

## Characterization of Hydrodynamics in SX Plants

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### ABSTRACT

Adopting chloride leaching technique at existing operations has put a very high bar to control the A/O entrainment in SX plants, because the chloride concentration in the PLS may increase one order of magnitude or even more, which multiplies the effect of the entrainment level.

A methodology to characterize the hydrodynamics in SX plants is provided, which involves experimental measurements at the existing plant to feed a predictive phenomenological model to anticipate the magnitude of entrainments and chloride along the whole SX circuit and the expected level of contamination in the EW electrolyte.

A novel procedure is introduced to measure the 3D field of velocity of the organic phase in industrial settlers and also measurement of droplet size distribution in mixers and settlers. The concept of critical droplet size is related, which conditions the drop size under which the decanter does not allow sedimentation and coalescence and it remain as entrainment in the exiting organic stream.

This methodology allows to design and dimension barriers like washing devices, post decanters, coalescence devices and similar, aimed to contain the aqueous entrainments and further contamination of the electrolyte. The modelling library also includes an electrochemical model to control chlorine gasification in the EW cells. It serves as an efficient tool to support decision making to face crud runs that always occur in SX plants.

A detailed case study is presented, including field measurements and scenario simulations. It allows safe planning of the chloride ramp up dynamics, facing the growing needs in time and verifying appropriateness of the planned control measures.

## INTRODUCTION

Chloride leaching at existing operations has put a very high bar to control the A/O entrainment in SX plants, with chloride concentration in the PLS ranging from 30 g/L to 150 g/L, this requires to produce less entrainment and also to have enough barriers to avoid this multiplying effect produce over contamination in the electrolyte. At conventional plant we still use the phase separation test to assess whether the organic is in good physical shape and the aqueous entrainments are scarcely measured.

Chloride leaching is the most probable route to dissolve chalcopirite nowadays, then we have the challenge to improve the knowledge in phase separation issues, with better comprehension of the fundamentals to develop new options to improve the hydrometallurgical business.

## METHODOLOGY

### What to measure

When we revise the state of the art in phase separation and handle of entrainment in SX systems, we feel lack of conceptual frame as well as fresh ideas to face this issue at industrial plants.

The primary condition for a drop to become entrainment is its size, but surprisingly drop size distribution is not ordinarily measured, neither in the mixer nor in the settler. Procedures to measure drop size distribution in mixer and settlers as well as how to properly relate these measurements to mixing, settling and coalescence variables are needed.

Once entering into the settler, aqueous drops in the organic phase are subjected to free settling in the moving organic phase, crud forms a number of aisles often located at the settler upper vertices and close to the organic weir. The organic moves through a net of channels promoted not only by the presence of crud, but also by channelling induced by the often defective picket fences. In aqueous continuous crud is expanded and located in the upper layer of the organic phase but in organic continuous it is pushed toward the O/A interface where the emulsion is eventually broken (Menacho, 1979). This produces additional velocity segregation throughout the upper and lower organic layers.

Average 3D measured organic velocity profile may differ significantly from that calculated from the organic flowrate divided by the cross section, bias is always to increase the calculated velocity. This underestimates the expected aqueous entrainment. Clearly, procedures to measure organic 3D velocity field as well as tools for useful interpretation are also needed.

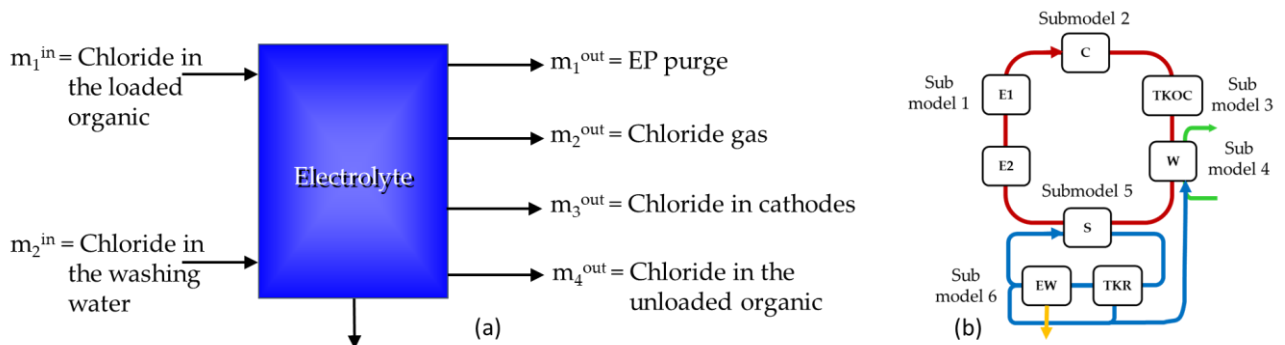
### The dynamic impurity balance

The transfer of chloride to the electrolyte can be dynamically represented assuming the differential change in impurity mass between  $t$  and  $t+dt$  is the difference between all mass flow entering and

the mass flow leaving the electrolyte at time  $t$ , solution of this equation drives to the mass of chloride along the time (Menacho, 2003):

$$\frac{dm_{Cl}}{dt} = \sum_p \dot{m}_p^{IN} - \sum_q \dot{m}_q^{OUT} \rightarrow m_{Cl} = f(t) \quad (1)$$

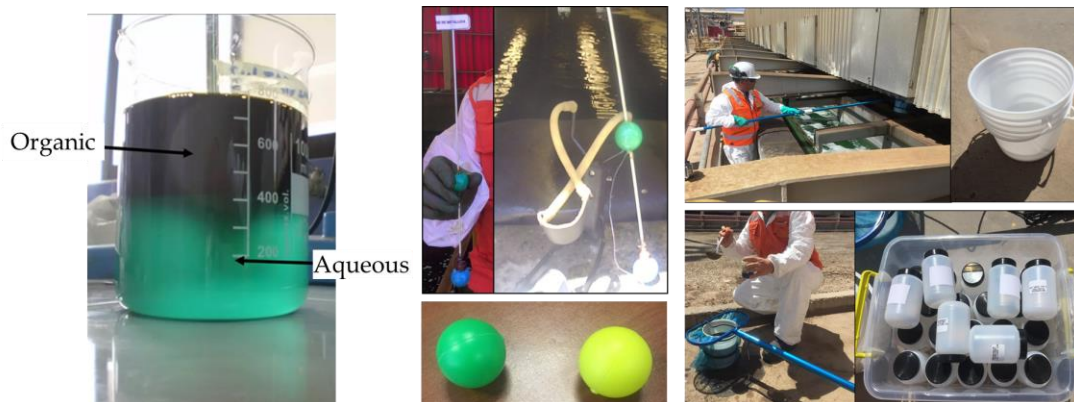
The above-set balance is illustrated in Figure 1a. In practice it is necessary to model the whole circuit to solve the overall balance, as illustrated in Figure 1b.



**Figure 1** Dynamic balance of impurities in the electrolyte

## Experimental Procedures

Main experimental procedures employed in this work are illustrated in Figure 2 below. In the left side the phase separation test using samples directly taken from the mixers, in the middle the apparatus to measure 3D organic velocity field is shown and finally, in the right side the sampling operation and the settling chamber to measure drop size distribution are presented<sup>1</sup>.



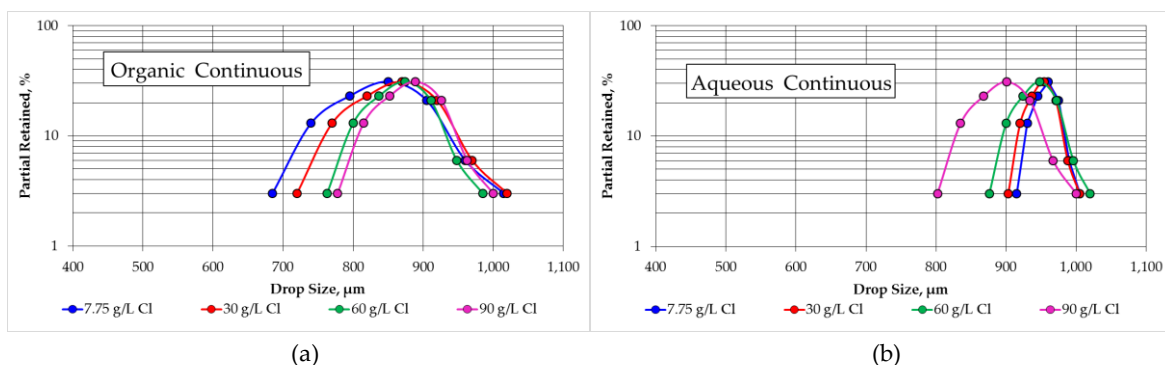
**Figure 2** Illustration of the experimental testing at the plant to get information on phase separation behaviour and entrainment control

<sup>1</sup> The drop size measurements in mixer and settler as well as the 3D velocity profile measurement are property of DRM and cannot be used without permission

## RESULTS AND DISCUSSION

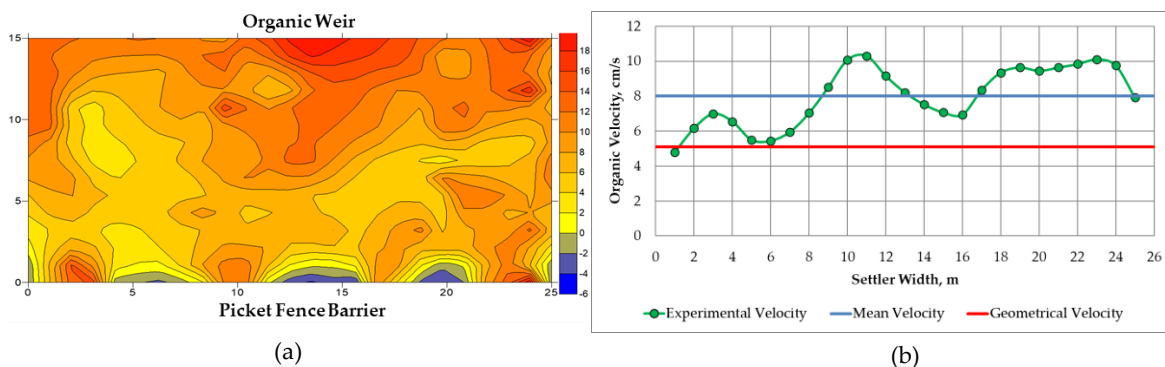
### Selected Results

Figure 3 shows partial drop size distribution deduced from phase separation tests, in this particular case, from chloride leaching tests. In organic continuous it can be seen that size of the aqueous droplets increase when the level of chloride increases, this is mainly attributed to the larger surface tension of the aqueous phase in high salinity media. The opposite situation occurs when operating in aqueous continuous, that is, smaller organic drops are produced, due to the increased viscosity of the aqueous continuous phase. Note that organic drops are larger than the aqueous ones.



**Figure 3** Drop size distribution at the mixer deduced from phase separation kinetic profiles

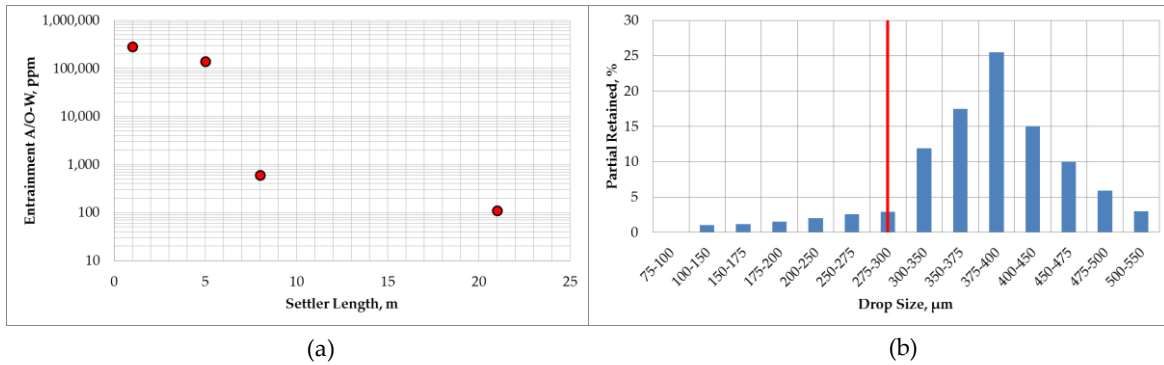
Figure 4a illustrates the velocity field measured in the organic phase in the settler, while Figure 4b shows the average lengthwise velocity. Note that the average from measurements is 8 cm/s while the geometrical average (flowrate divided by the cross section) is only 5 cm/s, strong difference for those skilled in the art.



**Figure 4** 3D organic velocity longitudinal profile

Figure 5a shows a typical lengthwise entrainment profile measured in samples taken from the side windows. In Figure 5b it is verified that the critical drop size is about 275 – 300 μm, that is, only drops staying at the right side of this size can be removed in this particular settler. If additionally,

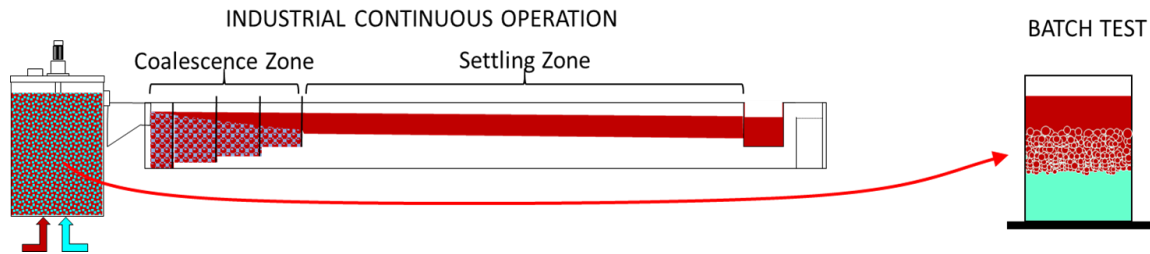
the entrainment level is known when exiting the previous stage, then entrainment leaving the present stage can be easily forecasted.



**Figure 5** Drop size distribution estimated from entrainment levels along the settler

## Drop Size Measurement

The continuous mixing of the two phases occurs in the mixer-chambers and separation in the subsequent settler. A batch phase separation test with same industrial dispersion taken from the mixer, is linked to the dispersion band dynamics in the settler, as it is shown in Figure 6.



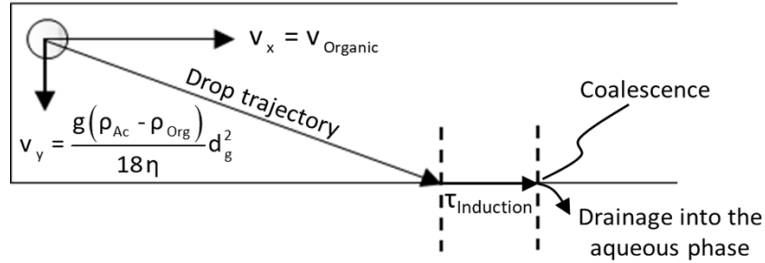
**Figure 6** Measurement and modelling of coalescence and settling phenomena

When a sample of dispersion is taken from the operating mixer, the interface appears after a while, moving slowly first and then faster to finally slow down again. Appearance of the aqueous solution means a reduction in volume of the dispersion, interpreted as the beginning of the coalescence after occurring packing of the aqueous drops toward the interface. Similar phenomena occur in the dispersion band of the continuous settler.

Assuming a sequential coalescence along time, drop size distribution is easily deduced from the batch phase separation test by applying the pedometric approach (Van Looy et al., 2017).

At industrial level the primary phase separation proceeds by coalescence of drops within the dispersion band, the remaining drops, coming from the mixer or produced during coalescence, move freely toward the exiting organic weir. Dynamics is driven by the balance between the force

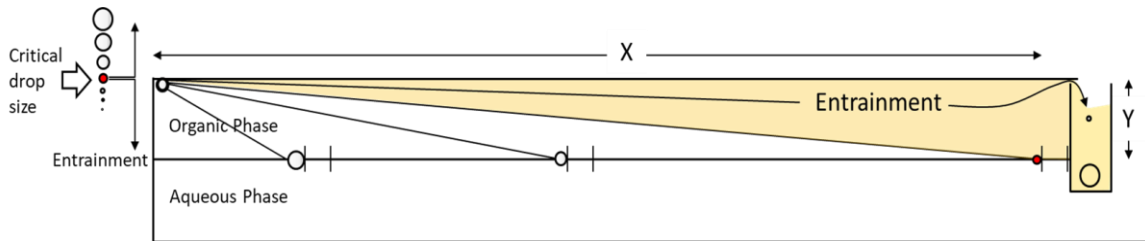
of gravity moving the drop down (Stokes law) and the force moving the organic phase horizontally toward the exit, as result, drops follow oblique path until reaching the interface and after passing the induction time, they coalesce into the aqueous phase as it is illustrated in Figure 7.



**Figure 7** Dynamics of isolated aqueous drops in the settler

## The Critical Drop Size Concept

Free settling of the drops along the settler is the main mechanism to reduce aqueous entrainment from the organic phase with a height  $Y$  moving along the length  $X$  of the settler, at a velocity  $v_x$ , drops reach the O/A interface at different times and length, but there exists a critical drop size which can settle and coalesce just in the maximum length of the settler, as it is shown in Figure 8. All drops smaller than the critical size are potential entrainments.



**Figure 8** Critical drop size which conditions magnitude of entrainment

Mathematically the critical drop size is given by:

$$d_{\text{crit}} = \sqrt{\frac{18\eta Y v_x}{\Delta\rho g X}} \quad (2)$$

If the drop size distribution and the critical drop size at the settler are known, then the efficiency and magnitude of the entrainment can be anticipated. Figure 9a shows a favourable condition to remove entrainment and Figure 9b shows the reverse situation.

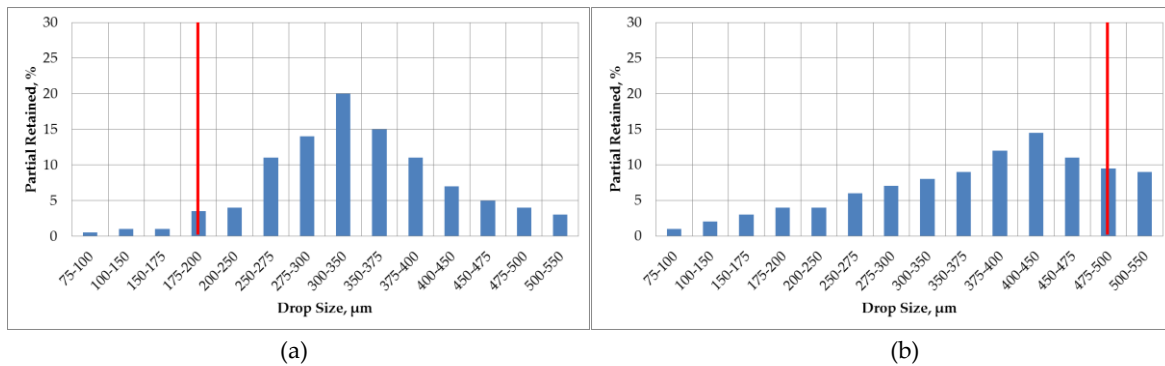


Figure 9 Effect of the critical drop size in potential entrainment

### Interpretation of the Phase Separation Test

The phase separation test is quite popular either at the SX industrial plants or as lab control test. The final separation time is compared to a reference time representing the organic in good physical shape.

Results in Figure 10 are analysed using two different approaches: (i) Criteria of the shorter phase separation time (standard criteria) and (ii) criteria based on the critical drop size.

In case (a) both approaches drive to same conclusion, in case (b) the standard criteria would drive to conclude the red line represent the best situation, but in reality, both lines are equivalent, given that both lines intersect at time  $\tau_{crit}$ . In the third case the standard criteria indicate the red line represents the best condition, but really it is the worse, given that width of the dispersion band is much higher.

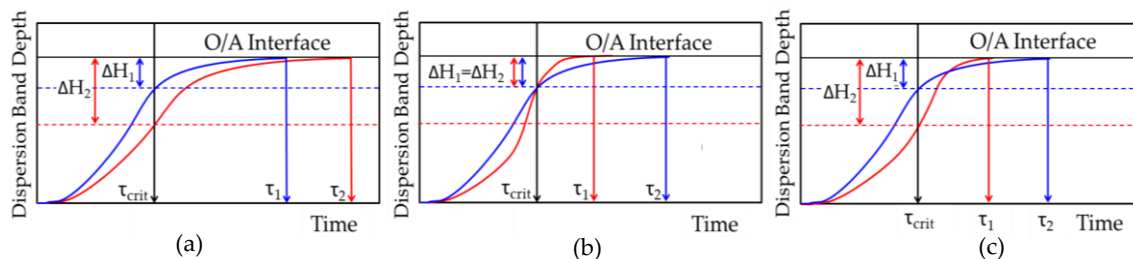


Figure 10 Different phase separation profiles

### Study Case: Ramp Up Forecast

After a comprehensive metallurgical testing and engineering survey, it has been decided to start the addition of NaCl as brine. Calculations indicate that along a 4-year period 30 to 35 g/L chloride will be reached.

The question is what to do at the existing SX plant in order that chloride do not overpass 40 ppm in the electrolyte, keeping basically the same current facilities but adjusting the operational conditions.

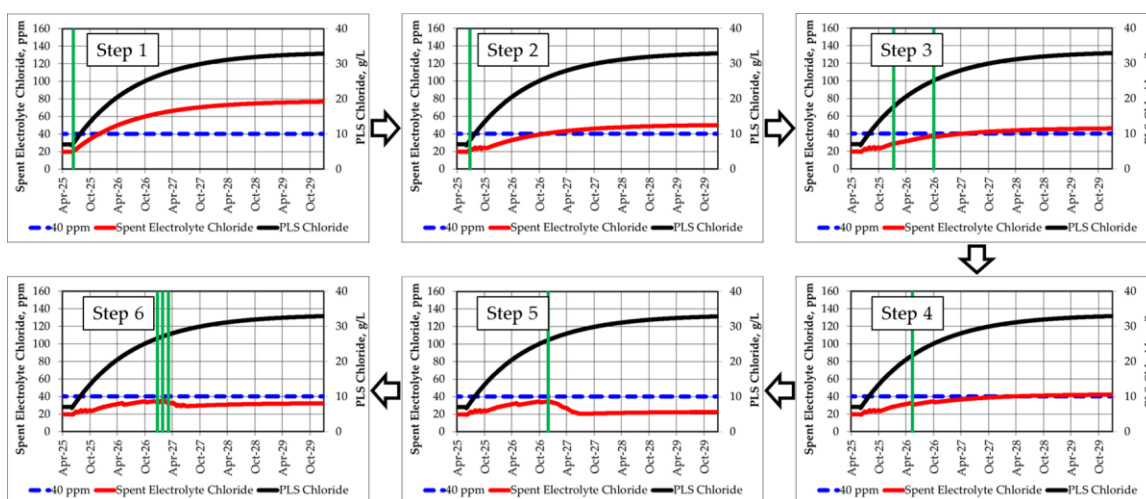


Two field campaigns oriented toward estimating drop size distribution in mixers and settlers in stages E1 and W and also measuring actual 3D organic velocity field in settlers of the same stages and entrainment level along the whole organic circuit were measured with the Imhoff cone method.

Parameters of the models were estimated in order to reproduce the current chloride balance centered in the accumulation in the electrolyte (see Figure 1). After modelling the plant circuit, simulations were run to look for the best pathway to avoid the plant go beyond 40 ppm chloride at any time. The optimal pathway is summarized in Table 1 and the expected results are graphically shown in Figure 11. Note that step 1 shows what would happen if we do not do anything but operating the plant under same current conditions, it is estimated we would reach 80 ppm chloride in the electrolyte at the end of the period. When the optimum pathway is considered we expect less than 40 ppm all the time.

**Table 1** Optimum ramp up pathway

Step N°	Description	Date	Before	After
1	Keeping current conditions, ppm	July 2025	20	78
2	Width of organic phase, cm	October 2025	25	38
3.1	Fresh wash water flowrate, m <sup>3</sup> /h	February 2026	30	50
3.2	Acid in fresh wash water, g/L	November 2026	24	30
4	Purge of spent electrolyte, m <sup>3</sup> /h	June 2026	30	40
5.1	PLS flowrate, m <sup>3</sup> /h	January 2027	6000	4500
5.2	Extractant level, % v/v	January 2027	20	24
6.1	Purge of spent electrolyte, m <sup>3</sup> /h	February 2027	40	30
6.2	Fresh wash water flowrate, m <sup>3</sup> /h	March 2027	50	30
6.3	Acid in fresh wash water, g/L	March 2027	30	24
6.4	Width of the organic phase, cm	April 2027	38	30



**Figure 11** Expected chloride in the electrolyte during the ramp up period. The green lines refer to date of operational changes according to Table 1



## CONCLUSION

The critical drop size is the size class which condition the level of entrainment at a given settler, according to dimensions and velocity of the organic phase. Options to estimate the drop size distribution at the mixer and the settler are given.

It is demonstrated that the classical interpretation of the phase separation time is not correct to estimate the magnitude of the entrainment at the plant. The correct way to do this is given.

The usual concept that the linear velocity of the organic phase is the flowrate divided by the normal area is not sufficient to estimate entrainments, because these are linked to the distribution of velocities, where the channelled flow may change drastically the real entrainment levels.

At any SX plant and particularly when chloride leaching is being adopted, a systematic sampling survey should be conducted aimed to characterize the hydrodynamic behaviour and its relationship with the entrainment, stable emulsions and contamination of the electrolyte with chloride and other impurities.

## ACKNOWLEDGEMENTS

We acknowledge our clients to give us the opportunity to learn about solvent extraction technology for more than fifty years.

## NOMENCLATURE

$m_{Cl}$	Chloride mass
$\dot{m}$	Mass flow
$d_{crit}$	Critical drop size
$\eta$	Dynamic viscosity of the continuous phase
$v_x$	Velocity in the x-direction
$\rho$	Density of the continuous phase
$g$	Gravitational acceleration

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