Modeling of Solid-liquid Extraction of Water-Solubles from *Salvia Coccinea* (Lamiacea)

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ABSTRACT

The aim of this study is to establish models to describe and explain the transfer phenomena of water-soluble solutes in a solid phase plant to a liquid phase (water). These are the leaves and stems of Salvia coccinea. The approach consists of a model establishment to simulate the kinetics of a solid-liquid extraction. Three models were used. The Mafarat and Beliard I, II and pseudo-diffusion models define the overall material transfer coefficients and the solutes concentration of the liquid phase. The Spiro and Kandiah model determines the two time constants corresponding to the diffusion of localized solutes in broken-wall and intact-wall cells, the amount of solutes fraction in broken-wall cells, and the solute concentration. The pseudo-second order kinetic model determines the kinetic constant of extraction and the extraction capacity. Comparing the results of the simulations with the experimental measurements indicates that the models satisfactorily represent the evolution of the extraction operation and that the transfer is divided into two stages, a fast first step consisting of diffusion and a slow step which is a sum of various phenomena.

Keywords: - *Modeling, Salvia coccinea, Extraction, Transfer, Kinetic and Diffusion*

1. Introduction

Extraction involves removing or extracting one or more chemical species from a solid or liquid medium. Solid-liquid extraction is often the best known industrially as the preparation of food products, drugs, dyes, perfume, pharmaceutical, etc. In principle, it allows to extract soluble components by dissolving solids with a solvent [4]. The solvent which is the liquid or extraction medium, dissolves the solid or liquid compounds, called solutes, to give a solution or an extract (solvent + solute) and leaves an exhausted solid called residue (inactive support), inert or insoluble containing little or no solute [1]. Although the inert solid does not dissolve in the solvent, it intervenes in the transfer kinetics and can retain more or less extract during solid-liquid separation. This can be due to its structure [5]. The diffusion of the soluble substances results from the concentration gradients between the solid (more concentrated) phase and the liquid phase, until solute distribution equilibrium is obtained in the two phases [6]. It should be noted that the solute must have a higher affinity with the solvent [1].Historically; solid-liquid extraction is a very old operation. Man has always sought to exploit the natural resources he has [1]. For Madagascar, a country sheltered by endemic plants, most are not yet studied. Malagasy ancestors and traditional medicine know and use medicinal plants. Among these plants, a plant scientifically named *Salvia coccinea* is used to treat different diseases [2]. *Salvia coccinea* is a species native to South America, cultivated everywhere in all tropical and subtropical regions (temperate zones), locally naturalized in Madagascar where it blooms all year [18]. It is a much branched plant with stems of square section and lignified base [19]. *Salvia coccinea* has been shown to have antibacterial, antiviral and antitumor activity [20]. The presence of molecules such as salviacoccin and anthocyanins shows the antioxidant and anti-aging activities of the plant [21, 22]. The most common solvent extraction technique is the solubilization. For percolation to infusion, maceration or concoction, each term refers to a domestic implementation of a solid-liquid extraction process, the solvent of which is usually water. The simplicity of these processes, the tools, the materials or the heating methods of the time made extraction more a matter of craftsmanship than of science. Even today, despite the use of precise automata and adapted materials, despite advances in process engineering, phytochemistry and analytical chemistry, the implementation of plant extraction remains a fair association between the mastery of these parameters and tradition. Solid-liquid extraction from the plant matrix is a

complex unitary operation because of the very nature of the substrate. Resistance to transfer of material due to the plant structure and the location of the desired compounds can be decisive [1]. The solute transfer phenomena in the solid, in this case the plant material, are affected by several factors characterizing the solid matter (size and shape of the particle, porosity, tortuosity and exchange specific surface), the solute (solubility or affinity with the solvent) and the solvent (polarity, viscosity), as well as by the operating conditions (temperature, agitation, humidity) [7]. The choice of solvent is very important in the food or pharmaceutical industry. It is done by several criteria such as its solubilization capacity, nature, viscosity, etc. [8].

Water is chosen as solvent because it is the solvent used in daily practice, so it is the water-soluble solutes that are consumed in tisane. Water is also a universal solvent in the industry. Several models have been proposed to represent the characteristics of material transfer between two phases. The boundary layer model, the penetration model or the surface renewal model are the most frequently encountered [10]. In the case of solid-liquid extraction, Fick's law is the basis of any modeling. Theoretically, the diffusion rate inside a solid matrix is difficult to study. In practice, the determination of this speed is feasible if the diffusion conditions are assumed to be non-stationary. In fact, the concentration of the solute varies according to the time that its position in the solid particle [11]. The 2^{nd} law of Fick is valid for a diffusion of a solute in a rigid porous body. This diffusion requires an experimental condition such that the structure is considered to be quasi-homogeneous and macroscopically isotopic. For the plant material, the molecular diffusion coefficient must be an apparent diffusion coefficient that takes into account the porosity and tortuosity of the solid matrix [12]. The determination of the molecular diffusion coefficient D_x depends on the initial conditions, the boundary conditions and the variation of solute concentration in the solid [13]. The classic method for solid-liquid extraction is soxhlet. The sample quickly contacts a portion of pure solvent, which helps shift the transfer equilibrium to the solvent. In addition, it does not require filtration after extraction and can be used regardless of the plant matrix [23]. In principle, the kinetics of extraction is in no case a function of time, even if it expresses the transformation (transfer, dissolution, reaction) of a quantity of matter per unit of time. The transfer of solute into the liquid requires some time to have balance [24].

2. Materials and Methods

2.1 Plant Materials

Salvia coccinea, used for this study, was collected in the field of the University of Antananarivo, in April 2017. The aerial parts of the plant were dried for a few weeks in a dry place and away from the sun. 700 g of the dried aerial part was reduced to powder with a coffee mill.

2.2 Potential of Plant

The device used is a Soxhlet extractor. For this, 110 g of solid is placed in a cotton cartridge placed in the soxhlet added of 250 mL of water. 500 mL of water is introduced in the flask. The solution at the flask is brought to a boil for evaporation in the upper part. The solvent is condensed through a refrigerant at the top of the installation and accumulates around and inside the cartridge. When the solution reaches the upper level of the siphon, it is returned to the flask. The cycle is repeated several times until the plant is exhausted of solutes. Total solute depletion is considered achieved when the siphoning solution in the extractor is colorless. The solution is evaporated at 70°C., using a rotary IKA Labortechnik RV 06-ML rotary evaporator, to dryness. The mass of the dry matter measured with a precision balance Sartorius L 220S and was noted in order to calculate the yield. But recovery of this extract is difficult, so it is again dissolved in ethanol 90 ° until a thick liquid is obtained. The latter was recovered in a crystallizer by rinsing with ethanol before being placed in an oven at 60-70°C to obtain the dry extract.

2.3 Batch Experiments

The extraction is carried out batchwise in a single jacket reactor with a capacity of 2 L, fitted with an IKA Labortechnik RW16 basis mechanical stirrer at variable speed, the mobile of which is an axFlow R500 mobile, radial turbine, 9 cm in diameter. In the case of this study, it is preferable to use the single-shell reactor since the operation was carried out at room temperature for a period of 4 h 30 min. It was kept constant during extraction. At the instant t = 0, 1000 g of water is introduced into the 2 L reactor; the agitation is started with speed n° 3. 110g of *Salvia coccinea* powder is then introduced and the stopwatch is started. The solid / solvent ratio is high, in order to ensure that the concentration in the liquid phase does not limit the diffusion phenomenon. A large volume has been used to ensure that the volumes withdrawn are negligible compared to the whole system. After 30 seconds, the first 5 mL sample is taken. Then, the time of each sample is noted because the time interval is not constant. At the beginning, the sampling times are close because the variation in concentration is very fast. Then, they are more

spaced because the variation is less. The volume taken with a pipette for each sample is 5 mL. It was considered that these samples have no influence on the process. The solutions taken are filtered through cotton to take off the solid particles sucked up with the sample. Each filtered solution is then weighed and their volume measured in order to deduce the concentration evolution of the solution. They are put in glass bottles and put in an oven until drying. The masses of the dry extracts are used to evaluate the concentration of each solution over time.
The experiment was repeated 3 times under the same operating conditions.

2.4 Models

Several approaches have been adopted to model the transfer of matter during solid-liquid extraction. In this study, the model of Spiro and Kandiah, the model of Mafarat and Béliard but also the kinetic model of pseudo-second order was studied. The resolutions of the equations are done with Kaleidagraph.

2.4.1. Pseudo-Second Order Kinetic

For the resolution of this equation, several hypotheses have been proposed. Extraction was assumed to be equivalent only to solute diffusion from the plant cells to the solution. The saturation solute concentration of the solution under the same conditions was considered constant.
According to the kinetic law of second order, the rate of dissolution of the material extracted from the plant in the solution is described by equation 1.

$$\frac{dC_t}{dt} = k(C_S - C_t)^2 \qquad (1)$$

where, k is the kinetic constant of second order extraction (L g^{-1} min^{-1}), C_S the extraction capacity (solute concentration at saturation in g L^{-1}) and C_t the solute concentration in the solution (g L^{-1}), at any time t (min).
After resolution, a linearized equation has been obtained (2).

$$\frac{t}{C_t} = \frac{1}{kC_S^2} + \frac{t}{C_S} \qquad (2)$$

The extraction rate was written in equation 3.

$$\frac{C_t}{t} = \frac{1}{\frac{1}{kC_S^2} + \frac{t}{C_S}} \qquad (3)$$

2.4.2. Spiro and Kandiah model

In this model, an E fraction of the solute is located in broken-wall cells and is easily accessible. Thus, a fraction 1-E is localized in intact cells walls. For this model, it is assumed that solid particles are assimilated to spheres whose diameter, density and temperature remain constant during extraction; extraction is likened to a chemical reaction; the extract obtained must have average physical and diffusion properties. The thermodynamic equilibrium at the interface is reached almost instantaneously. Considering the symmetry of the problem, the concentration of the solute depends only on the spatial variable and the time
Its principle is based on the resolution of the Fick equation for mass transfer at constant temperature and pressure. If the molecular diffusion coefficient is constant and the solid medium is isotropic, this law is written as equation (4).

$$C_l(t) = C_l(\infty)\left[1 - fe^{\left(-\frac{t}{T_1}\right)} - (1-f)e^{\left(-\frac{t}{T_2}\right)}\right] \qquad (4)$$

where T_1 and T_2 (min) are the both time constants characteristic of two solute diffusion phenomena, from broken cells easily achievable and intact cells more difficult and slower and f is the function parameter of solute fraction E located in broken-wall cells.

2.4.3. Mafarat and Béliard model

This model is based on the fact that the mass transfer is limited by the convection in the liquid film. The authors assumed that the diffusion process is the limiting process, not the solubilization process; the solute partition coefficient between the two phases is equal to unity and the solid phase mass loss following solute diffusion. is

compensated by an equivalent mass gain of solvent migrating into the solid phase. The 1st Mafarat and Beliard model can be defined by equation (5).

$$C_l(t) = sC_s(0)\left[1 - e^{-\left(\frac{K'}{1-s}\right)t}\right] \quad (5)$$

Where, and $C_l(t)$ is the concentration of the phase liquid in solute (g.kg^{-1}); K', the global material transfer coefficient (min^{-1}); s, the ratio between the mass of the solid phase and the total mass of the suspension, $C_S(0)$ (g.kg^{-1}), the initial content of the solute in the solid phase .

This equation can be presented in another equivalent form (6), noted 2nd model of Mafarat and Béliard.

$$C_l(t) = C_l(\infty)\left[1 - e^{-\lambda t}\right] \quad (6)$$

The introduction of a power b in equation 5 makes it pseudo-diffusional, noted pseudo-diffusional Mafarat and Beliard model (7).

$$C_l(t) = C_l(\infty)\left[1 - e^{-\lambda t}\right]^b \quad (7)$$

where b assesses the relationship between the phenomena involved in the mass transfer.

3. Results and Discussions

3.1 Extraction capacity

The aqueous extract obtained is dark brown. The volume of the aqueous solution V_{sol} collected is 450 mL with a mass of 442.1 g. After evaporation of the solvent, the dry extract obtained is a dark brown solid sticking to the wall of the flask. The mass of this dry extract is m_{es} = 21.0679 g. The concentration of water-soluble solutes, denoted C, in the aqueous extract was calculated.

This concentration corresponds to the extraction capacity C_S = 46.81 g.L^{-1}. Otherwise, assuming that the initial solute mass in the solid is equal to m_{es}, the solute concentration of the solid phase at the initial time $C_S(0)$ is equal to the ratio between the mass m_{es} and the mass of solid m (110 g). Thus, $C_S(0)$ is assumed to be about 192 g.kg^{-1}.

3.2 Extraction in batch reactor

During the extraction in a batch reactor, a volume V_S (mL) is sampled at time intervals noted t (min). The mass of each sample is noted m_S (mg). The concentration of the solution in the liquid phase at time t corresponds to the concentration of the sample taken, noted C_t (g.L^{-1}). This concentration is obtained by dividing the mass of the extract taken after evaporation of the solvent denoted m_e (g) by the volume of the sample V_S (mL). The mass concentration in solute of the liquid phase C_{lt} (g.kg^{-1}) is given by the ratio between the mass of solutes extracted m_e (g) and the mass of the liquid phase m_s (kg) of each sample (Table 1).

Table -1: Comparison between experimental and modelled concentrations

T (min)	m_s (mg)	V_S (mL)	m_e (mg)	C_t (g.L^{-1})	C_{lt} (g.kg^{-})	t/C_t (L min.g^{-1})
0	0	0	0	0	0	0
0,5	4245	4,7	15,9	3,38	3,75	0,14
1	4401	4,7	53,4	11,36	12,13	0,08
2	4361	4,7	54	11,49	12,38	0,17
3	4742	4,9	73,1	14,92	15,42	0,20
6	4866	4,9	76,7	15,65	15,76	0,38
11	3941	4,7	69,9	14,87	17,74	0,74
18	3754	4,7	66,9	14,23	17,82	1,26
27	4120	4,7	72,7	15,47	17,65	1,75
42	4099	4,7	78	16,59	19,031	2,53
62	3690	4,6	75	16,30	20,33	3,80
107	4215	4,7	83,9	17,85	19,90	6,00
167	3690	4,6	83	18,04	22,49	9,26
227	3789	4,6	86,4	18,78	22,80	12,09
270	4341	4,7	96,8	20,59	22,30	13,11

After an extraction time of 4 h 30 min, for a mass of *Salvia coccinea* of 110 g and 1 L of solvent, the volume of the filtered solution obtained was 0.7 L and its mass of 687 g. The mass sum of the liquid extract taken is 58.25 g. This means that the plant has absorbed less solvent because 240 g of solvent wets the plant powder against 300 g for soxhlet. This suggests that either filtration after extraction is more efficient.
The ratio of the mass of the solid phase to the liquid solution, *s*, is equal to the initial mass of solid on the mass of the remaining solution (687 g) and samples taken (58.25 g). This ratio is equal to 0.15.

3.3 Modeling

3.3.1. Pseudo-Second Order Kinetic

For the kinetic model of the second order, the variation considered is that of C_t as a function of *t*. Then curve t / C_t versus *t* is plotted (Chart 1). The resolution of this linearization by Kaleidagraph gave the coefficients in the table 2.

Table -2: Coefficients of the pseudo-second order linearized kinetic model

	Value	Error
k ($L.g^{-1}.min^{-1}$)	0,010809	0,005
C_s($g.L^{-1}$)	19,68	0,411
Chisq	1,6316	
R^2	0,99435	

It can be noticed that C_S is similar to C_l (∞). This allows us to deduce that the solute concentration of the liquid phase corresponds to the extraction capacity or the saturation concentration. The simulation between the experimental curve and the curve of the model equation is presented in chart 1.

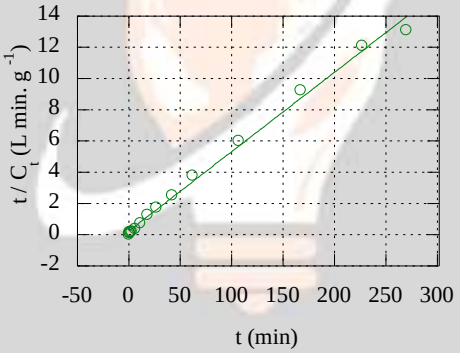

Chart -1: Comparison between the experimental data and the linearized linear pseudo-second order kinetic model

3.3.2. Spiro and Kandiah model

For this model, the variation considered is that of C_{lt} as a function of *t* (Chart 2). The objective of this model is the determination of the time constant T_1 (min) corresponding to the diffusion of solutes fraction E localized in broken-wall, the time constant T_2 (min) corresponding to the diffusion of solutes fraction 1-E localized in intact-wall cells, the amount of solutes fraction in broken-wall cells *f* and the solute concentration of liquid phase. This table 3 gave the coefficients of this model.

Table -3: Coefficients of the Spiro and Kandiah model

	Value	Error
C_l (∞) ($g.kg^{-1}$)	22,82	1,21
T_1 (min)	1,126	0,196
T_2 (min)	79,84	46,87
²	0,706	0,042
Chisq	15,916	
R^2	0,97411	

The correlation between the experimental curve and the curve of the model equation is showed in chart 2.

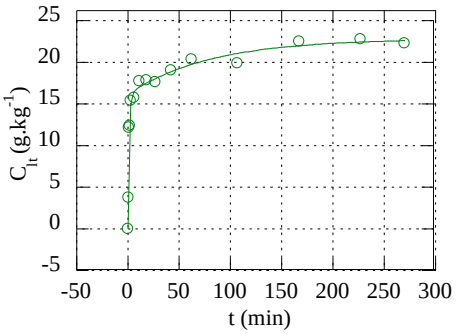

Chart -2: Comparison between the experimental data and the Spiro and Kandiah model

3.3.3. Mafarat and Béliard model

Three equations were established by Mafarat and Béliard to present the evolution of the concentration C_{lt} (g.kg^{-1}) as function of the time t (min). Although these three models based on the same formula; they don't present the same coefficients exactly.

3.3.3.1. The 1st of Mafarat and Béliard model

For this model, the coefficient of the transfer of matters, K' (min^{-1}), the concentration of the solid phase in aqueous solutions at the initial moment, $C_s(0)$ (g.kg-1), and the report/ratio of mass, S, while following the evolution of the concentration C_{lt} (g.kg-1) as function of the time t (min) are the coefficients to determinate. The curve fitting with equation 5 is given on chart 3.

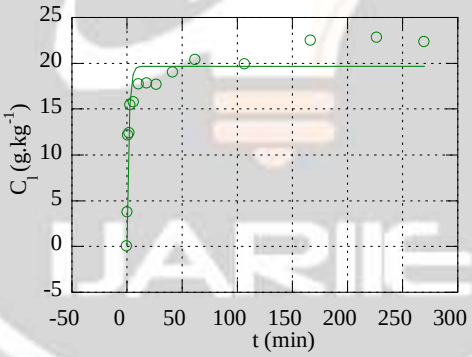

Chart -3: Comparison between the experimental points and the curve of the 1st Mafarat and Béliard model

The parameters of the model are gathered in table 4.

Table -4: Coefficients of The 1st of Mafarat and Béliard model

	Valeur	Erreur
S	0,12	1171,4
$C_s(0)$ (g.kg^{-1})	163	1,58.10^{-6}
K' (min^{-1})	0,44	1172,5
Chisq	62,98	
R^2	0,89758	

The value of Cs(0) obtained by the model of Mafarat and Béliard I is not the totality of aqueous solutions contained in the solid, it is the quantity of extractable aqueous solutions of the operating condition. Indeed, in the extraction into discontinuous, it is only part of aqueous solution which can be extracted. However, the comparison between this model and the experimental results shows that it does not represent the whole of the phenomenon governing the transfer of matters.

3.3.3.2. The 2nd of Mafarat and Béliard model

This stage aims at determining the value of the parameter of equivalence λ (min^{-1}). The model is done starting from equation 6. In this model, according to equations 4 and 5, the product of the report/ratio *s* by the concentration in aqueous solution of the solid phase at the initial moment $C_s(0)$ is equal to the concentration in aqueous solution of the liquid phase after an infinite time $C_l(\infty)$. The parameter λ is defined by the relation between the total coefficients of transfer *K'* and 1-s. In addition, the concentration $C_l(\infty)$ is equal to the product of *s* and of $C_s(0)$. The values of *s* and of $C_s(0)$ used are those obtained in the 1st of Mafarat and Béliard model. The comparison of the equation of the 2nd Mafarat and Béliard model with experimental measure is presented at chart 4.

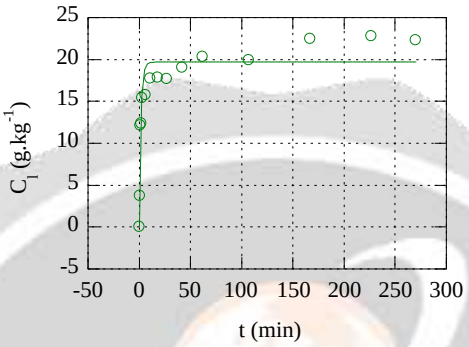

Chart -4: Comparison between the experimental points and the curve of the 2nd Mafarat and Béliard model

The table 5 gave the values provide by Kaleidagraph®

Table -5: Coefficients of the 2nd of Mafarat and Béliard model

	Value	Error
$C_l(\infty)$ ($g.kg^{-1}$)	19,68	0,71
λ (min^{-1})	0,56	0,11
Chisq	62,98	
R^2	0,89758	

Compared to the 1st Mafarat and Béliard model, the value of R^2 not change. It was fixed of 0,89758. What explains that the comparison between the curve of the model and the experimental curve is similar to that of 1st Mafarat and Béliard model. This model does not represent either the whole of the phenomenon governing the transfer of matters.

3.3.3.3. Pseudo-diffusional Mafarat and Beliard model

The models of the 1st and 2nd Mafarat and Béliard models do not represent in a satisfactory way the kinetics of the extraction when the time of the operation is short in front of time known as infinite. However, a modification in pseudo-diffusional form makes it possible to improve its performance considerably. In addition, and in order to improve this model which has the advantage of its simplicity, one proposes to modify it by introducing a power which returns it of pseudo-diffusional type. The curve of the model is presented at chart 5 with the experimental points.

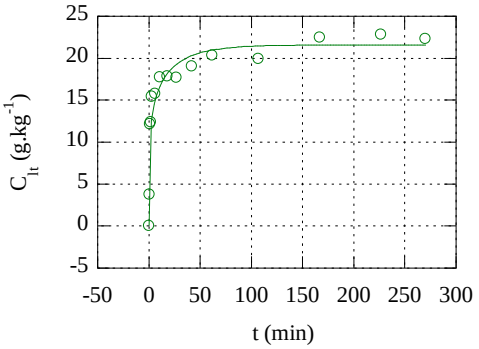

Chart -5: Comparison between he experimental points and the curve of the pseudo-diffusional Mafarat and Béliard model.

The calculated parameters are reported in table 6.

Table -6: Coefficients of pseudo-diffusional Mafarat and Béliard model

	Value	Error
$C_l(\infty)$ (g.kg^{-1})	21,58	1
λ (min^{-1})	0,034	0,02
b	0,22	0,05
Chisq	47,652	
R^2	0,9225	

The model is clearly improved. At the beginning of the extraction, the curve of the pseudo-diffusional model simulates correctly with the experimental curve. The difference is noted in the second phase of the extraction. The curve of this last model approaches that of the experimental one. The introduction of power induces a value very different from λ = 0,034 min^{-1}.

3.4. Comparison of Mafarat and Béliard models

This table 7 illustrates the differences between the concentrations calculated with the three models of Mafarat and Béliard, like their variations with the experimental data at each time considered.

Table -7: Concentrations obtained at each time for the 1st, 2nd and pseudo-diffusional of Mafarat and Béliard models

		Mafarat and Béliard models					
		I		II		Peudo-diffusionnel	
t (min)	C_{lexp}	C_{lmod}	ΔC_l	C_{lmod}	ΔC_l	C_{lmod}	ΔC_l
0	0	0	0	0	0	0	0
0.5	3.75	4.30	0.55	4.78	1.03	8.79	5.04
1	12.13	7.82	-4.31	8.39	-3.75	10.22	-1.92
2	12.38	12.36	-0.02	13.18	0.80	11.86	-0.53
3	15.42	15.25	-0.17	15.91	0.50	12.92	-2.50
6	15.76	18.58	2.82	18.88	3.12	14.88	-0.88
11	17.74	19.48	1.74	19.52	1.78	16.70	-1.03
18	17.82	19.56	1.74	19.56	1.74	18.17	0.35
27	17.65	19.56	1.91	19.56	1.91	19.29	1.65
42	19.03	19.56	0.53	19.56	0.53	20.32	1.29
62	20.33	19.56	-0.77	19.56	-0.77	20.97	0.65
107	19.91	19.56	-0.35	19.56	-0.35	21.45	1.55
167	22.49	19.56	-2.93	19.56	-2.93	21.56	-0.93
227	22.80	19.56	-3.24	19.56	-3.24	21.58	-1.22
270	22.30	19.56	-2.74	19.56	-2.74	21.58	-0.72

The comparison of the curves of these various concentrations is presented at chart 6.

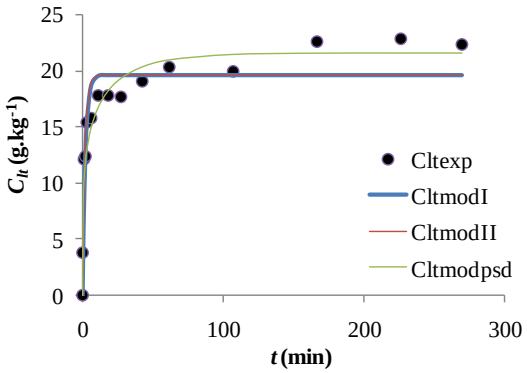

Chart -6: Comparison between the experimental points and the curves of the 1st, 2nd, and pseudo-diffusional Mafarat and Béliard models

If one refers to these three models, it is supposed that the time of diffusion (stage 3) is limited for many of other parameters (speed of dissolution, nature of the aqueous solution, porosity of solid etc...),so the modeling of the phenomenon of diffusion is possible only 0 to 6 minutes. In this interval of time, the diffusion is the major stage. For the remainder, the transfer can be the whole of many of other phenomena.

3.5. Comparison of Mafarat and Béliard models with Spiro and Kandiah model

All the models show that initially, the transfer is mainly governed by the diffusion only. The variations are observed as from 6 minutes. The description of each model becomes different as from this time. Chart 7 illustrates them.

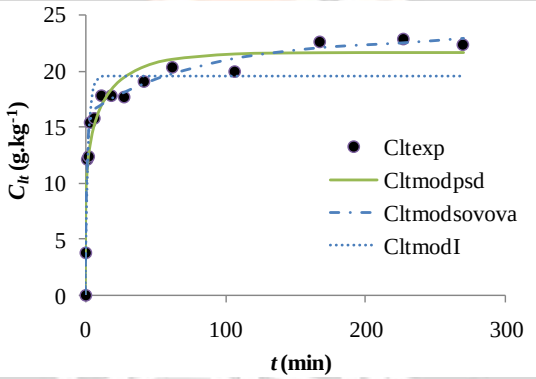

Chart -7: Comparison between the experimental points, the curve of Mafarat and Béliard models and the curve of Spiro and Kandiah (or Sosova) model

The coefficient f shows that the major part of the aqueous solution is in the cells with broken walls. There are only 30% which remain to imprison in the cells with intact walls. This result is consolidated by the evolution of the concentration modeled by Spiro and Kandiah. Indeed, a change is noted at 6 minutes, which corresponds to 16,38 g.kg^{-1} of concentration, and thus to 70% of the concentration $C_l(\infty)$.

4. CONCLUSIONS

This study allows to describe the phenomena of material transfer by extraction kinetics in the case of *Salvia coccinea* in discontinuous mode. Results of simulations undertaken during this study demonstrate the transfer mechanism of solute from a solid phase of plant origin (sage) to a liquid solvent (water). It is a molecular diffusion which occurs in the particles towards the liquid solution according to two parallel mechanisms having different characteristic times. For plant materials, the solute is often localized in the cells. Rapid diffusion from broken cells near the outer surface of the particles and slower diffusion from intact cells or into pores in the center of the particle. The models of Mafarat and Béliard I and II are not able to describe the phenomena of material transfer for *Salvia coccinea* except in the first part. Another model, Mafarat and Béliard pseudo-diffusional, has been proposed. Thus, in order to be able to clarify and discuss the results, two other models were studied, the Spiro and Kandiah model and the pseudo-second order kinetic model. For these three models, good agreements between model predictions and

experimental measurements were observed but in a different way. They also demonstrate that the kinetics are divided into two phenomena: a predominant mechanism, the molecular diffusion of particles towards the external surface and a slower mechanism attributed to the exit of solutes that are more difficult to extract due to their position (pores or unbroken cells) in plant cells. This clearly indicates that in *Salvia coccinea* most of the solute is in the broken-walled cells. Extraction of water soluble solutes is therefore easy by further breaking the cells.

5. REFERENCES

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