# Color measurements of minerals and mineralized froths

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**Abstract** — *Color measurements were made for pure minerals, mineral mixtures and flotation froths loaded with different minerals. The research objective was to correlate color with the composition of mineral streams. An industrially available system consisting of a fiber-optic-based illuminator and detector was used to measure color. The color values of binary mineral mixtures varied according to the type and proportion of minerals in the mixture. The measured color values of mineralized froths in the laboratory and in a commercial flotation circuit were dependent on the amount and type of minerals present.*

## Introduction

Experienced plant operators are able to estimate how well the circuit is performing from the color and consistency of the froth in the flotation cells. Since this evaluation is based on the optical properties of the froth, it would seem possible that an optical measurement might provide a quantitative or semiquantitative measure of the system. Color is used routinely in optical mineralogy to identify minerals (Cameron, 1961). Recently, laser diffraction was used to study froth loading and bubble size in flotation (Kordek and Lenczowski, 1989).

The objective of this study was to evaluate color measurements of mineralized froths to determine the mineral composition in the float product. The results were obtained from laboratory and plant tests, using a commercially available color-measuring unit. This instrument measured the hue and the intensity of light reflected from the test samples.

By providing instantaneous on-line information about froth composition, froth color measurement could augment the X-ray fluorescence analyses now used for flotation control. With froth color measurement, shielding for potentially harmful X-rays is not required. Also, it has the potential to be multiplexed, via fiber optics, to simultaneously monitor a number of individual flotation cells.

## Experimental

### *Principle of the color-measuring device*

The Qual-Probe 2000 system* (Hunter Associates Laboratory, Inc., Reston, VA) is designed for the on-line measurement of a product's color. The system consists of a sensor hardwired to an operator station, as per the *Qual-Probe 2000 Instruction Manual* (1989). This sensor employs a fiber-optic-based illumination and detection system, with the illumination coming from three light-emitting diodes at differing wavelengths. The preferred measuring distance was 1.5 to 2 in. The color of the reflected light is determined in arbitrary units, Q, based on the following equation:

$$Q = O + S\,(F_R R + F_A A + F_G G) \qquad (1)$$

where:

- O is the offset.
- S is the slope.
- $F_R$, $F_A$ and $F_G$, respectively, are the weighting factors for the red, amber and green wavelengths in the reflected light.
- R, A and G, respectively, are the normalized red, amber and green reflectance values.

The reflectance weighting factors, slope and offset values can be adjusted by the operator to maximize the system's sensitivity to the particular product being monitored. This color-measuring device was interfaced to a personal computer for automated data acquisition.

### *Color measurements*

Color measurements were made on dry mineral-particle beds and on mineralized froth in both laboratory and plant flotation cells. The dry mineral-particle beds were prepared by dry grinding, and the mixed mineral beds were prepared by mixing the appropriate amounts of the pure minerals. For color measurements, the sensor was positioned over a small bed of mineral particles (the upper exposed surface area was about 50 to 60 $cm^2$). The measuring distance was about 1.5 in., and the incident angle was 30°, unless otherwise specified. The color values were not significantly affected by the incident angle.

The color measurements of flotation froth layers in the laboratory were accomplished using a 5-L Denver cell at 1500 rpm. Tap water of natural pH was used, and Dowfroth 250 (0.1 mL) and potassium ethyl xanthate ($4.5 \times 10^{-4}$ mole) were added for mineral flotation. No froth was removed during the test, and all of the mineral in the cell was assumed to float under these conditions.

In-plant froth color measurements were performed at the molybdenite rougher and cleaner cells in a commercial

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*Reference to specific brand names does not imply endorsement by the US Bureau of Mines (USBM).

Table 1 — Color readings of dry mineral mixtures.

| Weighting factor | | | Q | | | |
|---|---|---|---|---|---|---|
| $F_R$ | $F_A$ | $F_G$ | $SiO_2$ | $CuFeS_2$ | $FeS_2$ | $MoS_2$ |
| 100 | 0 | 0 | 92.9 | 109.9 | 101.8 | 49.2 |
| 0 | 100 | 0 | 89.2 | 106.3 | 95.9 | 44.8 |
| 0 | 0 | 100 | 93.5 | 114.2 | 103.0 | 49.7 |

Instrument setting: slope = 1; offset = 0.

copper concentrator to assess the effectiveness of froth color for determining flotation performance. The sensor was installed on the flotation bank, perpendicular to the froth surface. Red, amber and green (RAG) weighting factors were determined using dry chalcopyrite and molybdenite particles. During the color measurements, froth samples were collected approximately every 20 min near the color measuring area. These samples were analyzed for pulp density and metal content, and four to six readings were averaged to obtain the reported correlations.

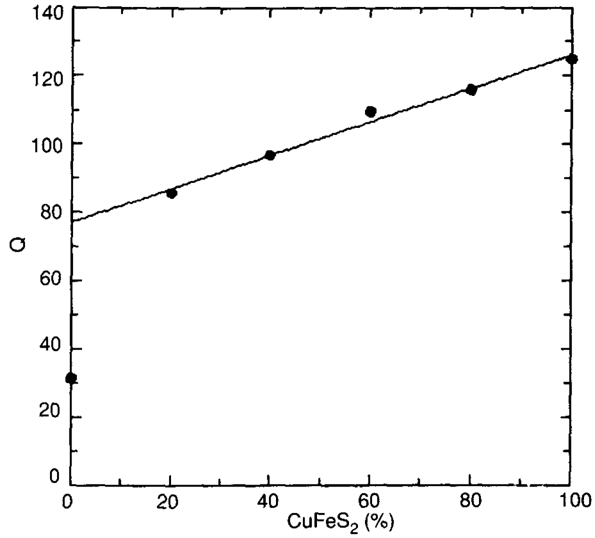


Fig. 1 — The Qual-Probe color signal for a dry quartz-chalcopyrite mixture. (RAG weighting factors = 31, 31 and 38, respectively; slope = 5.23; offset = –450.)

## Results and discussion

To investigate the capability of the color-measuring device to differentiate minerals, color measurements were performed for three types of mineral systems:

- pure minerals,
- dry mineral mixtures and
- mineral-laden flotation froth.

### *Dry single minerals*

Individual minerals were used to optimize the system setup. Color measurements were performed using beds of pure mineral: quartz, chalcopyrite, pyrite and molybdenite. The typical Q values for the minerals are listed in Table 1 for different RAG reflectance weighting factors.

The optimum instrument setting is very dependent on the system to be measured, and optimization is required only to differentiate between minerals. From the Table 1 data it appears that the range of responses was only slightly different for each of the three colors. The weighting factors required only slight adjustments to optimize differentiation among minerals in the test systems.

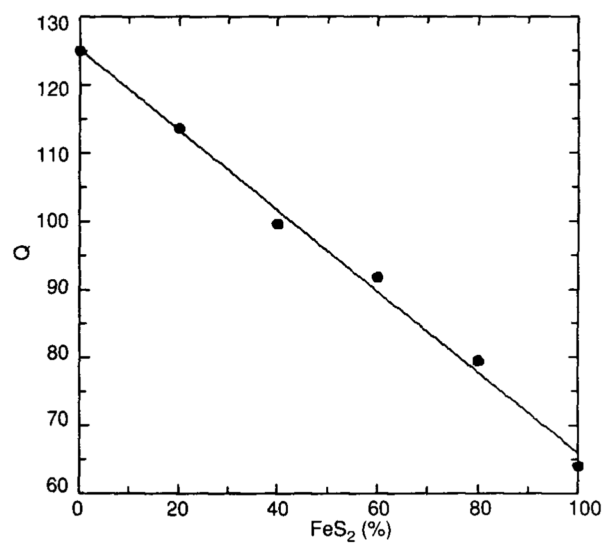


Fig. 2 — The Qual-Probe color signal for a dry chalcopyrite-pyrite mixture. (RAG weighting factors = 31, 31 and 38, respectively; slope = 5.23; offset = –450)

### *Dry mineral mixtures*

Initial color measurements were done in the laboratory using binary mixtures of dry minerals. The mixtures were chalcopyrite mixed with quartz, pyrite mixed with chalcopyrite, and molybdenite concentrate mixed with chalcopyrite tailings from the molybdenite flotation circuit.

The color readings for beds of quartz-and-chalcopyrite mixtures are shown in Fig. 1 as a function of the chalcopyrite content. The optimum weighting factors for this mixture were determined to be 31, 31 and 38, respectively, for the RAG signals. The instrument setting for the slope was 5.23, and the offset was –450. The color value for pure quartz was 31.4 units and was significantly different from that for chalcopyrite, which was 125 units. The signal increased gradually as the chalcopyrite content increased.

The readings for mixtures of chalcopyrite and pyrite are shown in Fig. 2. The values decreased as the pyrite content increased and reached 63.9 for pure pyrite. In this case, a fairly good linear relationship was observed, and the slope was –0.62 unit per pyrite wt %.

Similar color measurements were also performed using molybdenite rougher flotation concentrate and tailings obtained from a commercial copper concentrator. The concentrate and tailings contained mainly molybdenite and chalcopyrite, respectively. The readings for dry mixtures of these materials are shown in Fig. 3 as a function of molybdenite concentrate wt %. The sensor was positioned perpendicular to the mineral surface. The signals for the concentrate (69.8) and the tailings (91.7) were significantly different from each other, and the values decreased linearly as the molybdenite content increased.

### *Laboratory flotation froth*

The froth color measurements were made in a 5-L flotation

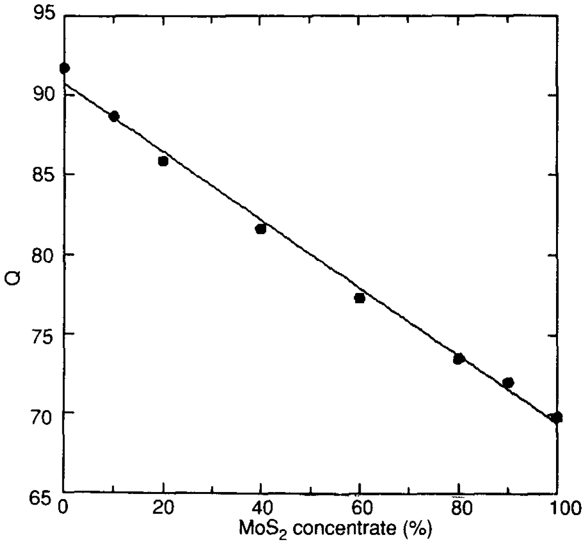


Fig. 3 — The Qual-Probe color signal for dry mineral mixtures of molybdenite rougher concentrate and tailings. (RAG weighting factors = 34, 32 and 34, respectively; slope = 1; offset = 0.)

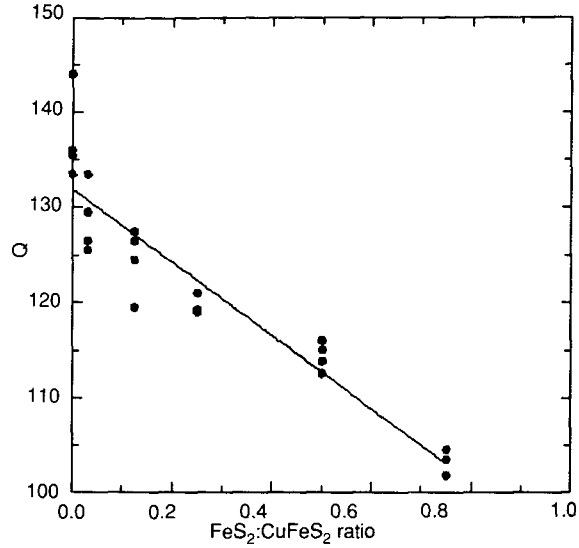


Fig. 5 — The Qual-Probe color signal for a froth layer loaded with a varying pyrite:chalcopyrite ratio. (RAG weighting factors = 31, 31 and 38, respectivley; slope = 5.23; offset = –450.)

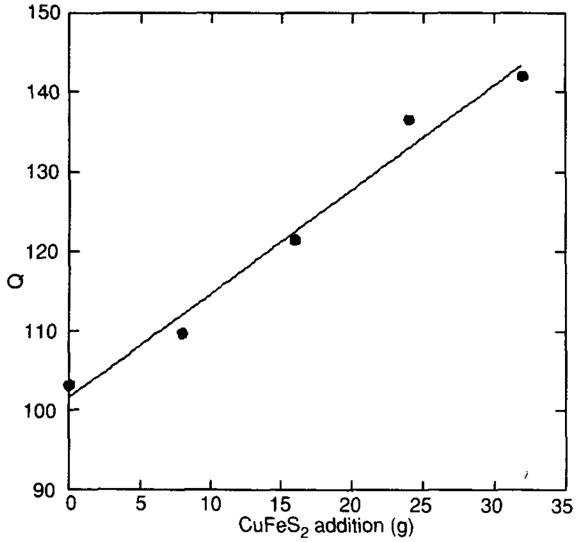


Fig. 4 — The Qual-Probe color signal for a froth layer loaded with varying amounts of chalcopyrite. (RAG weighting factors = 31, 31 and 38, respectively; slope = 5.23; offset = –450.)

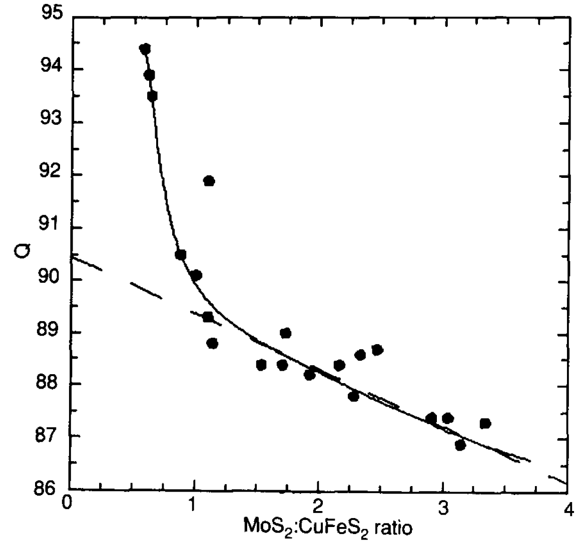


Fig. 6 — The Qual-Probe color signal for varying molybdenite:chalcopyrite ratios in the mineralized froths of plant molybdenite rougher cell. (RAG weighting factors = 34, 32 and 34, respectively; slope = 1; offset = 0.)

cell. A single-color reading was taken after 1 min of flotation. In one series, differing amounts of chalcopyrite were added to a constant 4 L of solution in the cell.

The color measurements for the flotation of pure chalcopyrite are shown in Fig. 4 for different amounts of chalcopyrite added to the flotation cell. The value for unmineralized froth was 103 and increased to 142 as the chalcopyrite content reached 32 g.

In a subsequent series, varying amounts of pyrite were added to the cell containing constant amounts of solution and chalcopyrite. Color measurements of mineral mixtures were conducted by adding pyrite to the 5-L cell containing 32 g of chalcopyrite, and the data are shown in Fig. 5. The addition of pyrite decreased the color value significantly. When the pyrite:chalcopyrite ratio was 0.75, the reading was similar to the value for froth only (Fig. 4).

These observations indicated that the color signal was quite sensitive to the proportion of chalcopyrite and pyrite in the froth. These data showed a 95% confidence limit of ±5.4 color units. One limitation of the present system is that the readings were not unique; a mineral-barren froth yields the same color response as a highly mineralized froth of chalcopyrite mixed with pyrite. Therefore, color measurements would need to be linked with other sensors for complete process control.

*Plant tests*

Color measurements were performed in a commercial molybdenite flotation operation. The color data from rougher and cleaner cells are shown in Figs. 6 and 7, respectively. The averages of the color signal measured during 1- to 1.5-min sampling periods are plotted as a function of the molybdenite:chalcopyrite weight ratio in the froth. The signal decreased as the molybdenite:chalcopyrite ratio in-

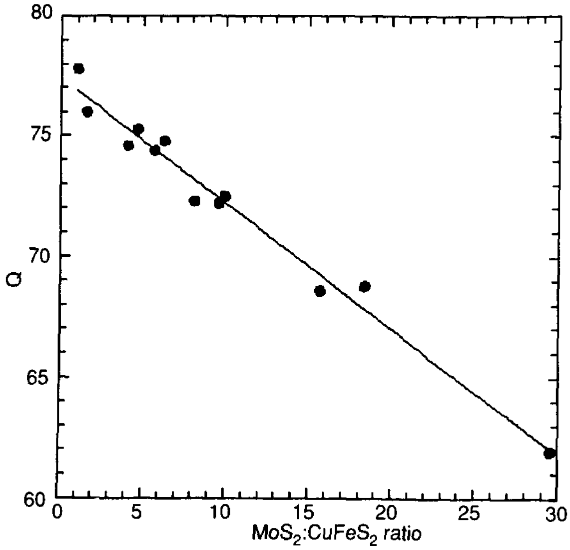


Fig. 7 — The Qual-Probe color signal for varying molybdenite:chalcopyrite ratios in the mineralized froths of plant molybdenite cleaner cell. (RAG weighting factors = 34, 32 and 34, respectively; slope = 1; offset = 0.)

creased for both the rougher and cleaner cells. In the case of the cleaner cell, a strong linear relationship was observed (Fig. 7, slope = −0.521 ± 0.025 unit per molybdenite:chalcopyrite weight ratio). A deviation from linearity was observed for a low molybdenite content in the rougher froth (Fig. 6). The reasons for the difference between these sets of observations are unclear. However, they may be due to differences in other variables, such as particle size, pulp density and impurity content.

*Application limits*

The color readings are likely to be affected by parameters other than froth composition, such as bubble size and froth loading. Also, sensor maintenance is a major concern since the sensor was contaminated by mist produced during froth breakage. Furthermore, for the best system response, the distance from the sensor to the sample surface must remain constant. If the sensor is to be developed for continuous use in a commercial flotation plant, aspects like these will require examination.

## Summary

The color measurements of dry minerals and mineralized froths showed that the color measuring device was able to detect differences in the composition of mineral particle beds and mineralized froths. The color signal changed linearly as the ratio of chalcopyrite:pyrite and chalcopyrite:molybdenite was varied within the mixtures. For the chalcopyrite-quartz mixture, the signal changed in a nonlinear fashion.

The utility of color measurements observed in laboratory flotation tests was verified in plant tests. Color measurements in plant molybdenite rougher and cleaner cells showed that the color signal decreased as the molybdenite:chalcopyrite ratio in the froth increased.

Froth color measurement could have an advantage over the X-ray fluorescence currently used for flotation control. The color measurement technique has the potential to provide instantaneous on-line information about froth composition without requiring shielding against potentially harmful X-rays. Also, via fiber optics, the froth color measurement system could likely be multiplexed to simultaneously monitor a number of individual flotation cells.♦

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## References

Cameron, E.N., 1961, *Ore Microscopy*, John Wiley & Sons, Inc., New York, p. 86.

Hunter Associates Laboratory, 1989, *Qual-Probe 2000 Instruction Manual*, Reston, VA.

Kordek, J., and Lenczowski, S., 1989, "Optical process control methods exemplified by diffractometric imaging of froth samples in flotation of copper ores," *Zesz. Nauk. Akad. Gorn.-Hutn. im. Stanislawa Staszica, Gorn.*, Vol. 146, 55 pp. (English abstract in *Chemical Abstracts*, 1990, Vol. 112, 238507b.)