbles produced on the surface of flotation cells and recommend actions, such as varying levels and modifying reagents [1].

The availability of low cost and powerful computers together with high performance frame grabbers and CCD industrial grade cameras, allow the use of artificial vision to support plant operators in their task of supervising and controlling the flotation process, providing them updated information about the state of the cells and systematizing the reasoning made by experts.

This work describes first ACEFLOT, an analyzer that measures the color, number, size, shape, density, speed and stability of the bubbles produced on the surface of a flotation cell, and secondly, an expert system based on ACEFLOT that detects abnormal operation states and proposes corrective actions, such as changing level set points or modifying the dose of reagents.

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THE ACEFLOT ANALYZER

Description

ACEFLOT is an artificial vision based instrument developed to support plant operators in the supervision and control of mineral flotation process. It determines the color, number, size, shape, density, speed and stability of the froth bubbles at the surface of a flotation cell. The image color is defined as the mean intensity value of each of the red, green and blue (RGB) image components. The size of the bubbles is defined and computed as the average of the area in cm^2 of all the bubbles appearing in the frame captured by the CCD camera. The shape of the bubbles is defined and computed as the mean ratio between the minor and major axis of each bubble in the image, and finally, the density is computed as the number of bubbles per cm^2 in the image.

ACEFLOT also determines the magnitude of the speed and the moving direction of the bubbles, as well as the froth stability, which is a measurement of the rate of bubble explosions. Additionally, ACEFLOT keeps historical register of the measured variables and displays current results and trends in time.

Hardware structure

Figure 1 shows a schematic view of the hardware structure of ACEFLOT. It consists of:

- Three video acquisition subsystems
- One communication subsystem
- One processing subsystem

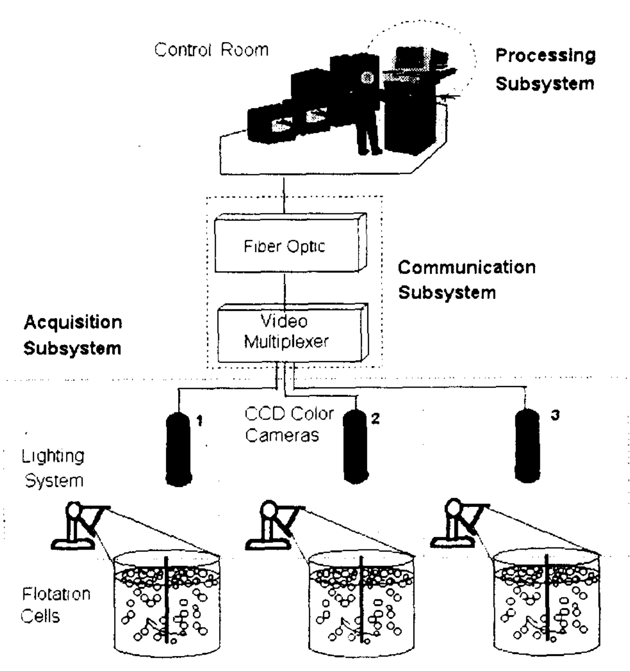

Fig.1 ACEFLOT hardware.

Each video acquisition subsystem is enclosed in a hard steel water and dust proof case, which houses an industrial grade color CCD camera, an AC/DC power supply and four special fluorescent lamps with flat color spectrum for illuminating the froth surface. The image captured by each camera is transmitted through a double insulated coaxial cable, to the communication subsystem.

The communication subsystem is composed of an analog video multiplexer, a fiber optic link for video transmission and a twisted pair cable used for camera selection. The optical fiber link consists of an electrical/optical converter, the optical fiber and an optical/electrical converter. The video signal is transmitted from the multiplexer output to the processing subsystem through the fiber optic link.

The processing subsystem consists of an 100 MHz. Pentium based PC with 32 MB of RAM, a 1.0 GB hard disk, a 17" SVGA monitor and a color frame grabber board that allows to display real time video in the monitor. Because the fiber optic link transmits only one video signal at a time, the processing subsystem selects the video source, using a twisted pair cable connected to an RS-232 port which sends a signal to the video analog multiplexer. A video frame is captured and digitized into memory by the frame grabber. The computer processes the image, displays the results on the screen of the computer and stores them into the hard disk.

Operation interface

The ACEFLOT analyzer was developed in C++ to operate under the Microsoft Windows® 3.1 environment in order to provide a friendly interface with selection menus, graphic buttons and on line explanation of functions. Figure 2 shows a general view of the user interface screen, which has three separate and identifiable areas.

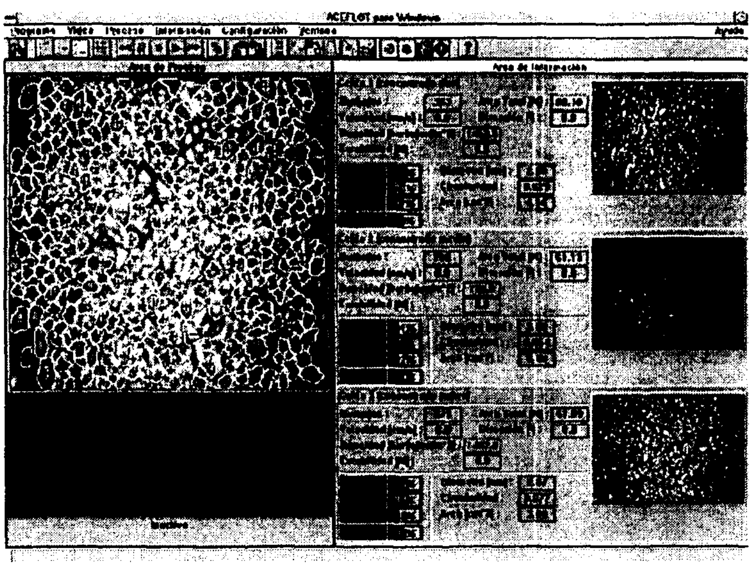

Fig.2 ACEFLOT operation interface.

The first one, on the top of the screen, allows the user to interact with the instrument using menus and icon identified buttons, which make possible to access and activate diverse functions of ACEFLOT. Several possibilities are available, such as choosing one of the flotation cells, showing the video in real time, freezing an image, processing the frozen frame, displaying and storing the results, etc.

The second area on the left of the screen, called processing area, shows the current frame under process. The display reflects the changes generated through the application of the image processing algorithms needed to extract the required information from the image.

The third screen area, called information area, has three sections, one for each flotation cell. Figure 3 shows a detailed view presenting the information corresponding to cell 1. The window displays the real time image of this cell and shows all the measurements, such as color, number, size, shape and density of the bubbles as well as the velocity and stability of the froth.

The ACEFLOT operation interface also displays graphs showing trends in time of the measured variables, which are obtained from automatically recorded hard disk historic data. It is also possible to display image histograms and to show results from the expert system. As an example Figure 4 presents a detailed view showing the histogram of the shape of the bubbles as well as the RGB variations (trends) during the last 20 minutes for a given cell.

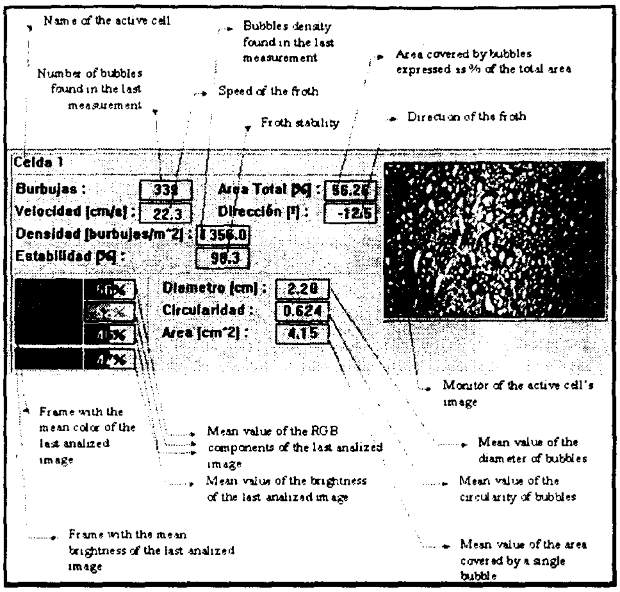

Fig.3 Information window of a single cell.

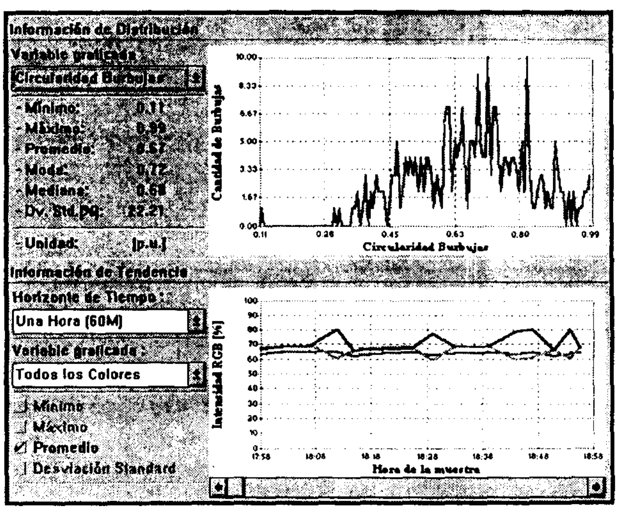

Fig.4 Histogram and trend graph.

Through the interface, the user can configure different operating options of the instrument, such as communication port configuration, selection of digital filters, selection of automatic or manual processing, and the processing itself. Running in a Pentium based computer, the software can process and extract all the required measurements from one image in about one minute. A whole system, including three cameras, can analyze one cell every three minutes.

Algorithms

To measure the froth color, the software computes the average value of the three (RGB) color components of each pixel, using the information given by the frame grabber [2].

To determine the number, size, shape and density of the bubbles, ACEFLOT localizes the center of the bubbles by recognizing the shiniest zones of the image, and the edges of the bubbles by recognizing the darkest zones [3]. The darkest zones are determined by searching the points with the lowest intensity in 12 radial directions starting from the center of the bubble.

Figure 5 shows an image with detected bubble centers and edges. Once bubble centers and edges are detected it is possible to compute the area, perimeter, diameter and circularity of the bubbles.

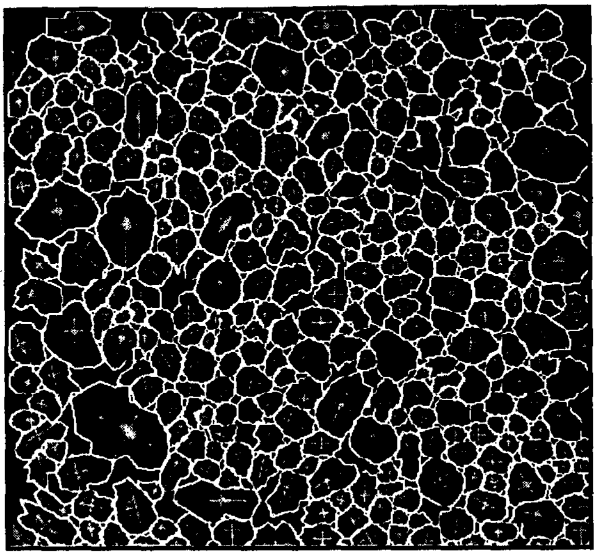

Fig.5 Edge and center detection.

The froth velocity and stability is evaluated through the processing of consecutive images, at a rate of 20 frames per second. The speed is computed determining the movement of the froth from one frame to the next. The stability is estimated comparing two consecutive image frames, and evaluating a measurement of the rate of change in the appearance [4]. Figure 6 shows an image with computed velocity vectors superimposed.

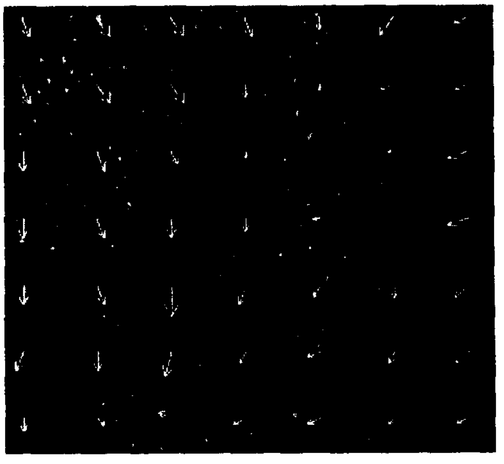

Fig.6 Vectors representing the movement of the froth surface.

THE EXPERT SYSTEM

Expert system structure

The analysis of the captured images, together with the information provided by expert flotation technician, allowed us to design a knowledge base structured in rules that determines the operation state of each flotation cell, using the froth color, velocity and stability information, together with the measurements of bubble size, shape and density obtained by ACEFLOT.

Figure 7 shows a block diagram of the expert system structure. As shown, the characterization of the cell performance is achieved through the analysis of the froth color, the geometric information of the bubbles and the froth dynamics.

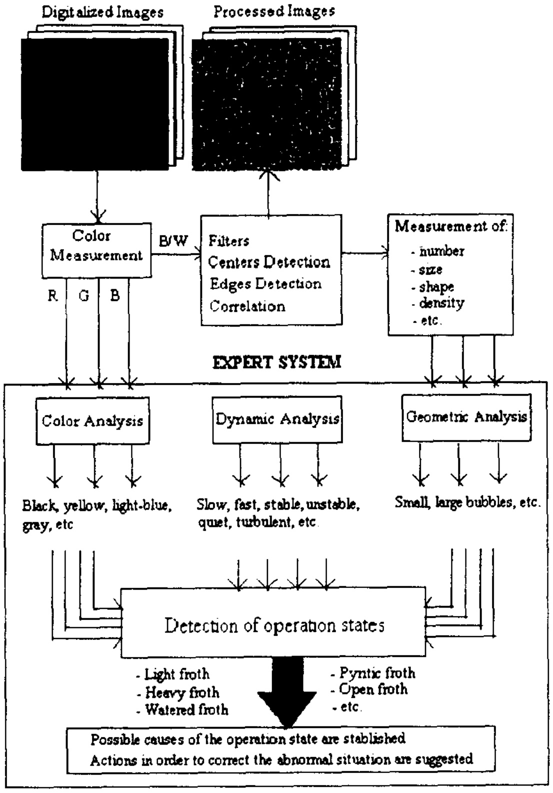

Fig.7 Expert system structure.

The color analysis describes the froth as black, yellow, light-blue, etc. The geometric analysis defines the bubbles as small, large, etc. The dynamic analysis determines the froth speed, stability, turbulence, etc., distinguishing cases such as slow or fast froth, stable or unstable froth, quiet or turbulent froth, etc.
Froth characterization is accomplished through the processing of *If ...Then* rules, in which the measured variables are checked against pre-established threshold levels.

Once the froth is characterized the expert system determines which operation state, defined in the knowledge base, fits to the studied cell. This is also achieved through the processing of *If ...Then* rules.
If the identified state corresponds to abnormal operation the expert system searches in a table the possible causes, which can be an inadequate dose of reagents, froth contamination with external agents such as petroleum, oil, detergents, etc., or an inadequate classification in the previous comminution process.

Then the expert system suggests possible corrective actions that the plant operator should follow in order to solve the problem, for example, adjusting the dose of reagents, opening the cell cap or reducing the water supply.

Operation interface

The information provided by the expert system is presented in a window within the ACEFLOT operation interface. This window displays the froth state, the possible causes of abnormal operation states and the suggested corrective actions. If the identified state needs an alarm the expert system makes the computer beep.

Figure 8 shows a display corresponding to cell 1 in which the state "excess of lime" has been detected.

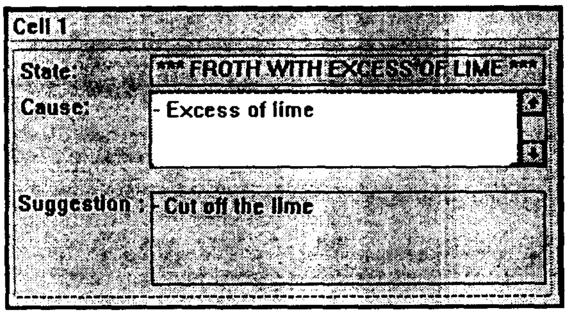

Fig.8 Expert system interface.

Programming structure

The expert system uses four text files for its operation. In the first one, *variable.exp*, the forty two variables measured by ACEFLOT, and listed on Table 1, are defined.

TABLE 1 Variables measured by ACEFLOT and used by the expert system

Variables			
V00	Number of bubbles	V21	Red mean value
V01	Bubble density	V22	Red standard deviation
V02	Area covered by froth	V23	Green minimum value
V03	Minimum area	V24	Green maximum value
V04	Maximum area	V25	Green mean value
V05	Mean area	V26	Green standard deviation
V06	Area standard deviation	V27	Blue minimum value
V07	Minimum perimeter	V28	Blue maximum value
V08	Maximum perimeter	V29	Blue mean value
V09	Mean perimeter	V30	Blue standard deviation
V10	Perimeter standard deviation	V31	Gray minimum value
V11	Minimum diameter	V32	Gray maximum value
V12	Maximum diameter	V33	Gray mean value
V13	Mean diameter	V34	Gray standard deviation
V14	Diameter standard deviation	V35	Velocity
V15	Minimum circularity	V36	Displacement angle
V16	Maximum circularity	V37	Stability
V17	Mean circularity	V38	Mean diameter change
V18	Circularity standard deviation	V39	Angle change
V19	Red minimum value	V40	Area covered change
V20	Red maximum value	V41	Brightness

Then, in order to determine which of the twenty nine characteristics stored in *caracter.exp* file the studied froth presents, the expert system compares the measured variables to forty two constants defined in *constant.exp* file. The characteristics and their corresponding rules are listed on Table 2. For example, rule C00 states that if the gray mean value V33 is between K00=0 and K01=25, then the froth is black. It is important to note that the constants are labeled from K00 to K49. However, constants K04, K05 and K18–K23 are actually not being used. They are available for specific requirements of each plant and can be defined by the user.

TABLE 2 Characteristics of the froth identified by ACEFLOT

Characteristic		Corresponding Rule	Characteristic		Corresponding Rule
C00	Black froth	K00<=V33<=K01	C15	Very fast froth	K35<=V35
C01	Yellow froth	K06<=V21<=K07 K08<=V25<=K09 K10<=V29<=K11	C16	Very unstable froth	V37<=K36
C02	Light-blue froth	K12<=V21<=K13 K14<=V25<=K15 K16<=V29<=K17	C17	Unstable froth	K36<V37<=K37
C03	Gray froth	K02<V33<=K03	C18	Stable froth	K38<=V37<K39
C04	Very opaque froth	V41<=K24	C19	Very stable froth	K39<=V37
C05	Opaque froth	K24<V41<=K25	C20	Very quiet froth	V39<=K40
C06	Brilliant froth	K26<=V41<K27	C21	Quiet froth	K40<V39<=K41
C07	Very brilliant froth	K27<=V41	C22	Turbulent froth	K42<=V39<K43
C08	Very small bubble	V13<=K28	C23	Very turbulent froth	K43<=V39
C09	Small bubble	K28<V13<=K29	C24	Very discharged tank	V40<=K44
C10	Large bubble	K30<=V13<K31	C25	Discharged tank	K44<V40<=K45
C11	Very large bubble	K31<=V13	C26	Charged tank	K46<=V40<K47
C12	Very slow froth	V35<=K32	C27	Very charged tank	K47<=V40
C13	Slow froth	K32<V35<=K33	C28	Stable size	K48<= V38<=K49
C14	Fast froth	K34<=V35<K35			

Finally the thirteen operation states that the expert system identifies are defined in *regla.exp* file using the froth characteristics mentioned above. These states and their corresponding descriptions are listed on Table 3. For example, rule R00 states that if the froth is black, very fast and unstable, then its corresponding operation state is "light froth".

Figures 9 to 12 present images illustrating some detected operation states. The upper left corner of Figure 9 presents a small number of bubbles, which indicates that the operation state is "open froth". Figure 10 presents a light-blue and opaque froth with very small bubbles, which corresponds to "demineralized froth". Froth of Figure 11 is yellow, brilliant and contains very small bubbles, which corresponds to "pyritic froth". Finally, bubbles of Figure 12 are very large and the froth is black, which corresponds to "froth contaminated with oil".

TABLE 3 Operation states identified by the expert system

N°	Operation state	Characteristics
R00	Light froth	Black, very fast and unstable froth: C00 AND C15 AND C17.
R01	Heavy froth	Yellow and slow froth, small bubbles: C01 AND C13 AND C09.
R02	Watered froth	Light-blue, fast and very unstable froth, small bubbles: C02 AND C14 AND C16 AND C09.
R03	Pyritic froth	Yellow, brilliant, slow and very stable froth, very small bubbles: C01 AND C06 AND C13 AND C19 AND C08.
R04	Open froth: absence of bubbles over part of the surface	Unstable froth, discharged tank and stable size: C17 AND C25 AND C28.
R05	Demineralized froth	Light-blue and opaque froth, very small bubbles: C02 AND C05 AND C08.
R06	Froth contaminated with sulphuric acid	Very stable froth and small bubbles: C19 AND C09.
R07	Froth contaminated with oil	Black froth and very large bubbles: C00 AND C11.
R08	Machine obstruction	Fast and turbulent froth: C14 AND C22.
R09	Excess of lime	Yellow and very slow froth, small bubbles: C01 AND C12 AND C09.
R10	Lack of lime	Yellow froth, discharged tank, stable size and small bubbles: C01 AND C25 AND C28 AND C09.
R11	Lack of collector	Gray and very brilliant froth, very large bubbles: C03 AND C07 AND C11.
R12	Normal froth	None of the above operation states.

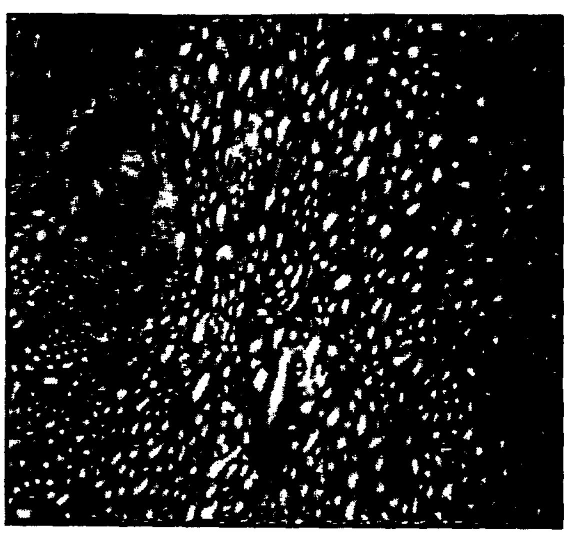

Fig.9 Open froth.

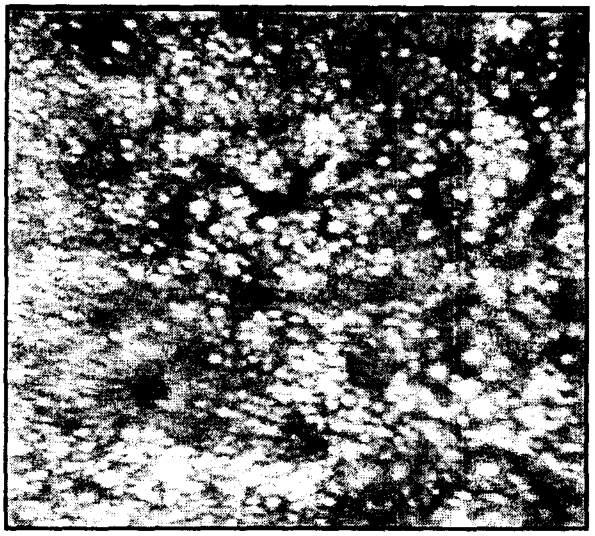

Fig.10 Demineralized froth.

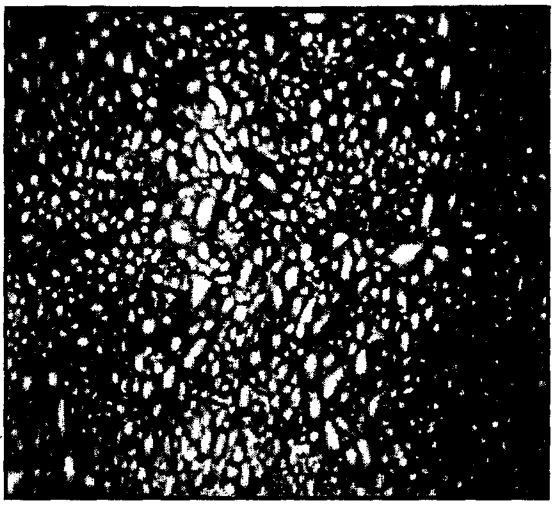

Fig.11 Pyritic froth.

Fig.12 Froth contaminated with oil.

FINAL REMARKS

The already described expert system has been installed recently in one of the concentration plants of the great copper mining in Chile, in which an industrial version of ACEFLOT supervises three flotation rougher cells, each one every three minutes. Currently we are working on the experimental validation of the knowledge base and on the evaluation of the benefits provided by ACEFLOT and the expert system. Once the knowledge base of the expert system be evaluated, we will investigate its application to scavenger and cleaner cells.

ACKNOWLEDGMENT

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