

## An applied comparison between conventional pre-dispersed solvent extraction (PDSE) contactors and new dissolved nitrogen PDSE (DNPDSSE) ones

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### Abstract

Efforts to increase the mass transfer coefficient, enhance the contact area, and decrease the power input of contactors have given rise to the development of the pre-dispersed solvent extraction (PDSE) contactor and the devise of the new dissolved nitrogen PDSE (DNPDSSE) contactors. The studies conducted after the design of the new contactor to determine the working conditions for its suitable performance (2.5-3.5 bar pressure, 0.1 L/min sparger flow rate, and 1.5 L of the aqueous phase) showed that for all the evaluated conditions (i.e. the pressure, polyaphron type, and dilution percentage), the recovery in the DNPDSSE contactor was higher than that in the PDSE one. In addition, pictures of the performance modes of the two contactor indicated the presence of the organic phase in the form of colloidal gas aphrons (CGAs) in the DNPDSSE contactor and of polyaphron aggregations in the PDSE one. This is a good reason for the increased copper recovery in the DNPDSSE contactor. The best recovery for the extraction process in the DNPDSSE contactor was achieved using the anionic polyaphron of sodium dodecylbenzene sulphonate (NaDBS) with five-fold dilution at 3.5 bar.

**Keywords:** *Dissolved Nitrogen Pre-Dispersed Solvent Extraction (DNPDSSE) Contactor, Pre-Dispersed Solvent Extraction (PDSE) Contactor, Colloidal Aphrons (CAs), Metal Extraction, Performance Study.*

### 1. Introduction

The solvent extraction (SX) method is of great importance in the industrial world today due to the production of high purity products, selective separation of metals and chemicals, and also contaminant control. To this end, considerable research efforts have been devoted to develop this technique through the design and construction of new contactors to reach better performances compared to those for the conventional SX contactors [1].

Save et al. [2] have been among the first who tried to reach this aim by an excellent review of the

conventional SX contactors. According to their investigations, the rate of mass transfer per volume unit of dispersion (R) can be written as follows:

$$R = K_L \cdot A \cdot \Delta C \quad (1)$$

where  $K_L$  is the mass transfer coefficient (m/s),  $A$  is the interface area ( $m^2/m^3$ ), and  $\Delta C$  is the concentration variation. Table 1 gives the range of the  $K_L$  and  $A$  values for various contactors.

**Table 1. Comparison of SX contactors [2].**

Contactor	$K_L \cdot 10^3$	Gas hold-up	A	$K_L \cdot A \cdot 10^3$
Spary column	0.1-1	0.05-0.1	1-10	0.1-10
Packed column	0.3-1	0.05-0.1	1-10	0.3-10
Column with mechanical agitator	0.3-1	0.05-0.1	1-800	0.3-800
PDSE	-	-	27000	-

This table shows that the gravity-operated contactors have much lower  $K_L.A$  values than a typical mixer-settler. However, they require a far less power input. It is also evident that an increase in the  $K_L.A$  value in a mixer-settler is mainly due to an increase in the  $A$  value. Therefore, the combination of a high  $K_L.A$  value and a low power input is possible if the contact area afforded by a gravity-operated contactor is increased without affecting the  $K_L$  value [2].

The investigations carried out by Sebba [3] in this field have given rise to introducing a new contactor, named pre-dispersed solvent extraction (PDSE). In this type of contactor, the process of separation of the solute from the pregnant solution takes place using the colloidal liquid aphrons (CLAs) and colloidal gas aphrons (CGAs).

For this purpose, at first, the solvent phase was converted to a biliquid foam called polyaphron, i.e. CLA aggregations or double layer bubbles with oily nucleus. Afterward, polyaphron was diluted due to its high viscosity and long dispersion time. The diluted polyaphron, after being added to the pregnant solution, rose to the surface, while transferring the mass due to its lower density than the solution. However, this operation is usually very slow due to the small size of CLAs. Therefore, by adding CGAs, i.e. the aggregates of double layer micro-sized bubbles with air nucleus, the ascending speed of CLAs to the surface increased due to the hydrophobic property of the soapy shell [2-4].

In this contactor, by choosing the appropriate surfactant for producing CGAs (i.e. a surfactant with a charge opposing to that used to produce CLAs), the operations can be adjusted such that the aphrons break after reaching the surface (because of the contra-foams effect), and a continuous solvent layer is attained on the surface. This performance mode causes a very important difference between the extraction theory of this method and that of the conventional SX method. In the SX method, the solute transfer from the pregnant solution to the solvent stops as soon as the equilibrium is achieved, and so there is a restriction in each extraction step. However, in this method, an equilibrium is achieved between each aphron and the pregnant solution in the exit point of the aphron from the solution (where the aphron enters the organic phase on the surface). Thus three important features were provided for the PDSE contactor, as follow:

1. Omission of the mixing-separation step that reduces the cost of the consumed electricity.

2. Decreased ratio of the organic phase to the pregnant solution (1/1000 or less).

3. Rapid mass transfer rate even at a very low solute concentration [3, 4].

The results obtained were considered promising for the appropriate extraction of the elements from very dilute solutions in high volumes [3]. However, the need for excessive dilution of polyaphron, low speed of the contactor, requirement of costly equipment for producing CGAs, etc. have prevented further extension of this contactor in an industrial scale.

The dissolved nitrogen pre-dispersed solvent extraction (DNPDSSE) contactor is a new one devised for improving the performance of the contactor proposed by Sebba [3]. The operation of mixing two phases in this contactor is based on the bubble dispersion of the organic phase (CGAs) instead of its droplet dispersion (CLAs) in the aqueous phase. In the DNPDSSE contactor, adding a new equipment in the PDSE contactor causes the following changes in its operation mode:

1. Conversion of CGAs (in the PDSE contactor) to the common air bubbles to increase the performance speed of the contactor, avoid dilution of the primary solution, and eliminate the need for costly equipment to produce CGAs.

2. Conversion of CLAs (in the PDSE contactor) into CGAs to significantly increase the contact area, enhance the buoyancy force, and prevent the recovery reduction due to less CGA dilution requirements.

The first conversion was carried out using a simple sparger. In fact, instead of applying CGAs produced by expensive equipment and their injection into the contactor, the common air bubbles produced by the compressors and sparger were used.

The second conversion requires a two-step process, as follow:

1- In the first step, by selecting a proper surfactant (silicone oil) for the organic phase (with a high foaming property, without an improper effect on the extraction and stripping processes [5]), and decreasing the temperature of the resulting polyaphron (to increase the foaminess of the oil derivatives [6], increase the air solubility, and augment the security level), the best foaming conditions were achieved. The aim was to improve the operational conditions of the dissolved air flotation (DAF) process [7].

2- In the second step, through the transfer of the prepared polyaphron into the tank and applying pressure, more gas solubility was enabled based

on the Henry's Law. To produce CGAs in this contactor, polyaphron was placed under a high nitrogen pressure (3-6 bar) to dissolve a large amount of gas in it. After the nitrogen solubilization in CLAs and before the pressurized polyaphron release, a pressure drop was induced by the presence of a constriction or an obstacle on the trajectory of its flow [8, 9].

In order to evaluate the success of this method in converting CLAs into CGAs, i.e. improved performance of the PDSE contactor, there is a need to carry out one of the following methods:

- Application of such techniques as differential scanning calorimetry (DSC), transmission electron microscopy (TEM), light scattering (LS) [10], and freeze-fracture transmission electron microscopy (FFTEM) [11, 12] using expensive complex equipments. Due to the small size of the bubbles (about 100 microns) produced in the DNPDSSE contactor, the best way to prove the conversion of droplets into bubbles is the application of these techniques.

- Comparative analysis of the recoveries in both contactors under the similar conditions.

Regarding the manner of conducting the DNPDSSE contactor and impossibility of using the mentioned expensive equipment, preferably, the second method was used. The reasons for the increased recovery rate in the DNPDSSE contactor, compared to the PDSE contactor, are an increase in the contact area resulting from the conversion of CLAs into CGAs and an improved dispersion. However, this contactor does not specify the exact amount of the conversion of CLAs into CGAs, though this change is expected to improve with increased tank pressure.

In this work, after explaining the contactor design mode and determining the working conditions in the DNPDSSE contactor, its performance was compared with that for the PDSE contactor. The main aim of this comparison was to show the increased contact area and the enhanced buoyancy force of the organic phase in the DNPDSSE contactor.

## 2. Materials and Method

### 2.1. Design principles of DNPDSSE contactor

In the design and construction of the equipment required for the contactor, the following three parts were evaluated:

#### 2.1.1. Tank design

Stirrers are usually used in the DAF process for more air solubility in the solution, and thus saturation of a higher volume of it (up to two-third

of the tank volume). However, in the DNPDSSE contactor, due to the limitation of using a stirrer inside the tank, a higher volume of nitrogen relative to the solution was used by designing a large tank (25 L). A scheme for the designed tank together with the equipment used (including the input and output taps, security valve, discharge tap, manometer, and inlet vent of the polyaphron phase installed on it) are shown in Figure 1.



Figure 1. DNPDSSE tank.

#### 2.1.2. Glass column design

In the column design, three general factors were regarded, as follow:

##### 2.1.2.1. Column volume

By choosing 1.5 L as the pregnant solution volume in each experiment, the design of a column of 2 L volume was deemed to be suitable.

##### 2.1.2.2. Column height

The choice of 1.8 m height was made considering the following points:

- In the DNPDSSE contactor, due to the very large contact area of CGAs, the equilibrium between each aphron and the pregnant solution is reached at a point where the aphron leaves the solution to enter the organic phase on the surface. However, considering the solution concentration, an increased mass transfer may not be significant after a certain height.

- In the DNPDSSE contactor, because of the conversion of CLAs to CGAs, enhanced buoyancy force, and higher ascending speed of CGAs to the surface together with the use of the

common gas bubbles for a faster rise of these CGAs, it is possible to increase the residence time for the bubbles through an increased height of the column.

- In the DNPDSSE contactor, an easy access to the top of the column is also important.

### 2.1.2.3. Column section

Due to the feasibility of choosing different forms for column section with a known height and volume, the choice of a proper sectional area was made with regard to the following points:

- In the DNPDSSE contactor, a sparger with an appropriate length to attain an adequate amount of bubbles is necessary. Therefore, the first factor in choosing the shape of a column is the length of the utilized sparger (50 mm).
- Most laboratory cells have a circular section due to the ease of construction. However, it was not possible, in the present work, to have a column with a volume of 2 L, a height of 1.8 m, and a diameter of 5 cm.
- As the sparger was fitted into a section of a circular column, the whole column section was not unanimously in contact with the bubbles.
- A decreased sectional area increased the amount of bubbles for the area unit.

Accordingly, a column with a square-circle (ellipsoid) section with the dimensions given in Figure 2 was used.

### 2.1.3. Lateral segment design

#### 2.1.3.1. Gaseous bubble sparger

The sparger was achieved by making several holes of 0.1 mm diameter on a segment with the dimensions given in Figure 3, covering it with a specific cloth and installing it at the bottom of the column 100 mm above the raffinate outlet.

#### 2.1.3.2. Reynolds tube

The basis of designing this segment was narrowing the tube in the central part with specific angles. Thus the pressurized polyaphron gains a maximum speed and a minimum pressure by passing through the nozzle designed in this part. The resulting pressure drop causes the excess gas out of the polyaphron and formation of CGAs. The dimensions observed in the design of this tube are based on the best results obtained by Dupre et al. [9] and Ponasse et al. [13].

Since the position of the Reynolds tube relative to the sparger on the column is very influential for a contactor performance, the results obtained by Save et al. [2] were used in locating this segment.

They showed that, by considering the position of the Reynolds tube 10 cm far from the top of the sparger, there would be no transfer of the organic phase into the raffinate sample. Figure 4 shows the different parts of the Reynolds tube.

### 2.1.4. Various column zones

The research work carried out by Save et al. [2] has resulted in the construction of a new contactor through minor changes in the contactor devised by Sebba. They called their contactor the pre-dispersed liquid contactor (PLC), and believed that it was a particular type of spray column without any obvious difference with it, except for the previous dispersion of the solvent. They described three general zones for this contactor, as follow:

1. Pick up zone: The part between the CGA and CLA outlets, in which CLAs are taken up by CGAs.
2. Extraction zone: The part between the CLA outlet and the lower surface of the coalesced organic phase, in which the extraction operation occurs.
3. Delivery zone: The part where CLAs are transferred into the organic layer.

As in the DNPDSSE contactor design, the principles mentioned by Save et al. [2] were considered for installation of the lateral segments. The resulting contactor was very similar to that introduced by these investigators. Thus the same nomenclature was used for the various zones of the DNPDSSE contactor (Figure 5).

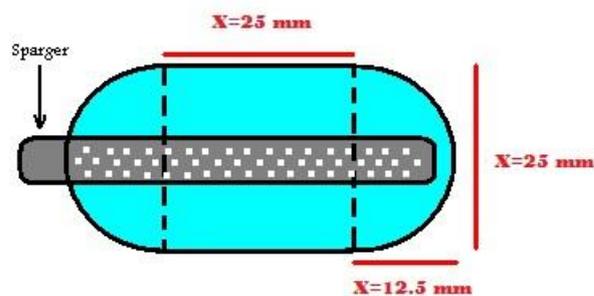


Figure 2. Designed DNPDSSE column section.

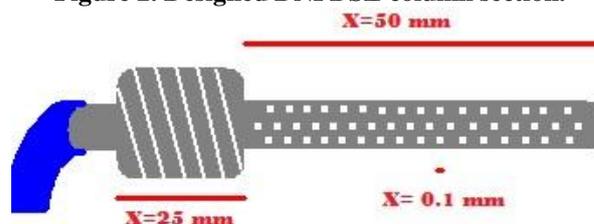


Figure 3. Dimensions of designed sparger.

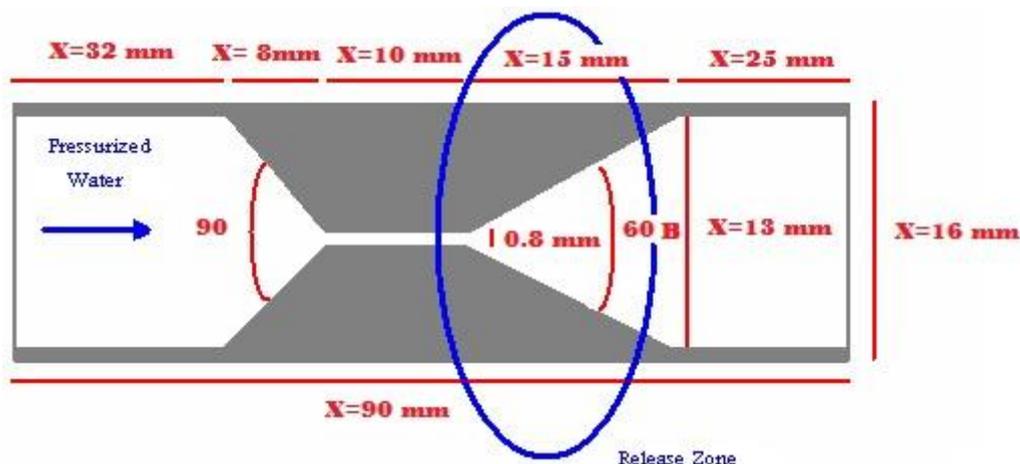


Figure 4. Dimensions of designed Reynolds tube.

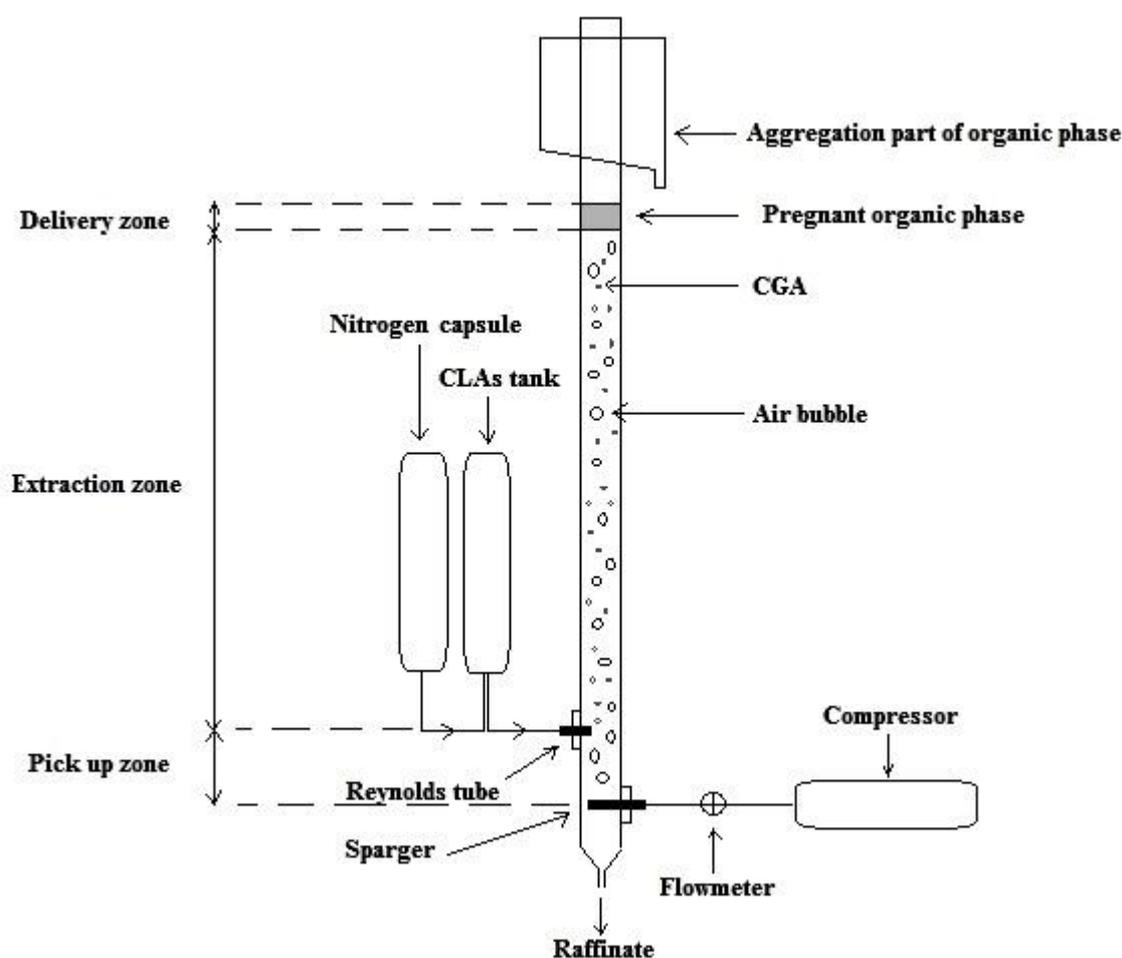


Figure 5. DNPDS contactor zones.

## 2.2. Reagents and solutions

4000 mg/L reagent grade  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  (MERCK, Germany) was used to prepare a synthetic solution with an average concentration of the dilute and dense solutions of copper [14]. The solvent contained 10% (v/v) of the chelating-type extractant Lix (984 N) (Cognis, USA) diluted in a 90% (v/v) kerosene containing 0.3 g/L of dilute silicon oil (Shin Etsu). 4 g/L of sodium

dodecylbenzene sulphonate (NaDBS) (Sigma, USA) and 4 g/L of dodecyltrimethyl ammonium bromide (DTAB) (Aldrich, USA) were used for the polyphron aqueous phase. The cationic polyphron was prepared using 0.3 g/L of DTAB and 0.3 g/L of NaDBS. To adjust the pH of the synthetic solution, a solution containing 500 mg/L of sulfuric acid, a buffer solution containing

NaOH (0.2 M), acetic acid (0.04 M), phosphoric acid (0.04 M), and boric acid (0.04 M) were used [15].

### 2.3. Solvent extraction experiments

#### 2.3.1. DNPDSSE test works

This method consists of two general stages, as follow:

**Polyaphron preparation stage:** Since the preparation conditions affect the size distribution and stability of polyaphron [11, 16], CLAs were prepared under relatively constant conditions. For this purpose, to produce 220 mL of the anionic polyaphron (with PVR = 10), 20 mL water was mixed with 4 g/L of the anionic surfactant NaDBS using a magnetic stirrer (900 rpm) to obtain a gaseous foam (1st stage). PVR is the volumetric ratio of the dispersed organic phase to the continuous phase. Then the resulting gaseous foam was placed in a container containing water and ice to reduce its temperature to about 5 °C (2nd stage). Afterwards, 20 mL of the extraction agent Lix (984 N) was mixed with 0.3 g/L of the non-anionic surfactant silicone oil, and its volume was increased to 200 mL by adding kerosene as the diluent (3rd stage). The resulting organic phase was also placed in a container including water and ice to reduce its temperature to about 5 °C (4th stage). After achieving the desired temperature, the organic phase was gradually added (with a flow rate of 1.5 mL/min) into the foamy aqueous phase, with mixing (5th stage). At first, the solvent dispersion in the aqueous phase was easily done. However, after adding about two-third of the total solvent, the mixture became viscous, and increasing its viscosity was continued to complete the dispersion of the solvent. Finally, a white creamy dispersion of CLAs was obtained (6th stage) [3, 4]. The polyaphron obtained was diluted for a more contact area in the continuous aqueous solution. For this purpose, polyaphron was gradually added to distilled water, with mixing (7th stage). The volume of the distilled water was four times more than the polyaphron volume, considering the dilution ratio of 5, and its temperature was nearly 5 °C. By the end of dilution, a proper polyaphron for transfer into the column was obtained (8th stage).

**Simultaneous extraction and separation stage:** This stage consists of two general sections, as follow:

- Extraction and separation by producing CGAs: In this part, the resulting polyaphron and the nitrogen gas (to produce a 3.5 bar pressure) were

transferred into the tank, and enough time was given to them to dissolve (30 min). Then the synthetic aqueous solution (1500 mL) containing 0.3 g/L of the cationic surfactant DTAB was transferred into the column. Afterwards, according to the A/O ratios desired, the polyaphron phase was injected into the column through the Reynolds tube. The first sampling from the aqueous phase (30 mL) was carried out from the middle part of the column 6.5 min after starting the operation.

- Extraction and separation by producing air bubbles: in this part, the air bubbles were used to transfer the remaining CGAs onto the surface, and for more mixing of the two phases. For this purpose, by an accurate adjustment of the flow-meter, 7.5 min after starting the operation, the air produced by the compressor with a flow rate of 0.1 L/min was passed through the sparger. After 15 min, 30 mL of the aqueous phase was taken as the second sample to evaluate the effect of the produced bubbles on the extraction process. Finally, the copper concentration in the aqueous samples was determined by atomic absorption spectrometry (AAS) (VARIAN model, Germany).

#### 2.3.2. PDSE test works

To conduct the PDSE method, the conditions considered in the DNPDSSE method were used with the exception that, in the first section of the simultaneous extraction and separation stages, considering the required aqueous/organic ratio, the polyaphron phase was injected into the column using a peristaltic pump with a flow rate of 0.0006 m<sup>3</sup>/min.

## 3. Results and discussion

### 3.1. Choice of best working conditions for DNPDSSE contactor

#### 3.1.1. Determining suitable tank pressure

The proper pressure in the DNPDSSE contactor, disregarding the security and economic issues, is the pressure capable of spraying polyaphron (in a cloudy form) into the aqueous phase. Therefore, evaluation of the visual results was sufficient. The results obtained from the experiments showed that, at pressures lower than 2.5 bar, the polyaphron injection was in the form of very large droplets, instead of a cloudy form, due to an insufficient volume of the nitrogen dissolved in the polyaphron to produce CGAs, and negligible pressure drop within the Reynolds tube owing to a low initial pressure. In addition, the low pressure behind the organic phase in the connecting tube between the tank and the Reynolds tube allowed

enough opportunity for the aggregation and adhesion of CLAs together at the time of their exit from the Reynolds tube. Also at pressures higher than 3.5 bar, the dispersion operation of the organic phase ceased after a few appropriate injections. In this case, owing to the insufficient exit of the organic phase from the Reynolds tube and the simultaneous entry of the extra organic phase into the connecting tube, enough opportunity was provided for the aggregation and adhesion of CLAs together in the connecting tube, and thus the Reynolds tube was clogged.

Thus in evaluating the effect of an increased pressure upon the extraction process in the DNPDSSE contactor, 2.5 and 3.5 bar were used as the minimum and maximum pressures applicable, respectively.

### 3.1.2. Determining suitable flow rate of Reynolds tube

Although changing the flow rate of the Reynolds tube at different pressures changed the contactor performance, it was not feasible to use the same flow rate for all pressures during the extraction process. Thus by applying the two pressures 2.5

and 3.5 bar, two different flow rates were provided for the release of the organic phase from the Reynolds tube. Their values remained constant for each pressure throughout the extraction process.

### 3.1.3. Determining suitable flow rate of sparger

Visual assays of the bubble-making mode by sparger showed that, at flow rates higher than 0.5 L/min, the ascending speed of the bubbles to the surface increased owing to their more contact and coalescence. This situation was aggravated by increasing the flow rate. Due to the narrowness of the DNPDSSE column, the large bubbles were stabilized by the wall, and a spiral flow was created. Through this flow throughout the column, the bubbles functioned as a piston, and filled the whole column section [17].

In order to evaluate the effect of the flow rates lower than this value upon the DNPDSSE conductor experimental results, the performance of this method in the 0.1 and 0.5 L/min flow rates was evaluated. The results obtained for evaluating this effect are presented in Table 2.

**Table 2. Conditions and results of experiments evaluating effect of sparger flow rate on copper recovery in DNPDSSE contactor.**

Pressure (bar)	Sparger flow rate (L/min)	Changing initial height (cm)	Initial concentration of pregnant solution after dilution (ppm)	$A/O_{real}$	Cu ions concentration in aqueous phase after the first step (ppm)	Cu ions concentration in aqueous phase after the second step (ppm)	Real recovery of the first step (%)	Total real recovery (%)
3.5	0.1	37.70	885.44	33.67	753.57	753.54	17.17	14.90
	0.5	37.80	885.21	33.61	733.20	732.64	17.24	17.24

According to this table, by using the 0.1 L/min flow rate, perhaps due to the extra mixing possibility of the two phases and maintenance of the relatively still conditions in the coalescence part of the organic phase on the surface, the total actual recovery in the second step of the extraction process increased. Upon the use of the 0.5 L/min flow rate, due to the high turbulence in the interface and the lack of still conditions in the coalescence part of the organic phase on the surface, the total actual recovery in the second step of the extraction process reduced.

### 3.1.4. Determining suitable volume of aqueous phase

As mentioned earlier, due to the very large contact area of CGAs in the DNPDSSE contactor, the equilibrium between each aphron and the pregnant solution was achieved in the exit point of the aphron from the solution. Therefore, by increasing the volumes of the aqueous and organic phases (by keeping their volume ratio constant) in the extraction process, it is anticipated that, due to the increased height and thus longer residence time of CGAs in the aqueous phase, the recovery would increase. This can be demonstrated by evaluating the effect of the volume changes in the aqueous phase upon recovery in the constant ratios of the two phases. The results obtained from the experiments performed to evaluate this effect are presented in Table 3.

**Table 3. Conditions and results of experiments evaluating effect of volume (height) of aqueous phase upon recovery in DNPDSSE contactor**

Pressure (bar)	Initial volume of aqueous phase (L)	Changing initial height (cm)	Initial concentration of pregnant solution after dilution (ppm)	$A/O_{real}$	Cu ions concentration in aqueous phase after the first step (ppm)	Cu ions concentration in aqueous phase after the second step (ppm)	Real recovery of the first step (%)	Total real recovery (%)
3.5	1	25.30	884.74	33.50	737.68	737.58	16.62	16.63
	1.5	37.80	885.21	33.61	733.20	732.64	17.17	17.24

As shown in this table, due to the gradual increase in the recovery with increased column height and restriction of using columns with more heights, 1.5 L was considered as the suitable volume for the aqueous phase in the DNPDSSE method. It is expected that, with increased initial concentration of the solution and more collision of the metal ions with the extraction agent, the effect of increased height upon recovery would reduce.

### 3.2. Performance comparison of PDSE and DNPDSSE contactors

Due to the impossibility of applying precise aqueous/organic ratios in examining the performance of the two contactors, the metal ion concentrations in the organic phase were also regarded in addition to comparing the values resulting for the recovery. The following results were obtained through the numerical comparison of the parameters, referred to in Table 4.

- The use of anionic polyaphron with five-fold dilution gave the best extraction results for the PDSE contactor.
- In comparable conditions, i.e. polyaphron type and dilution ratio, the increased pressure involved more effective performance of the extraction process in the DNPDSSE contactor.

- The highest recovery (metal ion concentrations in the organic phase) in the DNPDSSE contactor was attained using the anionic polyaphron with a five-fold dilution at 3.5 bar.
- Higher recoveries for all the evaluated conditions (including the amount of pressure, polyaphron type, and dilution ratio) in the DNPDSSE contactor indicated more appropriate performance of this contactor compared with the PDSE one.
- To have a more appropriate performance in the PDSE contactor, sometimes it is necessary to dilute polyaphron by 50 times [3]. Hence, using two-fold and five-fold dilution ratios, due to the presence of more polyaphron aggregates relative to solitary aphrons in the solution and their faster rise to the surface, the residence time provided for the CLAs in the first stage was not sufficient. Therefore, the use of air bubbles in the second stage resulted in a significant increase in the recovery, and also, the transfer of metal ions from the aqueous phase to the organic phase compared to that for the DNPDSSE contactor.

The picture of CGAs in the DNPDSSE contactor, and that for CLAs together with the polyaphron aggregates in the PDSE contactor are shown in Figure 6.



(a)



(b)

**Figure 6. Dispersion mode of organic phase: a: CGAs in DNPDSSE contactor; b: CLAs in PDSE contactor.**

#### 4. Conclusions

The main points emerging from this research work are as follow:

- The investigations performed for the choice of the best working conditions in the DNPDSSE contactor indicated the possibility of suitably performing this contactor at 2.5 to 3.5 bar pressures, 0.1 L/min sparger flow rate, and 1.5 L of aqueous phase volume.
- The best recovery (17.24%) in the DNPDSSE contactor was obtained at 3.5 bar using the anionic polyaphron with a five-fold dilution.
- For all the evaluated conditions, the extraction results (i.e. metal ion concentrations in the organic phase) obtained for the DNPDSSE contactor were better than those for the PDSE one, indicating a much more appropriate performance of this new contactor.

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**Table 4. Conditions and results of experiments accomplished for comparison of PDSE and DNPDSSE contactors.**

Contactor	Polyaphron type	Flow rate (L/min)	Pressure (bar)	Dilution ratio	Changing	Initial concentration	A/O <sub>real</sub>	Cu ion	Cu ion concentration	Total real recovery (%)
					initial height (cm)	of pregnant solution after dilution (ppm)		concentration in aqueous phase after first step (ppm)	in aqueous phase after second step (ppm)	
PDSE	Anionic	0.6	-	two-fold	-	981.97	31.58	849.10	845.10	13.94
				five-fold	-	883.34	33.17	756.18	750.18	15.07
	Cationic	0.6	-	two-fold	-	981.81	29.67	840.39	834.30	15.02
				five-fold	-	881.95	32.84	753.60	747.90	15.20
DNPDSSE	Anionic	-	2.5	two-fold	13.73	982.59	30.22	819.65	819.11	16.64
				five-fold	34.80	883.34	33.17	734.38	733.88	16.92
				two-fold	15.00	982.97	30.50	815.76	815.32	17.06
				five-fold	37.80	885.21	33.61	733.20	732.64	17.24
	Cationic	-	2.5	two-fold	13.73	982.59	30.22	823.06	822.98	16.24
				five-fold	35.30	881.49	32.74	733.75	733.11	16.83
				two-fold	14.94	983.13	30.62	820.43	820.18	16.57
				five-fold	37.70	885.44	33.67	737.17	736.74	16.79

## مقایسه عملیاتی تماس دهنده‌های مرسوم استخراج با حلال از قبل متفرق شده (PDSE) و جدید با نیتروژن محلول (DNPDSSE)

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### چکیده:

تلاش‌ها برای افزایش ضریب انتقال جرم، بهبود سطح تماس و کاهش توان تماس دهنده‌ها منجر به توسعه تماس دهنده استخراج با حلال از قبل پخش شده (PDSE) و ابداع نوع جدید با نیتروژن محلول آن (DNPDSSE) شده است. مطالعات انجام شده بعد از طراحی تماس دهنده جدید جهت تعیین شرایط کاری برای عملکرد مناسب آن (فشار ۳/۵-۲/۵ بار، دبی اسپارجر ۰/۱ لیتر بر دقیقه و حجم فاز آبی ۱/۵ لیتر) نشان داد که برای همه شرایط مورد مطالعه (فشار، نوع پلی‌افرون و درصد رقیق‌سازی)، بازیابی در تماس دهنده DNPDSSE بالاتر از آن در نوع PDSE بود. بعلاوه، تصاویر نحوه عملکرد دو تماس دهنده، حضور فاز آلی را به شکل افرون‌های گاز کلونیدی (CGA) در تماس دهنده DNPDSSE و تجمعات پلی‌افرونی در نوع PDSE نشان داد. این دلیل خوبی برای افزایش بازیابی مس در تماس دهنده DNPDSSE است. بهترین بازیابی برای فرآیند استخراجی در تماس دهنده DNPDSSE با به‌کارگیری پلی‌افرون دو دسیل بنزن سولفات (NaDBS) با پنج برابر رقیق‌سازی در فشار ۳/۵ بار به دست آمد.

**کلمات کلیدی:** تماس دهنده استخراج با حلال از قبل پخش شده با نیتروژن محلول (DNPDSSE)، تماس دهنده استخراج با حلال از قبل پخش شده (PDSE)، افرون‌های کلونیدی (CA)، استخراج فلز، مطالعه عملکرد.