

## **Parametric Study of Leaching Processes Using a GUI Developed in Matlab**

**Gian Roncallo<sup>1</sup>, Kelly Barrios<sup>1</sup>, Luis Guillermo Obregón<sup>1</sup>,  
Guillermo Eliecer Valencia<sup>2</sup> and Javier Cardenas<sup>3</sup>**

<sup>1</sup> Research Group on Sustainable Chemical and Biochemical Processes  
Universidad del Atlántico, Carrera 30 No 8 – 49, Puerto Colombia, Colombia

<sup>2</sup> Efficient Energy Management Research Group, Universidad del Atlántico  
Carrera 30 No 8 – 49, Puerto Colombia, Colombia

<sup>3</sup> Civil Engineering Program, Faculty of Engineering  
Universidad Francisco de Paula Santander Colombia – Cúcuta, Colombia

Copyright © 2018 Gian Roncallo, Kelly Barrios, Luis Guillermo Obregón, Guillermo Eliecer Valencia and Javier Cardenas. This article is distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium provided the original work is properly cited

### **Abstract**

With the aim to enhance the learning process of the unit operation of Leaching, it is presented a GUI in Matlab® for designing systems with different types of contact where the stages reach the equilibrium between the solid and liquid phase. The program called LeachING is an application of theoretical studies and material balances presented in highly relevant documents and popular academic books, which has a general procedure that initiates by introducing the feed and solvent quantities with their respective compositions, and a raffinate exit condition for multistage equipment. Finally, material balances and multiple iterative routines were used to calculate raffinate and extract exit conditions, and the minimum number of stages necessary to reach them, allowing the user to get the approximate size and cost of the equipment making this software a powerful academic tool. With the program, it was compared the maximum separation for given conditions between countercurrent and crosscurrent equipment, the behavior of the percentage of separation when increasing feeding with constant solvent, and the behavior of the maximum feeding for the different types of contact.

**Keywords:** leaching, graphical user interface, engineering education

## 1. Introduction

Unit operations are the basic processes involved in the physical and chemical transformations of reactant preparation, separation, and purification of products, including distillation, leaching, absorption, adsorption, evaporation, drying, crystallization, among others, which are implemented according to the nature of the substances involved.

Leaching, also known as solid-liquid extraction is a mass transfer phenomenon in which a substance of interest (solute) mixed with a solid is recovered using a liquid solvent. The separated solution is commonly named extract, and the inert solid with solution retained is named raffinate [1, 2]. This operation has a great importance in industries as miner, where important metals are obtained like gold, copper, and platinum. Leaching is relevant in sugar extraction, where is presented a counter-current extraction tower for leaching sugar beets crops or crushed sugar cane [3], a different sugar extraction method by an alteration of the diffusion process [4], and the use of moderate electric field pulses (MEFP) for enhanced leaching of sugar beet crops [5]. A significant application of leaching processes is orientated to the environment, as is the removal of heavy metals (lead and cadmium) from contaminated soils using EDTA [6], the recovery of zinc from alkaline batteries using microwave or ultrasound assisted leaching [7], and a process for recycling tin, bismuth and copper from E-wastes and wastewater using swelling, ammonia leaching and hydrochloric acid leaching [8]. The main contribution of this paper is the development of a powerful and interactive software for calculating leaching operations under single stage, multistage crosscurrent, and multistage countercurrent using iterative routines and material balances, allowing the user to graphically visualize the operation.

## 2. Algorithm Presentation

The leaching operation has the following 3 methods of extraction, simple contact, contact in direct current, and contact in counter-current as shown in Figure 1. The simple contact is the simplest form of leaching. It contacted all solid with all solvent, for subsequently separating the formed solution and the remaining solid with a certain amount of retained solution. In addition, the contact in cross-current is a succession of leaching in one step, e.g., the total amount of solvent is subdivided and one part is mixed in each step. The refining of each step is brought into contact with a new solvent in the next separating the extract and the refining, which is again contacted with more solvent until all the leaching stages are exhausted. Finally, the counter-current contact is the leaching method most used in the industry. The feed and the solvent flow in opposite direction through the whole equipment.

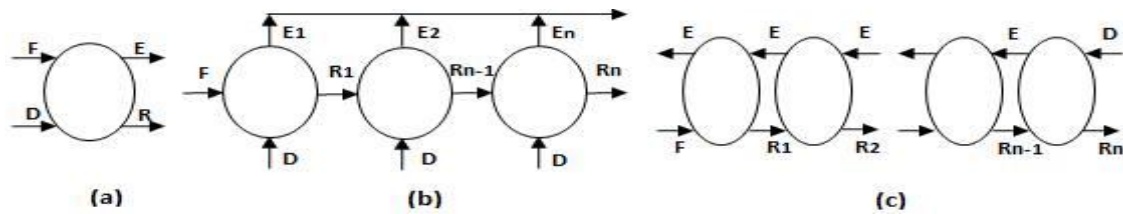


Figure 1. Leaching operation a) Single-contact, b) Direct current c) Counter-current.

The LeachING V1.0 program has an easy-to-use graphical interface, which is aimed at students, teachers, and chemical engineering professionals as a design tool for solid-liquid separation equipment. Figure 2 shows the data entry interface for a multistage countercurrent contact with a ternary diagram.

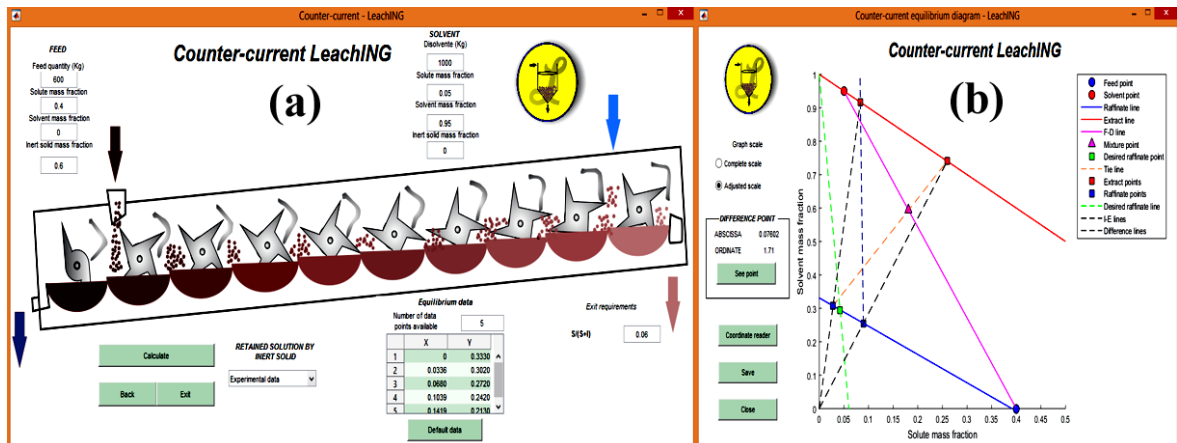


Figure 2. Main view of LeachING V1.0. a) Input data for counter-current contact, b) triangular equilibrium diagram.

Leaching problems can be solved by means of material and energy balances. In this work, it was considered only the material balances and the concept of the theoretical stage. The procedures used to solve this type of approach were graphic and algebraic. The graphical user interface created is a pedagogical tool for academic training of engineering students.

The computer flowchart for multistage countercurrent contact is shown in Figure 3.

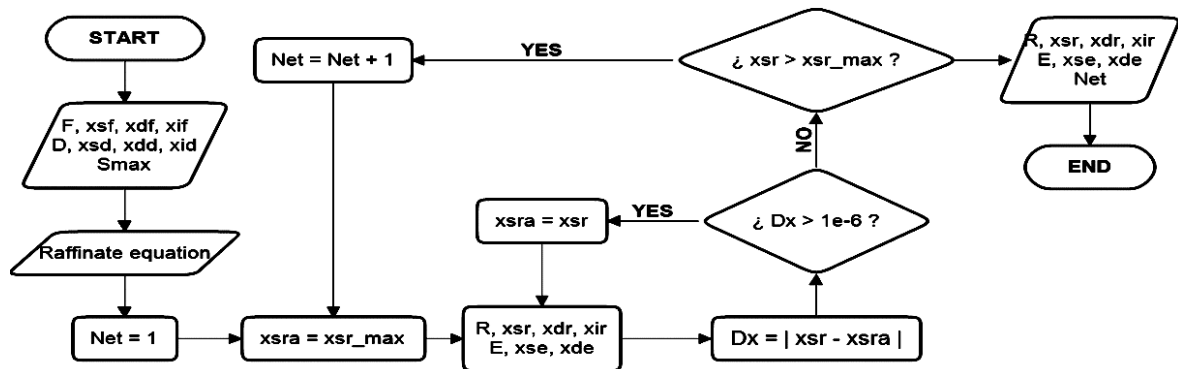


Figure 3: Flowchart for multistage countercurrent leaching

### 3. Discussion and Results

With the help of the LeachING software, three proposed case studies were analyzed with the aim of knowing the importance of the tool. It let to know the design conditions of the equipment, the current output conditions, and the triangular equilibrium diagram process.

#### Case study 1: Effect of the number of stages needed to obtain the desired separation for different types of contact

In order to obtain an appropriate value of the number of stages for a batch separation equipment, and for these steps to meet the specified separation percentage, it is necessary to determine the feed and solvent flow, and the composition of both streams. The given conditions were 1000 kg for feed quantity containing 40% solute and 60% inert, and 600 kg for solvent quantity, 100% solvent.

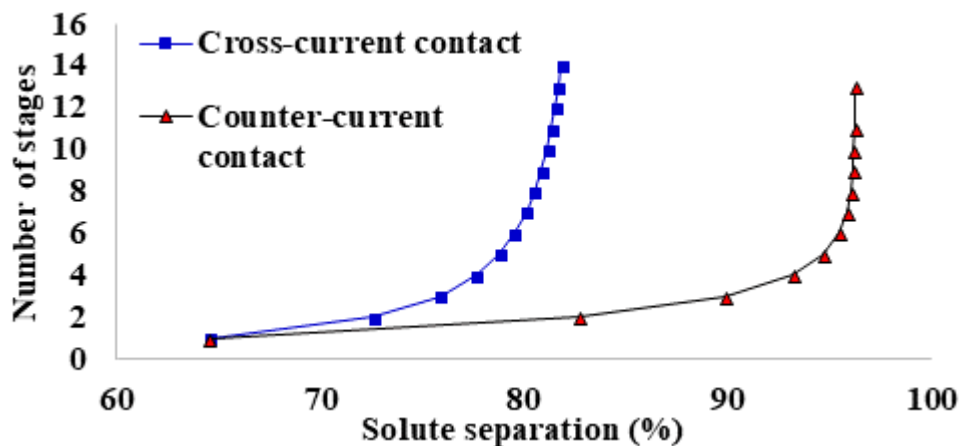


Figure 4. Behavior of the number of stages for different types of contact.

As can be seen in Figure 4, the separation obtained with the multistage countercurrent contact using a small number of stages is higher than that the

obtained with the cross-current contact, reaching a maximum separation percentage of approximately 95% while it was obtained 81% of separation for cross-current contact. Considering the point of view of cost minimization (fewer stages involve smaller equipment), choosing a counter-current operation system would be the most recommended. Both lines have an asymptotic behavior, which means that an increase in the number of separation steps does not have a considerable effect on solute removal.

### Case study 2: Effect of food to solvent ratio on the percentage of separation

In this experiment, the separation behavior in different equipment is evaluated when the load of the currents is varied. For this practice, the amount of total solvent that is loaded to the equipment is maintained constant, and the feed amount is gradually increased to get an increase in the ratio feed to solvent ( $F/D$ ).

The separation of the solid-liquid system is treated with the aim is to separate the trapped solute into a solid (inert) stream, using a liquid solvent. The given operating conditions for the Feed ( $F$ ) is variable but contains, 12% of solute, 3% of solvent and 85% of inert. The amount of Solvent ( $D$ ) is 1000 kg containing 100% solvent. It is evaluated the effect of the feed load and solvent ratio for each of the leach systems, with respect to the separation percentage and the number of steps required using the LeachING program. The results are shown in figure 5.

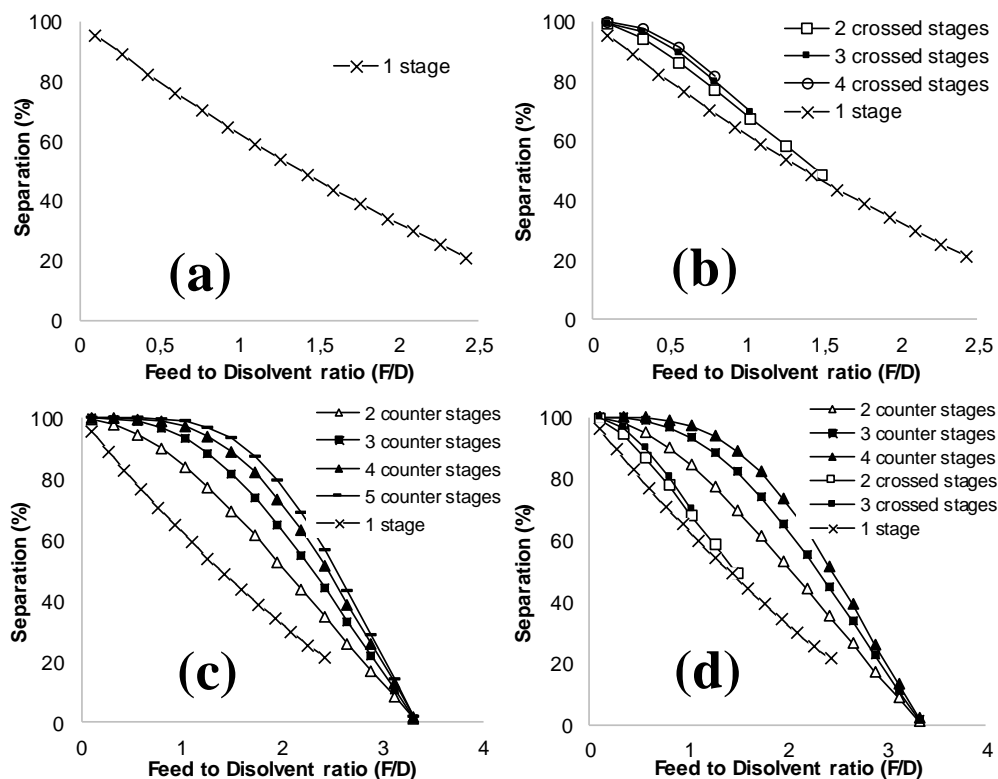


Figure 5. Behavior of the degree separation as a function of  $F/D$  a) One step, b) Crosscurrent, c) Counter-current, d) Comparison crosscurrent - countercurrent

Figure 5a, b, c, and d show that an increase in the ratio feed/solvent causes an increase in the percentage of solute separation, regardless of the type of contact. When using a cross-current contact in the range of  $F/D$  from 0 to 1, the higher the number of stages, the higher the separation (see figure 5b). For values of  $F/D > 1$ , the number of stages does not affect the degree of separation, so it is recommended to work with the lowest number of stages in this range. A similar behavior is obtained when using countercurrent contact (see figure 5c). However, higher degrees of separation are obtained when using the same number of stages (see figure 5 d). This pattern is maintained in the range of  $F/D$  from 0 to 3.4. For values of  $F/D > 3.4$ , no separation is obtained.

### Case study 3: Maximum separation to different operating conditions.

The behavior of the maximum separation with different types of contact is evaluated when the composition of solute is varied in both incoming streams, keeping fixed the amounts of solvent and food that enter to the process. The maximum separation is determined from the separation values obtained by experimentation with each operating condition. The operating conditions for the Feed (F) was 1000 kg with variable composition of solute and inert, with 0% solvent and the Solvent (D) was 1000 kg with variable composition of solute and solvent with 0% inert.

In this case study, It was evaluated the effect of the amount of solute present in both streams in the feed and solvent streams, following a similar process as the one performed in the first case study. The results obtained are shown in figure 6.

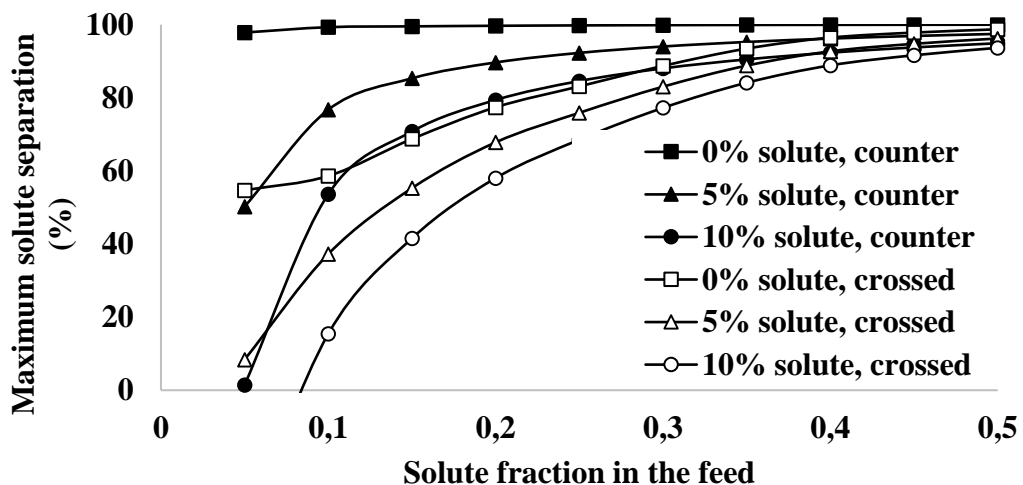


Figure 6. Comparison of maximum separation behaviors for both types of contact.

Figure 6 shows that the higher the purity of the solvent, the greater the amount of solute that can be withdrawn from the initial feed. It can be seen that countercurrent contact is more efficient than crosscurrent contact because the former achieves a higher amount of solute separation for the same solute fraction in the feed.

## 4. Conclusion

With the aim of improving the distribution of leaching knowledge, this article presents a software of high robustness and easy access for the user, called LeachING. It is able to compute by means of iterative routines and material balances, the output conditions of the separation process, and to show its graphical representation in a right triangle equilibrium diagram. It was represented the three general types of contact, single contact, crossed-current contact, and counter-current contact, making the software highly useful for leaching at industrial operation scale. It is useful for purposes of equipment design. The equilibrium diagram output allows the user to visualize the mass fraction behavior throughout the whole equipment, thus helping in the decision-making process. Three case studies were presented, the first one is the effect of the number of stages needed to obtain the desired separation for different types of contact. It was found that the separation obtained with the multistage countercurrent contact using a small number of stages, is higher than that obtained with the cross-current contact, reaching a maximum separation percentage of approximately 95% while it was obtained 81% of separation for cross-current contact. The second case was the effect of food to solvent relation on the percentage of separation. It was found that when using a cross-current contact in the range of  $F/D$  from 0 to 1, the higher the number of stages, the higher the separation. For values of  $F/D > 1$ , the number of stages does not affect the degree of separation. The same pattern was found when using countercurrent contact. The last case was the maximum separation to different operating conditions. It was found that countercurrent contact is more efficient than crosscurrent contact because the former achieves a higher amount of solute separation for the same solute fraction in the feed.

## References

- [1] J. Ocon Garcia and G. Tojo Barreiro, *Problemas de Ingeniería Química, Operaciones Básicas*, 1 ed. Vol. 2, Editorial Aguilar, 1972.
- [2] R. E. Treybal, *Mass-Transfer Operations*, 3rd ed., McGraw-Hill Book Company, 1980.
- [3] W. Dietzel and S. Matusch, Extraction Tower for Sugar Beets Cossettes or Crushed Sugar Cane, Germany Patent, 1974.
- [4] G. E. Vahdettin, Process for sugar extraction, Turkey Patent, 1964.
- [5] A. B. Jemai and E. Vorobiev, Enhanced leaching from sugar beet cossettes by pulsed electric field, *Journal of Food Engineering*, **59** (2003), 405-412. [https://doi.org/10.1016/s0260-8774\(02\)00499-5](https://doi.org/10.1016/s0260-8774(02)00499-5)

- [6] Q. Hao, J. Tian, X. Li and L. Chen, Using a hybrid of green chemistry and industrial ecology to make chemical production greener, *Resources, Conservation and Recycling*, **122** (2017), 106-113.  
<https://doi.org/10.1016/j.resconrec.2017.02.001>
- [7] S. Maryam Sadeghi, G. Vanpeteghem, I. F. F. Neto and H. M. V. M. Soares, Selective leaching of Zn from spent alkaline batteries using environmentally friendly approaches, *Waste Management*, **60** (2017), 696-705.  
<https://doi.org/10.1016/j.wasman.2016.12.002>
- [8] S.-H. Jeon, K. Yoo and R. D. Alorro, Separation of Sn, Bi, Cu from Pb-free solder paste by ammonia leaching followed by hydrochloric acid leaching, *Hydrometallurgy*, **169** (2017), 26-30.  
<https://doi.org/10.1016/j.hydromet.2016.12.004>

**Received: July 25, 2018; Published: August 18, 2018**