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The Effects of Operational Parameters on the Efficiency of a Mixer-Settler Extractor

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Abstract
The effects and influences of various operational parameters on the efficiency of mixer-settlers are thoroughly studied in this paper. One of the most important factors in designing a mixer-settler is to obtain an optimum operational extraction and overall efficiency. These two factors are dependent on various parameters such as impeller shape, size and speed of impeller, baffle size, residence time, volumetric flow rates and the ratio of heavy to light phases. In this paper, the effect of impeller speed and volumetric flowrates of two phases on efficiency are studied. Also, the effect of hold-up of each stage upon stage efficiency is studied.
According to the above experiments and achieved results, it can be concluded that in general, an increase in impeller speed and solvent amount results in an increase in extraction efficiency. Also, when hold-up of the dispersed phase decreases, the stage efficiency usually increases up to a certain point.

Keywords: *Liquid-Liquid Extraction, Mixer-Settler, Efficiency*

Introduction

There is a variety of equipment used in solvent extraction. However, mixer-settlers, due to their high flexibility, high capacity and efficiency, are often used in different processes in industry such as chemical, pharmaceutical and nuclear industries. Although their large hold-up, as compared to other extractors, is considered a weakness, mixer-settler extractors are widely used in industries because of their high capacity and low number of stages. Mixer-settlers can also withstand high turbulence rates without producing flooding. In addition, they can easily withstand continuous start-up and standby during working periods without destroying the solution [1, 2].

The efficiency is usually considered as one important parameter in selecting optimum conditions for designing mixer-settler extractors. Also, the study of efficiency helps to achieve appropriate performance of the extractor. Several investigators have studied the effect of some parameters such as impeller speed, solvent amount and hold-up on efficiency [3-5]. They observed that the efficiency would increase when agitation speed and solvent amount increase. Also, it has been observed that the efficiency increased monotonously with agitation speed

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and also the stage efficiency based on the dispersed phase concentration varied with the ratio of slopes between the equilibrium line and the operating line [6].

The mixer-settler extractor used in these experiments is made of two separated inter-connected cylindrical chambers, a mixer and a settler. In each stage, the light and heavy phases are mixed in a mixing chamber and the mixed liquid (dispersion) is transferred to the settling chamber (settler). The settler unit has two outlets where the light phase after separation leaves at the top and the heavy phase leaves at the bottom. Both outputs are then led to the next stages. A drawing of a mixer-settler and one of the stages used in these experiments are shown in Figures 1 and 2, respectively.

Efficiency

Efficiency depends on different parameters such as impeller speed, solvent amount, feed amount and hold-up [7]. In this paper, we studied the effect of these parameters on stage extraction and overall efficiencies. Figure 3 shows the characteristics of a co-current single stage where line "AB" is the operating line, point "C" is the intersection of operating line and equilibrium curve and point "B" is the output concentration of each stage and in general, the locus of actual effluent concentrations from the stages are represented by the "Pseudo-equilibrium" curve. The definitions for measuring efficiencies are as follow:

$$E_{ext} = \frac{X_{in} - X_{out}}{X_{in} - X^*} \quad (1)$$

$$E_{stage} = \frac{x_1 - x_2}{x_1 - x_e} = \frac{y_2 - y_1}{y_e - y_1} \quad (2)$$

$$E_o = \frac{N_{ideal}}{N_{actual}} \quad (3)$$

Characteristics of the Mixer-Settler and the Chemical System

The counter-current mixer-settler used in these experiments consisted of ten stages in cascade with a pump-type pattern propeller in each stage, which could pump the solution between stages. All stages are made of glass in order to observe the two phases. The interface level of the two phases in every settler can be controlled and also samples can be taken from two phases by a sampling device mounted on each settler. The rotor speed and the pumping degree, which are digitally adjusted, can be easily controlled. Of course, first the calibration curves for the feed and the solvent pumps were also obtained.

The chemical system used in these experiments is water/acetone/toluene, where water is considered as the continuous phase (solvent), toluene as the dispersed phase and acetone as a solute. At the beginning of the operation, water and toluene are brought to saturation and acetone with a known concentration is then added to the toluene phase (feed phase). Physical properties of the chemical system used in these experiments are shown in Table 1. The equilibrium curve data for this system are derived from international references and also the data are checked in the laboratory [8]. The equilibrium curve data are shown in terms of the concentration of acetone in toluene and water phases in equilibrium conditions at a temperature of 27 °C.

Experimental Procedure

In order to start operations, at the beginning of experiments, the two pumps for the feed and the solvent phases are turned on until all stages are filled with the two phases. Then, the interface level in each settler was carefully controlled to bring the system to the steady-state condition.

Table 1. Physical properties of the chemical system under study

System	μ_d (cP)	μ_c (cP)	ρ_d (gr/cm^3)	ρ_c (gr/cm^3)	σ (dyne/cm)
Toluene/ Acetone/ Water	0.574	1.08	0.864	0.994	27

To obtain optimum results, before collecting samples from each stage, enough time was given to the system to let the two phases to leave the stages. The concentration of acetone was measured by gas chromatography method. Some experiments were repeated two or three times in order to eliminate any errors and to ensure the results.

Totally, four series of experiments were carried out in order to study the effect of operational parameters on efficiency.

The first series of experiments were made with the following parameters:

- A known and constant volumetric flow rate for both phases
- A known concentration of acetone in toluene (3% by weight)
- Three different impeller speeds: 800, 900, and 1000 rpm

These experiments were made to study the effect of impeller speed upon the efficiencies.

The second series of experiments were made with the following parameters:

- A constant impeller speed (1000 rpm)
- A constant volumetric flowrate for the continuous phase
- Different volumetric flowrates for the dispersed phase

In this series of experiments, the effect of volumetric flowrate of the dispersed phase upon the efficiencies was studied.

The third series of experiments were made with the following parameters:

- A constant impeller speed (800 rpm)
- A constant volumetric flowrate for the dispersed phase
- Three different volumetric flowrates for the continuous phase (heavy phase)

In this series of experiments, the effect of continuous volumetric flowrate upon efficiency was studied.

Finally, in some experiments, we measured the hold-up of the dispersed phase. For measuring hold-up, the mixer-settler is shut down and then the volume of each phase is measured in all stages. The ratio of dispersed phase volume to total volume in each stage is defined as hold-up.

Experimental Results

Figures 4, 5 and 6 show the effect of impeller speed, and volumetric flowrates of dispersed and continuous phases upon the efficiency, respectively. Figures 7 and 8 show how hold-up and stage efficiencies change along the cascade, respectively. From the above figures, the following results can be obtained:

- An increase in impeller speed results in an increase in extraction efficiency and a decrease in overall efficiency. Also, an increase in impeller speed results in an increase in the distance between operating curve and equilibrium curve at constant conditions (Figures 9, 10 and 11).
- An increase in volumetric flowrate of the dispersed phase results in a decrease in extraction efficiency and an increase in overall efficiency. Also, with an increase in volumetric flowrate of the dispersed phase, the operating curve approaches the equilibrium curve at constant conditions (Figures 12, 13 and 14).
- An increase in volumetric flowrate of the continuous phase results in an increase in extraction efficiency and a decrease in overall efficiency. Also, an increase in volumetric flow rate of the continuous

phase results in an increase in the distance between the operating and equilibrium curves at constant conditions (Figures 15, 16 and 17).

- When the dispersed phase hold-up increases, the stage efficiency decreases (Figures 7 and 8). Of course, the stage efficiency also depends on residence time of drops.

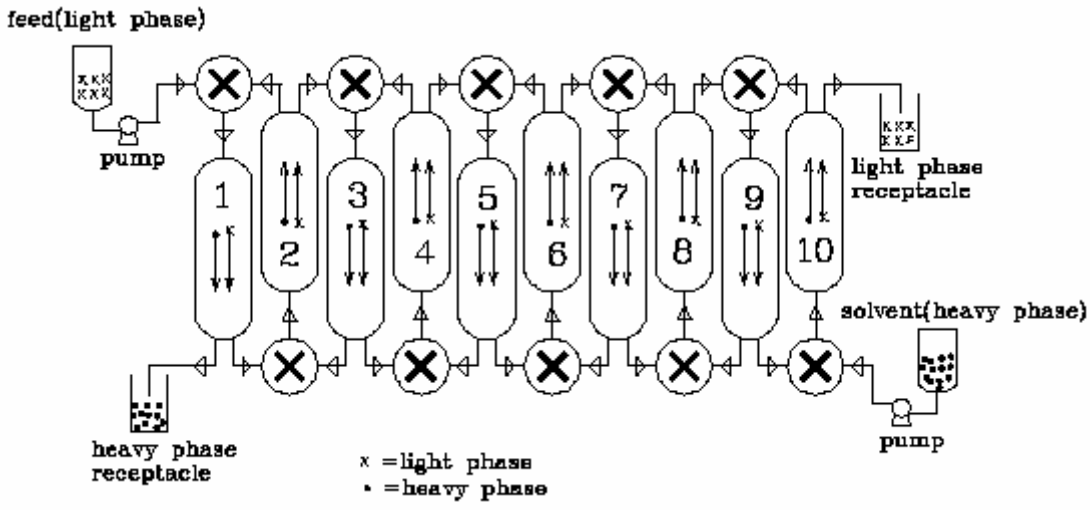


Figure 1. Schematic of a horizontal mixer-settler

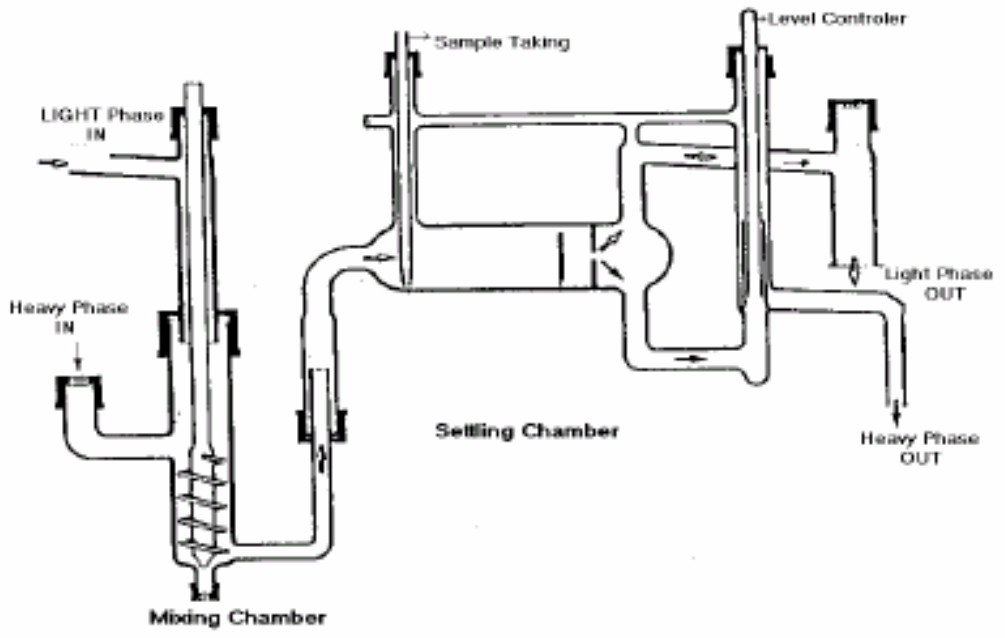


Figure 2. Characteristics of a single stage

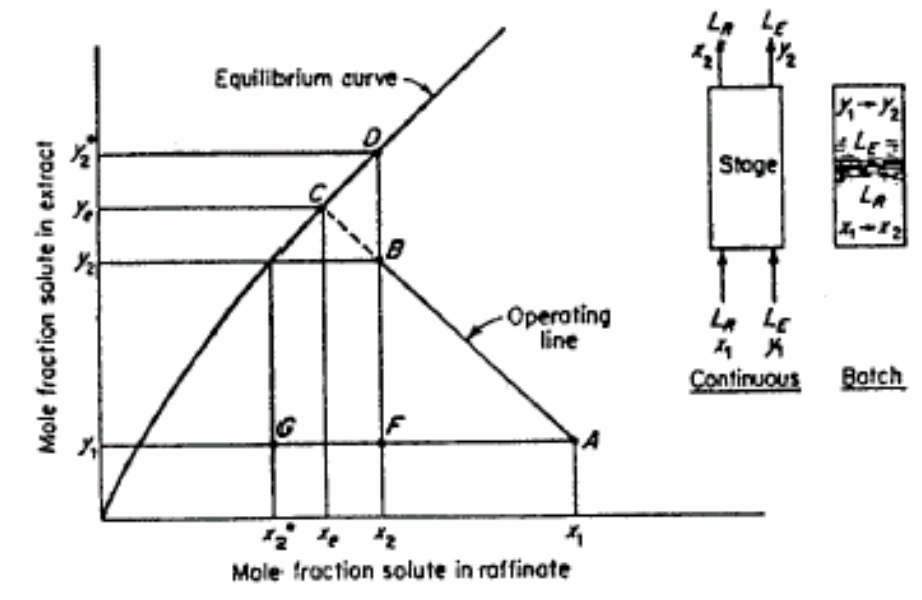
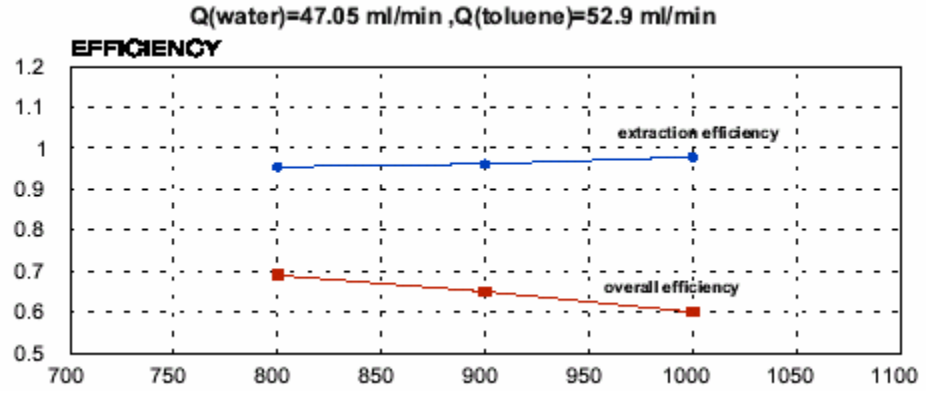


Figure 3. Stage efficiencies of a single stage [7]



	800	900	1000	
EXTRACTION EFF.	0.9547	0.9621	0.9791	
OVERALL EFF.	0.69	0.65	0.6	

Figure 4. Extraction and overall efficiency versus impeller speed

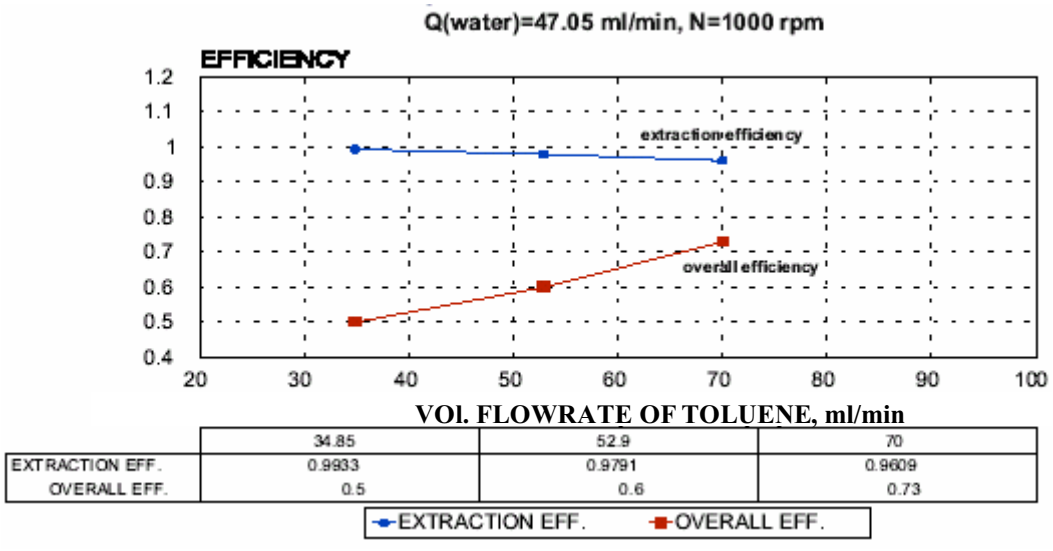


Figure 5. Extraction and overall efficiencies versus dispersed phase volumetric flowrate

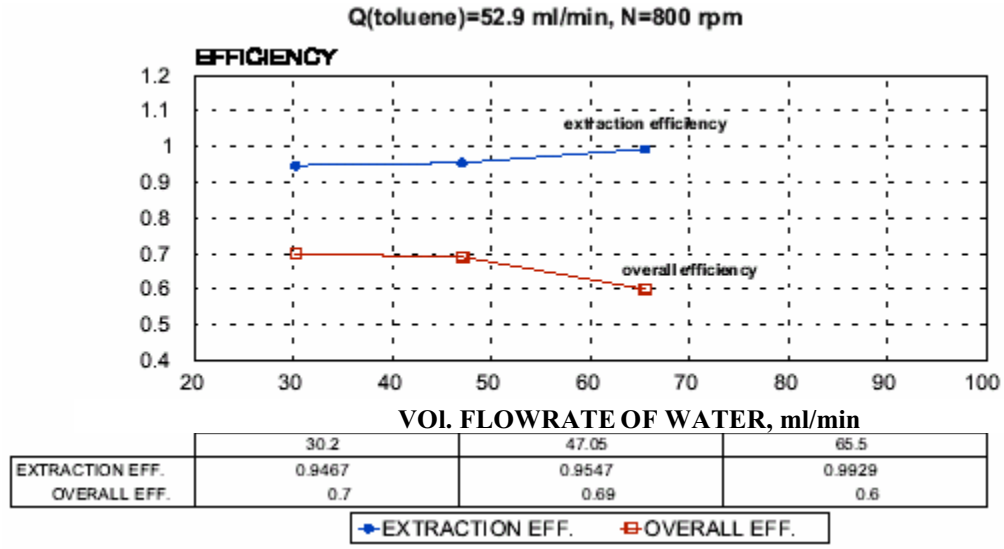


Figure 6. Extraction and overall efficiencies versus continuous phase volumetric flowrate

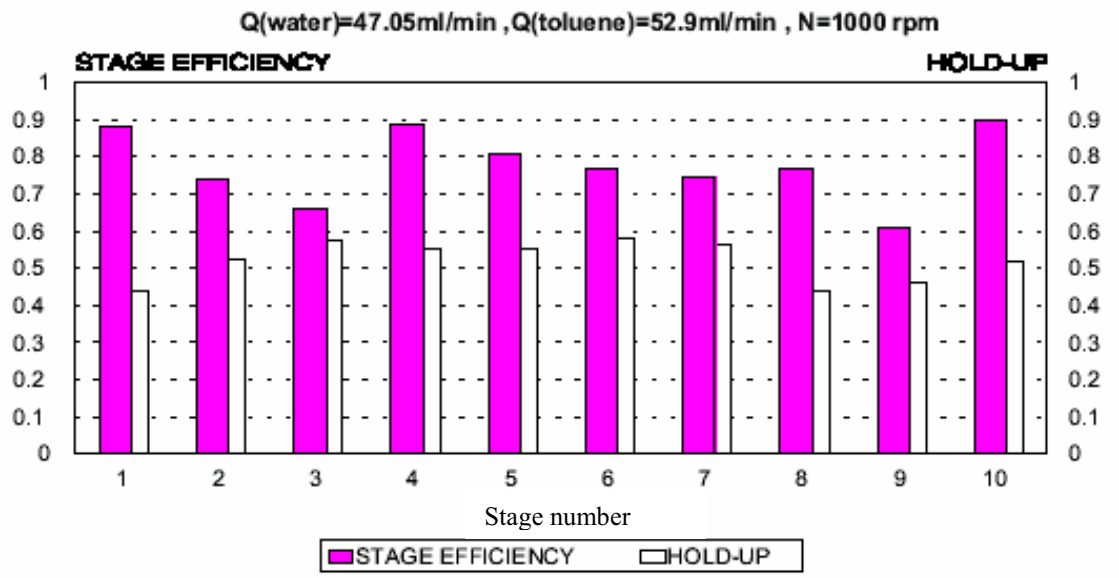


Figure 7. Variation of stage efficiency and hold-up among stages

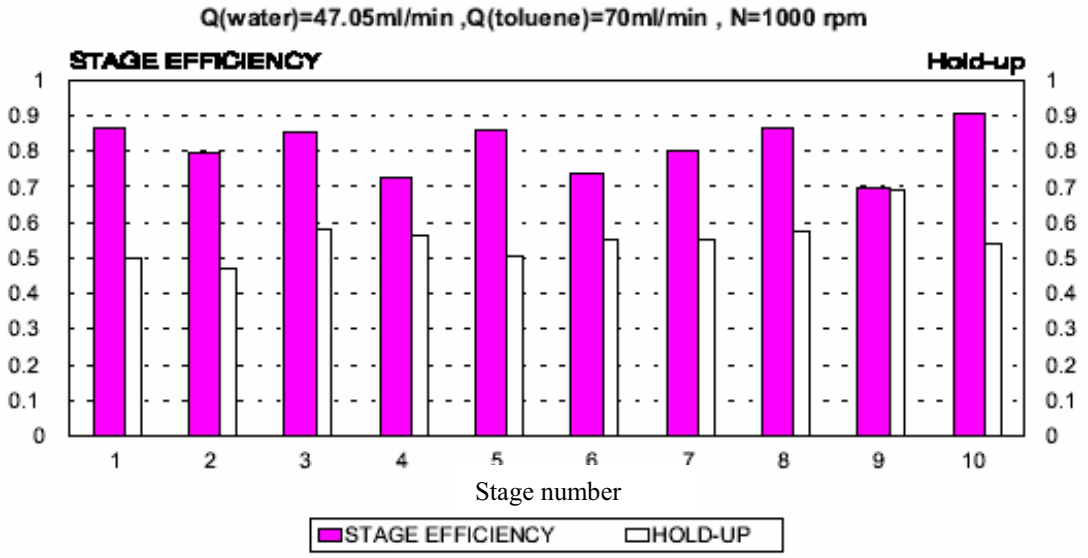


Figure 8. Variation of stage efficiency and hold-up among stages

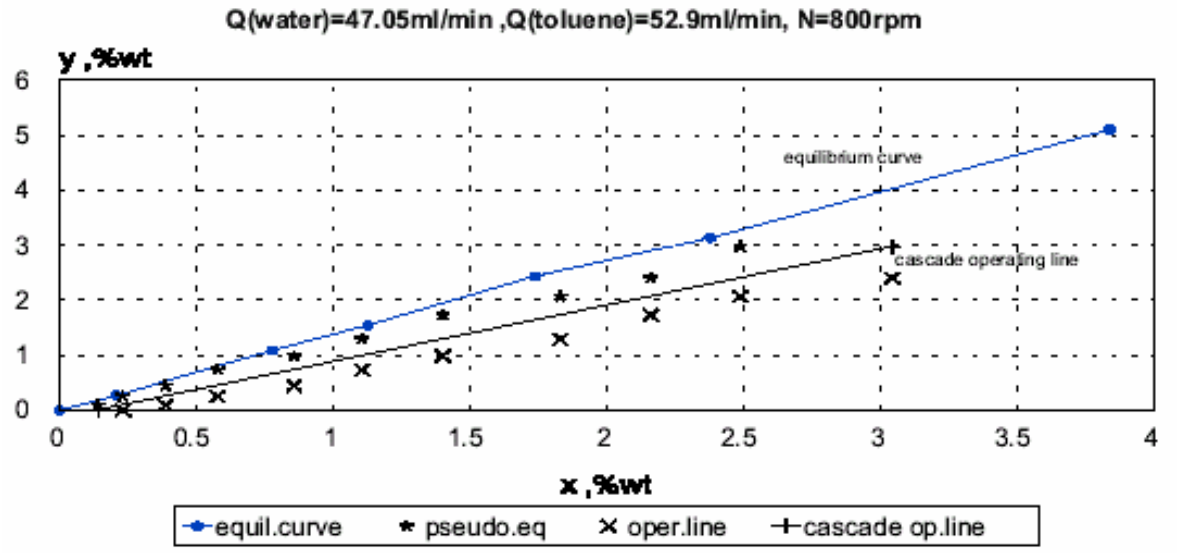


Figure 9. The operating curve of mixer-settler at 800 rpm

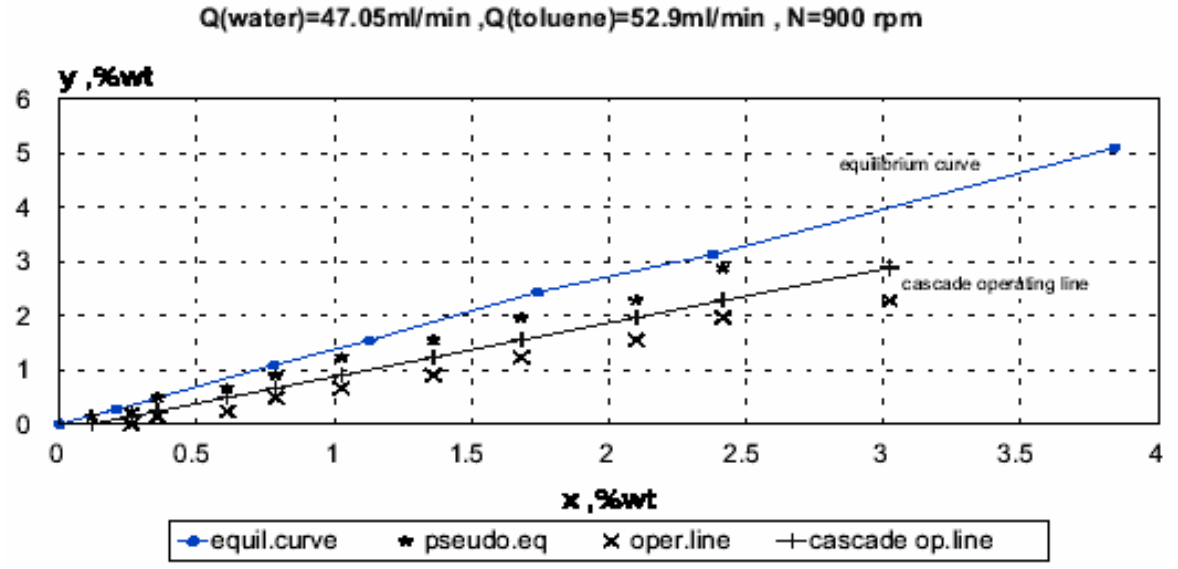


Figure 10. The operating curve of mixer-settler at 900 rpm

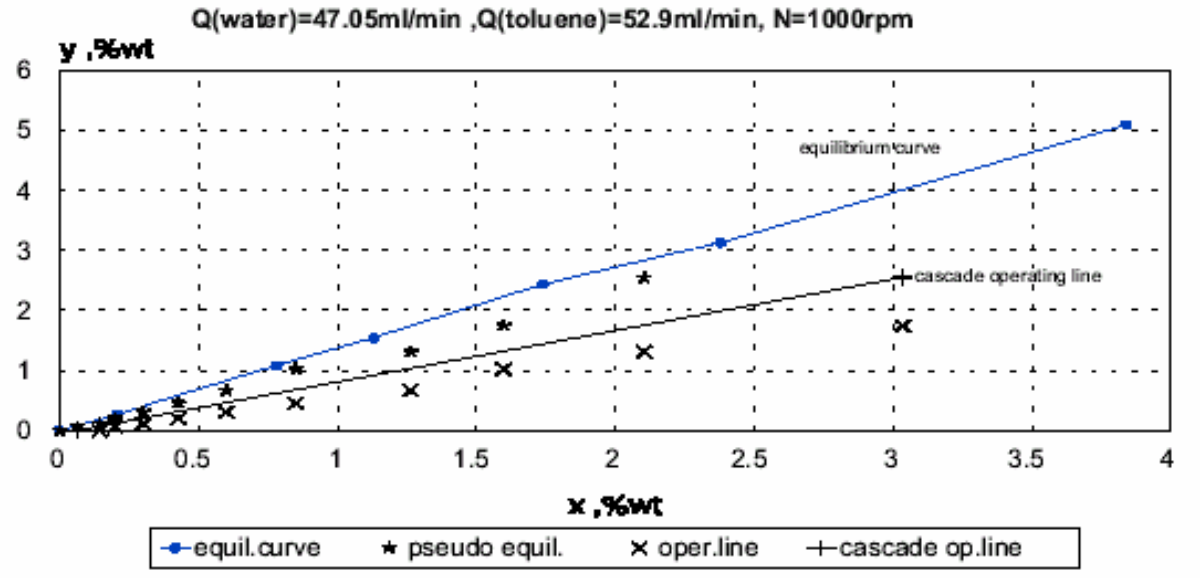


Figure 11. The operating curve of mixer-settler at 1000 rpm

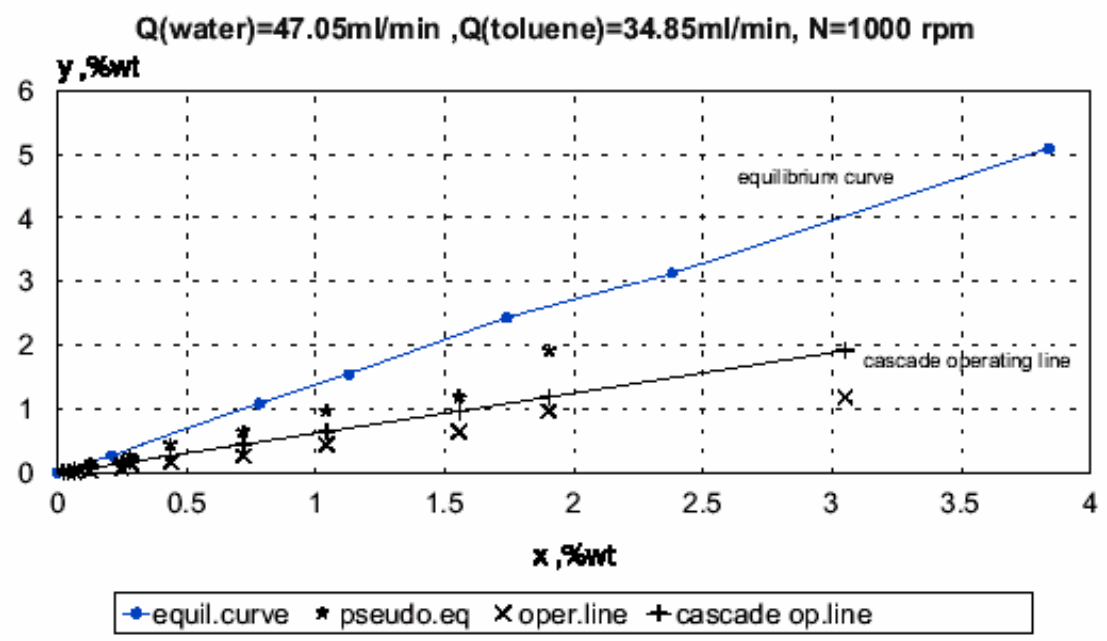


Figure 12. The operating curve of mixer-settler at 1000 rpm

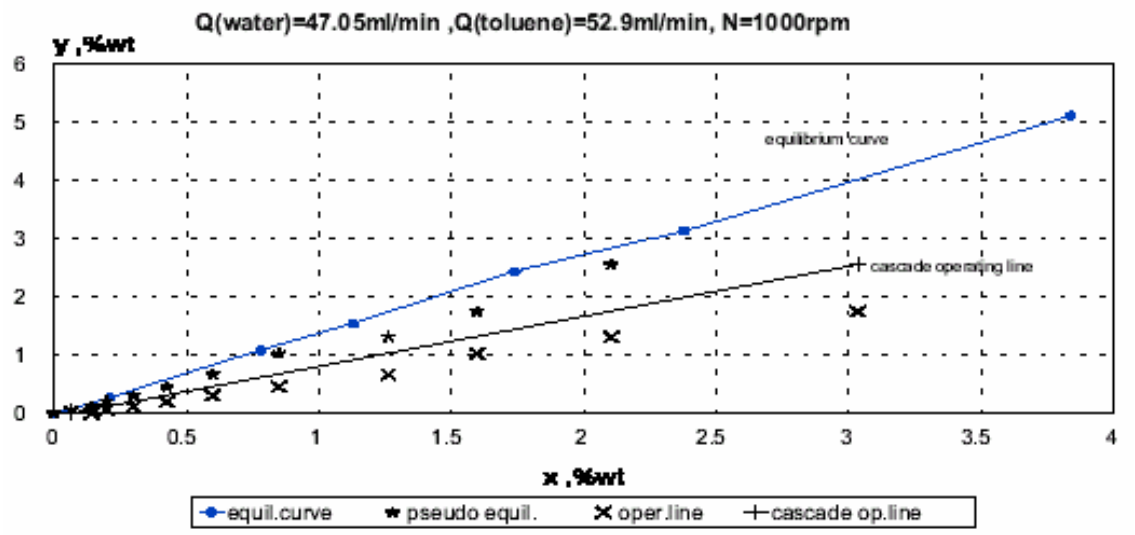


Figure 13. The operating curve of mixer-settler at 1000 rpm

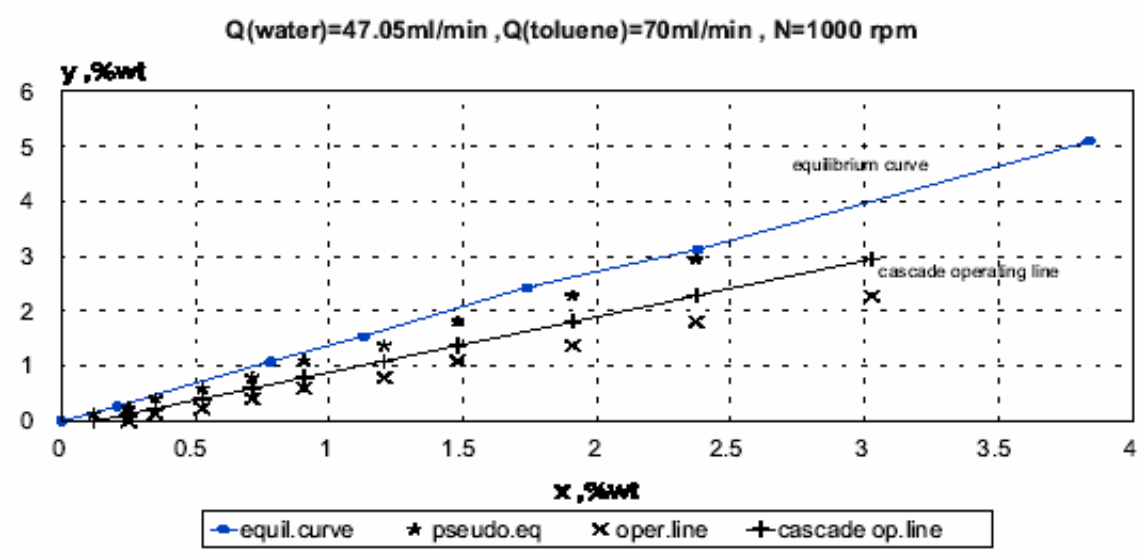


Figure 14. The operating curve of mixer-settler at 1000 rpm

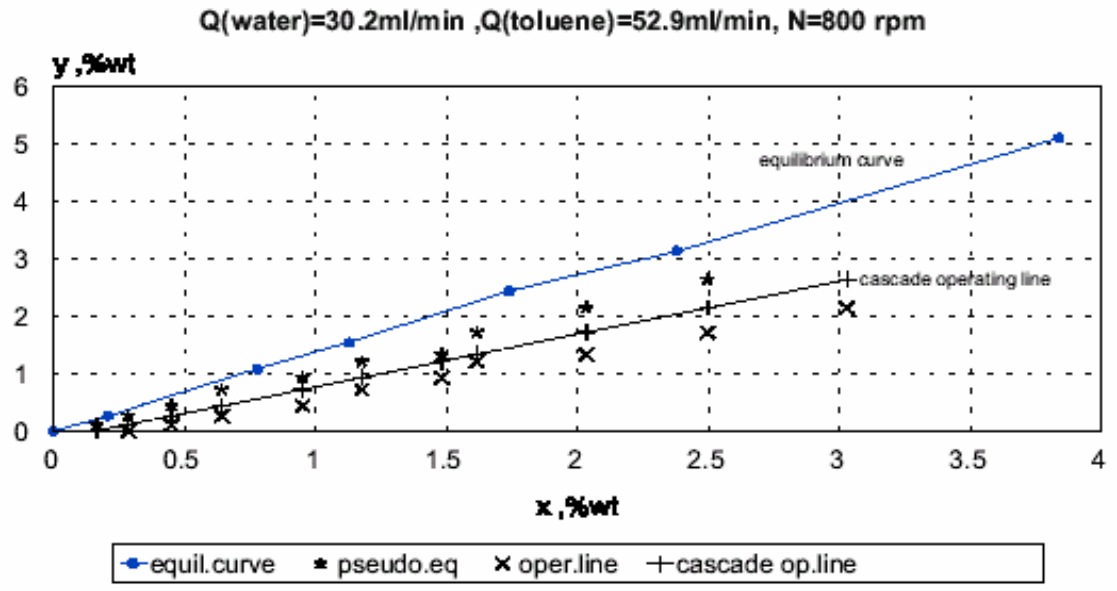


Figure 15. The operating curve of mixer-settler at 1000 rpm

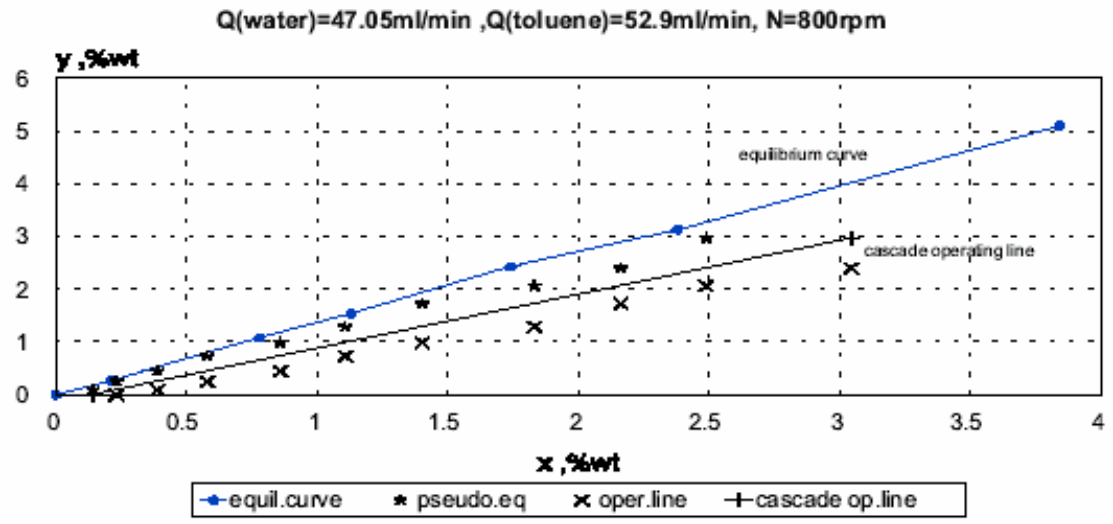


Figure 16. The operating curve of mixer-settler at 800 rpm

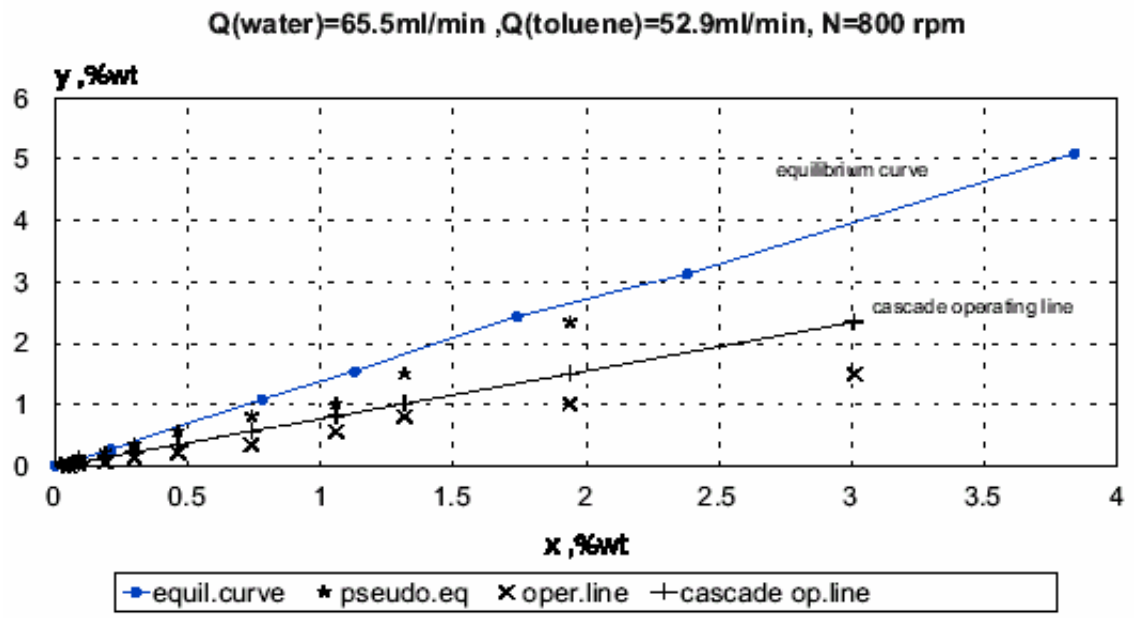


Figure 17. The operating curve of mixer-settler at 800 rpm

Discussion and Conclusion

According to the above experiments, the following conclusions can be made:

1. An increase in impeller speed at constant volumetric flowrates of two phases increases the number of drops and mass transfer area (decrease of drops sizes and increase of drops settling time), which in turn changes the mass transfer mechanism. Therefore, the separation rate and extraction efficiency will increase and this increases the distance between the operating curve and the equilibrium curve that means a lower overall efficiency (because of decreased number of ideal stages).
2. An increase in volumetric flowrate of the dispersed phase (raffinate phase) decreases the extraction efficiency. In fact, increasing volumetric flowrate of the dispersed phase increases the number of drops (increasing of hold-up). In other words, the ratio of solvent to dispersed phase decreases and therefore separation rate and extraction efficiency decrease. On the other hand, the decreasing of mass transfer and extraction efficiency causes the operating curve to approach the equilibrium curve, which in turn increases the number of ideal stages and consequently, overall efficiency is increased.
3. An increase in volumetric flowrate of the continuous phase (extract phase) increases the extraction efficiency. In other words, an increase in volumetric flowrate of the continuous phase, will increase the ratio of solvent to dispersed phase. Therefore, the separation rate and the extraction efficiency will increase and this increases the distance between the operating and equilibrium curves (at constant conditions). In other words, the number of ideal stages decreases and therefore, the overall efficiency decreases.

According to the obtained results, one can conclude that the hold-up of each stage and average hold-up of all stages have an influence on the efficiency. In general, increasing of solvent-to-feed ratio results in a decrease in dispersed phase hold-up and therefore, this causes improvement of mass

transfer and efficiency. Of course, this is only an observation, which can not be accepted as a general rule because the hold-up also depends on the volumetric flowrates of the two phases, impeller speed and residence time of drops.

Nomenclature

E_{ext} Extraction efficiency
E_o Overall efficiency
E_{stage} Stage efficiency
N Impeller speed, rpm
N_{actual} Actual number of stages
N_{ideal} Ideal number of stages
n Number of components
Q_c Volumetric flowrate of the continuous phase, ml/min
Q_d Volumetric flowrate of the dispersed phase, ml/min
X_{in} Weight ratio of acetone to toluene in input of raffinate
X_{out} Weight ratio of acetone to toluene in output of raffinate
X^* Equilibrium weight ratio of acetone to toluene in raffinate corresponding to extract
x_1 Weight fraction of acetone in input of raffinate for each stage
x_2 Weight fraction of acetone in output of raffinate for each stage
x_e Equilibrium weight fraction of acetone in raffinate
x_{in} Weight fraction of acetone in input of raffinate for each stage
x_{out} Weight fraction of acetone in output of raffinate for each stage
x^* Equilibrium weight fraction of acetone in raffinate corresponding to extract
y_1 Weight fraction of acetone in input of extract for each stage
y_2 Weight fraction of acetone in output of extract for each stage
y_e Equilibrium weight fraction of acetone in extract
y_{in} Weight fraction of acetone in input of extract for each stage
y_{out} Weight fraction of acetone in output of extract for each stage
y^* Equilibrium weight fraction of acetone in extract corresponding to raffinate
ρ_c Continuous phase density, gr/cm^3
ρ_d Dispersed phase density, gr/cm^3
μ_c Continuous phase viscosity, cP.
μ_d Dispersed phase viscosity, cP.
σ Surface tension, dyne/cm

Abbreviation

eff. Efficiency
equil. Equilibrium
ext. Extraction
pseudo eq. output of each stage operating line (or pseudo-equilibrium curve; see [7])
oper. line input of each stage operating line
op. line operating line
vol. volumetric

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