# MATHEMATICAL MODELLING OF EXTRACTION OF THE SUNFLOWER OIL AND EXPERIMENTAL DETERMINATION OF CHARACTERISTICS OF THE RAW MATERIAL.

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*Abstract. The extraction of vegetable oils grows in importance in Brazil and in the world impelled by the urgent need of use of fuels less pollutant than derived them of petroleum. The grain of the sunflower possesses high oil percentage, being one of the most suitable for the human feeding, as well as for the biodiesel production. The industries of vegetable oils use great facilities for extraction with solvent use. For optimization of the equipments they are necessary mathematical models that describe the processes efficiently. This work presents the mathematical modelling of the sunflower oil extraction in an extractor of fixed bed, as well as, the experimental determination of characteristics of the raw material, as: porosities, specific masses, equilibrium coefficient between the pore phase and "bulk", average diameter of the particle and oil concentrations, among other, requested in the model. The experimental part was accomplished in equipment laboratorial built for the research, being controlled the temperature at levels used in the industries. Simulations were accomplished and the results were compared with the data obtained experimentally.*

*Keywords: Extraction, Oil, Sunflower, Modelling, Solvent.*

## 1. INTRODUCTION

In Brazil and in the world there is an industrial area dedicated to the extraction of vegetable oils, as soy oil, canola, rice and sunflower. Traditionally those industrial installations are returned to the production of the vegetable oil used for the feeding. Nevertheless, nowadays there are high investments for the extraction in industrial scale for the biodiesel production.

Being the sunflower a culture that presents a percentage of oil between 40% and 50%, what turns this culture one of the most profitable for the production of oil vegetable or combustible. The sunflower oil is considered as the one of nutritional characteristic best in relation to other vegetable oils. Besides the importance as component feeds the sunflower is a great alternative for the production of vegetable fuel. The biodiesel is a derived fuel of renewable sources, that can be produced starting from animal fats or of vegetable oils, existing several species in Brazil that can be used, such as castor oil, sunflower, peanut and soy.

Seeking alternatives that assure the survival in a very competitive market, the industries of vegetable oils are investing in programs of improvement of the quality and efficiency. This work accomplishes the mathematical modelling of the extraction process of the sunflower oil, that will be able to in future, to give support to the industries to decide the characteristics of raw materials and installations, or another variable that influence in the process.

The oil industries use continuous installations of large tonnage prevailing extractors for solvent of the type "Rotocell","De Smet" and "Crow-Model". It is observed the need of mathematical models that describe this process with efficiency optimizing the process extraction. For modelling of the processes in those equipments, are necessary the understanding of extractors of smaller complexity as the extractor of fixed bed.

Considering that the bibliography possesses incomplete data and divergent relative to the raw materials and that these data are necessary to the modelling of the equipments, in this work was developed an equipment laboratorial of the type fixed bed, through support financial of FAPERGS (Foundation of Support to the Research of the State of Rio Grande do Sul), that allows to determines characteristics of the material raw that are not found in the literature. The extractor laboratorial become allowed to obtain reliable data, similar to the industrial results, because makes possible to control the temperature of the system and all of the masses involved in the process. The results refer to the raw material sunflower, after passing for a preparation process, where a portion of the oil was already extracted.

Through the mathematical model composed by partial differential equations, that were semi-discretizadas for the method of lines and solved by Runge-Kutta, were accomplished numeric simulations that reveal properties of the extraction field. These results are compared to the obtained during the extraction in the extractor of fixed bed and show that are in agreement with the experimental results.

## 2. MATHEMATICAL MODEL

The fixed bed, as "Fig. 1", is constituted of vertical columns where the raw material particles are deposited, that stay immobile during the extraction. The solvent enters in the top of the column and crosses refined layer extracting the solute contained in them and turning into micela. Each raw material particle is constituted by two phases, the pore phase (inner porosity of the particle) and the solid phase. The spaces between grains form the "bulk" phase, where it happens

the percolation of the micela (the liquid mixture of the solvent with oil). The enriched mixture going the bed through the perforated bottom. This device is important to determine the characteristics of extraction process and the properties of the raw material, as well as to create the models for industrial installations.
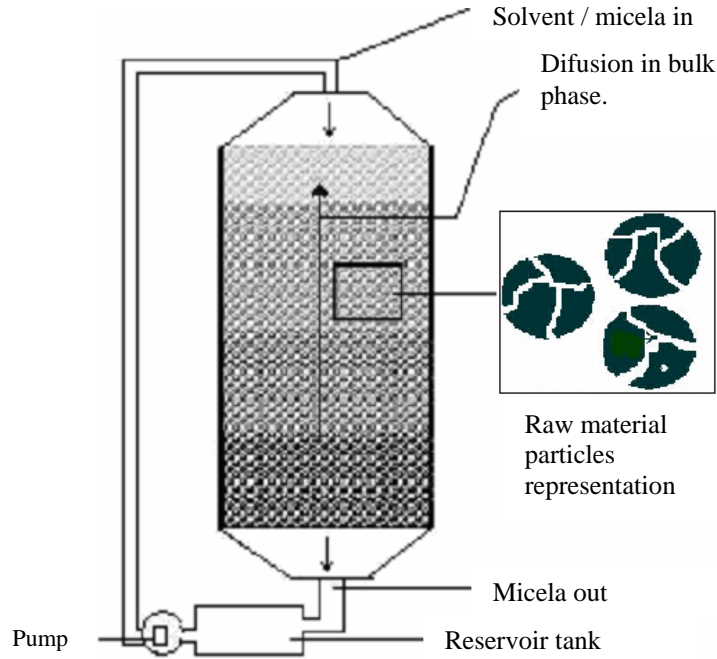


Figure 1. Operational scheme of the fixed bed extractor.

The fixed bed model for the sunflower oil extraction, takes into consideration the transfer of the oil contained from the solid phase to the pore phase and, after to the "bulk" phase; the percolation of the micela throughout the raw material, the oil diffusion in "bulk" phase within the extraction field, in sense ascendancy. The following simplify hypotheses are considered: the oil concentration into the particles are assumed to be uniform; don't exist concentration radial gradients in the "bulk" phase; the solvent doesn't penetrate in the solid phase; the cellular walls of the grains are broken and; the temperature and particles porosities of the bed are assumed to be constant and uniform during extraction.

The model is composed by four differential equations, evolutionary one-dimensional, representing the variations of the flow of the "bulk" phase, the alteration of the oil concentrations of pore and "bulk" phases during the extraction process and the evolution of the average concentration of the micela into the reservoir.

The continuity equation to the "bulk" phase:

$$\frac{dU_s}{dz} = \frac{1-\varepsilon_b}{\varepsilon_b} k_f a_p \left( C^P - C \right) \tag{1}$$

The continuity equation to the species into the "bulk" phase:

$$\frac{\partial C}{\partial t} = -\frac{\partial UC}{\partial z} + D_{AB} \frac{\partial^2 C}{\partial z^2} + \frac{(1-\varepsilon_b)}{\varepsilon_b} k_f a_p \left( C^P - C \right) \tag{2}$$

The continuity equation to the species the pore phase:

$$\frac{\partial C^P}{\partial t} \left[ \varepsilon_b + (1-\varepsilon_p)\frac{\partial C^N}{\partial C^P} \right] + k_f a_p \left( C^P - C \right) = 0 \tag{3}$$

The average concentration equation of the micela into the reservoir:

$$\frac{d\overline{C}}{d\tau} = \frac{U\varepsilon_b A_v (C_L - \overline{C})}{V_b} \tag{4}$$

The boundary and initial conditions:

The initial condition to the equation (3), at t=0, $C^P = C_i^P$, $U = U_0$ for all x.

The "Equations (1, 2 and 3)" were no dimensional zed by using:

$$U = \frac{U_S}{U_0} \quad ; \quad z = xL \quad ; \quad \tau = \frac{U_0 t}{L}$$

(5)

and considering the no dimensional groups:

$$Sh = \frac{k_f d_p}{D_{AB}} \quad ; \quad Pe_{in} = \frac{U_0 d_p}{D_{AB}} \quad ; \frac{D_{AB}}{U_0 L} = -\frac{1 d_p}{Pe_{in} L}; \quad \frac{k_f}{U_0} = \frac{Sh}{Pe_{in}}$$

Then, in no dimensional equations were given by:

$$\frac{dU}{dz} = \frac{1 - \varepsilon_b}{\varepsilon_b}(a_p L)\frac{Sh}{Pe_{in}}\left(C^p - C\right)$$

(6)

$$\frac{\partial C}{\partial \tau} = -\frac{\partial(UC)}{\partial x} + \frac{1}{Pe_{in}}\frac{d_p}{L}\frac{\partial^2 C}{\partial x^2} + \left(\frac{1 - \varepsilon_b}{\varepsilon_b}\right)a_p L \frac{Sh}{Pe_{in}}\left(C^p - C\right)$$

(7)

$$\frac{\partial C^p}{\partial \tau}\left[1 + \left(\frac{1 - \varepsilon_b}{\varepsilon_b}\right)\frac{\partial C^N}{\partial C^P}\right] + \frac{1}{\varepsilon_b}\frac{Sh}{Pe_{in}}(a_p L)\left(C^p - C\right) = 0$$

(8)

$$\frac{d\overline{C}}{d\tau} = \frac{U\varepsilon_b A_v(C_L - \overline{C})}{V_b}$$

(9)

$A_v$ - section traverse area of the extractor; $U_0$ – initial velocity; $U_S$ – real velocity; $U$ – relative velocity; $z$– height of the bed coordinate; $t$ –time; $\rho$ - specific mass micela; $L$ –bed height; $k_f$ -mass transfer coefficient between pore end "bulk" phase; $C_L$ –micela concentration outlet; $C$ – oil concentration into the micela; $D_{AB}$ – diffusion coefficient; $C^P$ -oil concentration within of the pore phase; $\overline{C}$ -average oil concentration within of the reservoir; $d_p$ - average diameter of the particle; $C^N$ - residual oil concentration in the solid phase; $V_b$ -volume of the micela within the reservoir; $x$– relative height of the bed coordinate; $\tau$ -relative time; $\varepsilon_b$ - "bulk" porosity; $\varepsilon_p$ -pore porosity; Re - Reynolds number; $Sc$ - Schmidt number; $Pe_{in}$ - Peclet number.

Sherwood (*Sh*) number is given by:

$$Sh = 2,4\,\text{Re}^{0.34} Sc^{0.42} \quad , \quad 0,08 < Re < 125$$

(10)

$$Sh = 0,442\,\text{Re}^{0.69} Sc^{0.42} \quad , \quad 125 < Re < 5000$$

(11)

The equilibrium relationship between the residual oil concentration of grain ($C^N$) valid for and the concentration oil within the pore phase ($C^P$), experimental obtained, is given by: $C^N = 0,8337 C^P$.

## 3. EXPERIMENTAL WORK

Experiments were accomplished for determination of characteristics of the raw material sunflower, of the solvent and of the micela. These characteristics are information necessary because the model takes into consideration and it is inexistent to the sunflower.

"Recently, Thomas *et al*. (2005) and Veloso and Kriukov (1999)" refer to other oleaginous and constant temperature, what is different of the real process utilized on industries that use temperatures at 50°C, approximately, for

facility a better solubility of the oil existent into raw material. In the same way, the works are divergence for porosities, densities, equilibrium constant, etc., relative to the sunflower.

In this research the experiments were accomplished in mounted equipments in the Laboratories of Chemistry and on Nucleus of Foods in the Pole of Technological Modernization of UNIJUI, Santa Rosa/RS. The "Figure 2" show an extractor laboratorial, that was built for the research. This equipment allowing the control of the extraction temperature, masses and volumes, allowing acquisition of the data agree well with to the produced in the industry.

The raw material is deposited in the metal column ($D$), with 0.14 meters of internal diameter and 0.6 meters of height. The column is provided of a screen basket that keeps the raw material, lets the micela to flow, being deposited on an analytical balance ($J$). The micela circulates continually for the centrifugal pump ($B$), percolate through the column by the gravity force and enters into the reservoir ($A$). This process is repeated by 60 minutes, could be collected micela samples through the valve ($L$). The micela goes by the fluxometer ($C$) and in the coil ($E$) submerged in warm water maintained the temperature constant by a kettle. The temperatures of the micela are measured by the thermometers ($F$), ($G$), ($H$) and ($I$). The micela flow is constant, measured by the fluxometer and for a level meter ($K$).
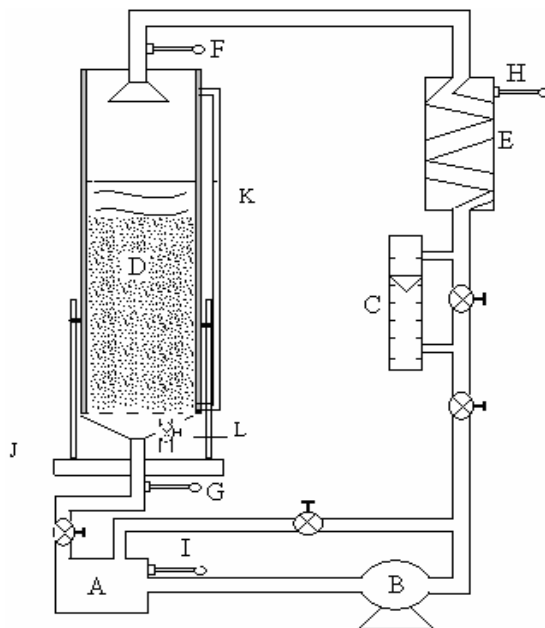


Figure 2. Physical scheme of the extractor laboratorial of Fixed Bed.

They were determinate the inner porosities and outer of the raw material, being the first characterized by the porous spaces that exist within the particles and denominated of pore phase ($\varepsilon_p$) and, the second, call of "bulk" phase ($\varepsilon_b$), they are the spaces between the particles. Is assumed that the porous of the raw material and the change relationships happened in agreement with the presented outline in "Fig. 3", being: micela flow (1), diffusion of the oil of the pore phase (2), pore phase (3), solid phase of the raw material and passage of the oil to the pore phase (4), raw material particle (5).
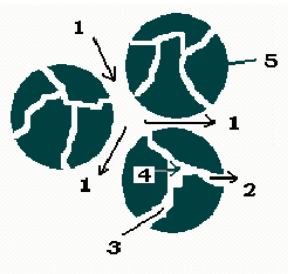


Figure 3. Porosities and oil transfers scheme among phases.

To simulate the extraction process, one mass (1 $Kg$) of raw material is place in the extractor of the "Fig. 4", measuring the height that reaches in the column ($D$). Then, the solvent is insert until that same height, and the solvent mass represents the sum of the pore phase and bulk existent in the bed. At the end of the extraction, when the micela reaches the superior level of the raw material, it to drain for the valve ($L$). This volume represent the measure of the "bulk" phase ($V_{bu}$) and any portion of oil remaining in the pore phase ($V_p$).

The porosities $\varepsilon_T, \varepsilon_b, \varepsilon_p$ were determined through of the volumes:

$$\varepsilon_b = \frac{V_{bu}}{V_\Sigma} = \frac{V_{bu}}{V_N + V_p + V_{bu}} \tag{12}$$

$$\varepsilon_p = \frac{V_p}{V_N + V_p} \tag{13}$$

$$\varepsilon_T = \frac{V_{bu} + V_p}{V_N + V_p + V_{bu}} \tag{14}$$

Where $V_\Sigma$ is the total volume, $V_N$ is the volume of the solid phase .

During the simulations were collected the samples of the micela, at 10 for 10 minutes, through the valve (*L*), for to calculate the oil concentration into the micela in function of the time $(g_m^t)$. Then, the masses of the samples were collected and heated up, for a time of 3 hours in a sterilizer, until that happens the complete evaporation of the solvent t. After 12 hours inside of in a desiccators, the masses were determined again.

The rate between oil mass resulting ($M_{ol}^m$) and the micela mass ($M_m$) gives us the oil concentration in the micela in each collection and is given by "Eq. (15)".

$$g_m^t = \frac{M_{ol}^m}{M_m} \tag{15}$$



Figure 4. Extractor laboratorial of Fixed Bed.

After 70 minutes the system is in equilibrium, that is, there aren't more oil transfer between the phases of the raw material and micela. Nevertheless, not even the whole oil was extracted.

The residual concentration in the raw material ($g_N^R$) is determined by the "Eq. (16)".

$$g_N = g_m + g_N^R \tag{16}$$

and the equilibrium constant $(E_d)$, that establishes the equilibrium between the oil concentrations in the solid phase and pore of the raw material, is determined by the "Eq. (17)".

$$E_d = \frac{g_N^R}{g_m} \tag{17}$$

Where $(g_m)$ is the oil content into the micela.

## 4. RESULTS

### 4.1 Experimental results.

The data obtained with the experiments are showed in the "Tables 1 to 3" and in the "Figures 4 and 5". The shown results are considered the best, that is, they presented average values very approximated amongst them selves. The result of the analysis of the hexane specific mass ($\rho_{he}$) showed good agreement with the results of the "recent works in Majumdar *et al.* (1995), Thomas *et al.* (2005), Veloso and Krioukov (1999)". For the calculations the found average was used, $\rho_{he} = 0.6693$ g/cm³.

Table 1. Experimental Results.

| | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | Média |
|---|---|---|---|---|---|---|---|---|---|
| $\rho_{he}$ | 0.6704 | 0.6690 | 0.6697 | 0.6695 | 0,6690 | 0,6683 | 0,6702 | 0,6685 | 0.6693 |
| $V_\Sigma$ | 2463 | 2463 | 2486 | 2390 | 2445 | 2440 | 2460 | 2450 | 2449.62 |
| $V_N$ | 454 | 535.8 | 573.7 | 430 | 446 | 424 | 518 | 523 | 488.06 |
| $V_{bu}$ | 1645 | 1620 | 1540 | 1610 | 1543 | 1535 | 1590 | 1574 | 1582.12 |
| $V_p$ | 364 | 307.2 | 372.3 | 350 | 456 | 481 | 352 | 353 | 379.43 |
| $\varepsilon_T$ | 0.816 | 0.782 | 0.769 | 0.820 | 0.817 | 0.826 | 0.789 | 0.786 | 0.8009 |
| $\varepsilon_b$ | 0.6668 | 0.658 | 0.619 | 0.674 | 0.631 | 0.629 | 0.646 | 0.642 | 0.6459 |
| $\varepsilon_p$ | 0.445 | 0.364 | 0.393 | 0.449 | 0.505 | 0.531 | 0.404 | 0.403 | 0.4370 |
| $\rho_{Mn}$ | 0.406 | 0.406 | 0.402 | 0.418 | 0.409 | 0.410 | 0.406 | 0.408 | 0.4083 |
| $g_N^R$ | 0.037 | 0.037 | 0.046 | 0.044 | 0.037 | 0.038 | 0.040 | 0.037 | 0.0396 |
| $g_m$ | 0.045 | 0.044 | 0.053 | 0.052 | 0.045 | 0.047 | 0.048 | 0.046 | 0.0475 |
| $E_d$ | 0.825 | 0.856 | 0.867 | 0.843 | 0.831 | 0.806 | 0.827 | 0.803 | 0.8337 |

where: $V_\Sigma$, $V_N$, $V_{bu}$, $V_p$ - total volumes, of the solid phase, "bulk" and pore (*cm³*), respectively, $g_m$ - oil in the micela, $\varepsilon_T$, $\varepsilon_b$, $\varepsilon_p$ - total porosities, "bulk" and pore, respectively, $\rho_{Mn}$ - specific mass of the raw material (*g/cm³*), $g_N^R$ - residual oil into the raw material, $E_d$ - equilibrium constant between solid phase and pore.

The low specific mass of the sunflower prepared for the extraction by solvent denotes that their porosities are high. Although the differences of specific masses are not so salient, the porosities determined of the samples of sunflower are larger than the samples of the other species, described in the "recent work Thomas *et al.* (2005)".

The porosities are of great importance for the extraction process. It implicates that if the "bulk " porosity is very big, the oil concentration of the micela in the exit of the extractor will be smaller, increasing the flow and needing more energy to pump. Nevertheless, if the inner porosity (pore phase) is big, there will be a larger retention of micela in the raw material, increasing the cost at energy for the evaporation of the hexane, but on the other hand the contact area of the particle increases, becoming favorable to the process.

The comportment of the changes between solid phase and pore is defined by equilibrium constant $(E_d)$ given by "Eq. (17)". The obtained experimental results show accentuated differences if compared with researched data of other oleaginous ones.

Table 2. Comparison of data with other raw materials.

|  | Sunflower | Soya | Rice |
|---|---|---|---|
| $\varepsilon_b$ | 0.6546 | 0.321 | 0.400 |
| $\varepsilon_p$ | 0.4051 | 0.366 | 0.300 |
| $E_d$ | 0.8482 | 0.190 | 0.203 |
| $\rho_{Mn}$ | 0.4081 | 0.564 | 0.592 |

The specific mass analysis of the sunflower brute oil produced in the experiments demonstrates very close values of this found in the literature for the sunflower, as well as for the soy oil. The average values for six samples of each experiment were collected and the results are showed in the "Tab. 3".

Table 3. Specific mass analysis of the sunflower oil.

|  | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 | Média |
|---|---|---|---|---|---|---|---|---|---|
| $M_{ol}$ | 90.35 | 90.49 | 89.61 | 89.61 | 90.01 | 90.47 | 90.42 | 90.14 | 90.32 |
| $V_{ol}$ | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| $\rho_{ol}$ | 0.903 | 0.905 | 0.896 | 0.896 | 0.910 | 0.905 | 0.904 | 0.901 | 0.9032 |

Where: $M_{ol}$ - sample mass ($g$), $V_{ol}$ - volume ($cm^3$), $\rho_{ol}$ - oil specific mass ($g/cm^3$)

The behavior of the extraction process could be determined with the analysis of the obtained data for the samples micela obtained during at 70 minutes for each experiment. The "Figure 5" showed the variation of the oil concentration into the micela. It is observed that in the first 20 minutes happens the largest variation of micela concentration, in other words, almost the whole oil is extracted in this period of time the subsequent variation is slower and, after 50 minutes, the process is already in equilibrium, not having more oil change between the solid phase and pore.
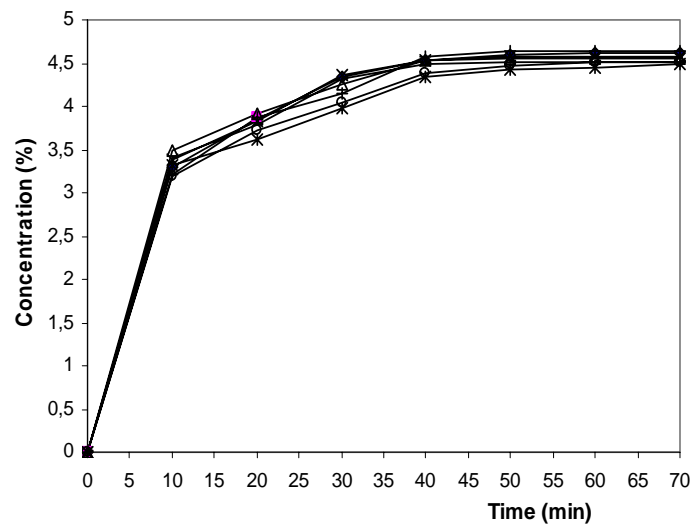


Figure 5. Variation of the oil concentration in the micela by extraction time.

As the percentage that the oil reaches in the micela is low, 3% to 5%, in function of the quantity of the solvent necessary for the extraction, the specific mass of the micela presents very small variations. The pure hexane, presents approximate specific mass of 0,667 g/cm³ and the micela concentrated, in the end of the extraction process, is of the 0,676 g/cm³, approximately.

The variation of the micela mass specifies in "Fig. 6" presents a similar behavior to variation of the oil percentile: as larger the oil concentration, larger the specific mass. It is also verified that the process is already in equilibrium on 50 minutes. That can help to define the time of extraction to be used in the industry, reducing the cost.

Through the variation of the oil concentration and of the variation of the specific mass, it was possible to build a graph showing the profile of the efficiency of the extraction process in time. The variation of the quantity of extracted

oil for unit of time is larger, while the concentration in the raw material is big and, smaller, when the micela concentration increases.
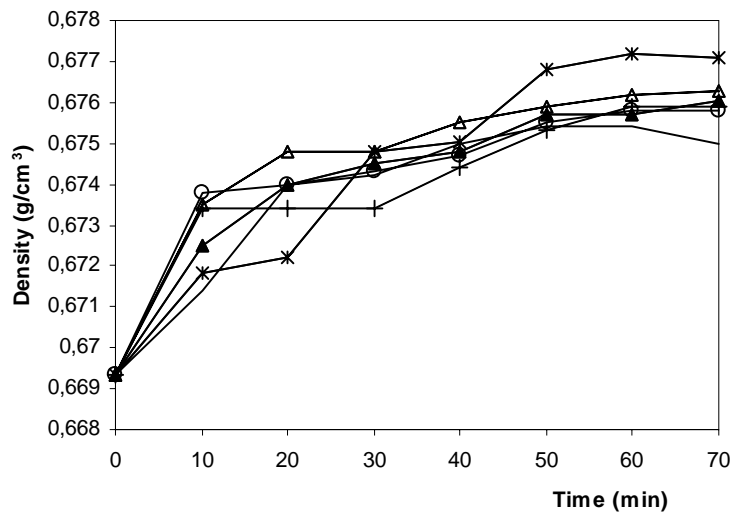


Figure 6. Variation of the specific mass of the micela by the extraction time.

## 4.2 Numeric simulation

To accomplish the numeric simulations an applicative was developed in which was used as calculation algorithm the method of lines. The differential equations are transformed into ordinary differential equations by retaining the temporal derivatives and discrediting the spatial derivatives within the extraction field. To integrate the system of equations a fourth-order Runge-Kutta method was used. There is the need to evaluate the system parameters, their main characteristics and the influences of the same ones, being necessary to establish a basic regime, whose data initials are: $L= 0,16(m)$; $a_p= 23,0(1/m)$; $d_p= 0,0025(m)$; $C= 0$; $\varepsilon_b= 0,6459$; $\varepsilon_p= 0,437$; $U= 0,01(m/s)$; $E_d = 0,8337$; $t_f=3600(s)$; $D_{AB}= 1.3e-6(m^2/s)$; $\mu = 7.0e-3(Kg/(m \cdot s))$; $\rho = 0,6693(g/cm^3)$; $C^{p=}19,0$.

It was assumed that in the initial moment the hexane already filled out the space among the pores (of the raw material) and is clean. In the "Figure 7" are presented the experimental average variation of the $C$ ("bulk" concentration of the micela) in time and the variation obtained in the numeric simulation with the basic regime.

In the beginning of the process the oil concentration in the micela is practically "zero", and the oil with considerable velocity, under action of the difference of the concentrations begins to transfer for the "bulk" phase. After some time, the oil transfer decreases because the existent micela concentrations and raw material tend to the equilibrium.
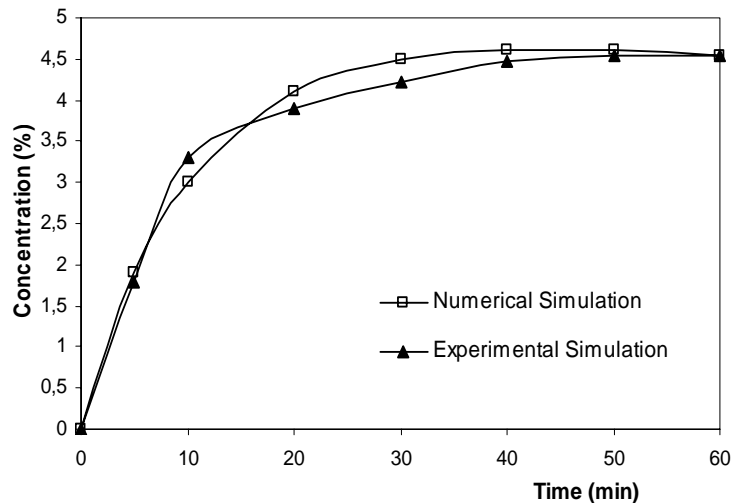


Figure 7. Oil concentration in the micela ( $C$ ) variation by time: comparison of the experimental results and simulated.

The preparation of the raw material are important in the efficiency of the extraction process. The variation of any characteristic causes modifies in others. Change the diameter of the particles, there will be alterations in the porosities and contact area among the phases. Considering a particle is with very big diameter, that automatically determines a smaller contact area between the porosity pore and "bulk". Consequently the extraction is prejudiced because of the larger spaces among the particles, what alters the porosity "bulk" and the specific mass of the raw material that enters in

the extractor. Changing the volume of the "bulk" phase in relation to the total volume of the bed the inner porosity if alters because it depends on both volumes.

For the exposed, starting from the basic regime was realized modifications in the characteristic data of the raw material (the porosities, the diameter of the particles and the specific area of contact) and, with numeric simulations was verified for which data the extraction process is more efficient. In the "Figure 8", can see that as minor is the size of the particle and consequently, larger the specific area of contact, minor will be the "bulk" porosity and larger the pore porosity. With that, the extraction process is more efficient, reaching larger oil concentrations in the micela in smaller time.
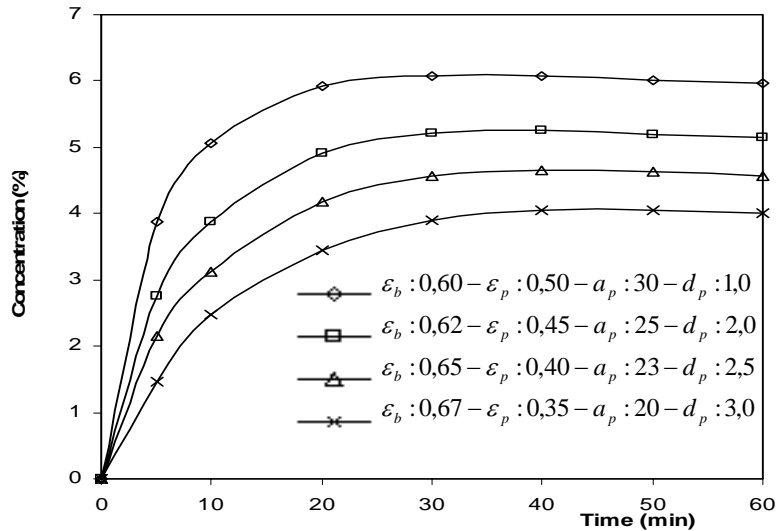


Figure 8. Variation of the oil concentration in the micela by time, in the extractor exit to different porosities "bulk" ($\varepsilon_b$), pore ($\varepsilon_p$), contact area among the phases ($a_p$) and average diameter of the particles ($d_p$).

Same conclusions are extracted in the analysis of the concentration variation in the raw material, through the "Fig. 9". The oil is extracted with larger velocity, reducing more quickly the concentration $C^p$, when the raw material is better prepared.
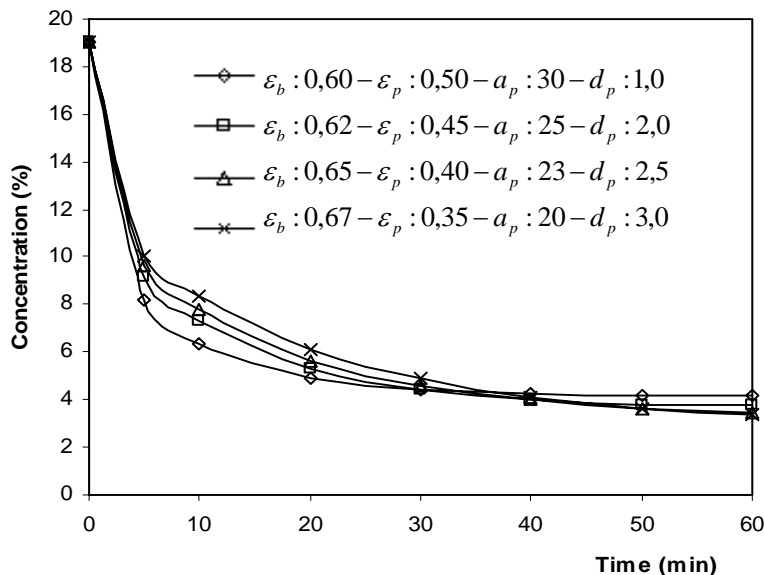


Figure 9. Variation oil concentration in the material raw by time for different porosities "bulk" ($\varepsilon_b$), pore ($\varepsilon_p$), contact area ($a_p$) and average diameter of the particles ($d_p$).

A comparative analysis between the results of the used basic regime and the most efficient results obtained with the simulations was necessary. It is observed through the numeric research the possibility of significant improvements in the real extraction process. It was compared the results obtained for the variation of the oil concentration in the micela

($C^p$) and for the variation of the oil concentration in the raw material ($C$), for both simulations (basic regime and resulted better). To enrich the comparison in "Fig. 10" was inserted the experimental results. Observing the "Fig. 10", it is verified that the industry should prepare the raw material in the same way suggested by the more efficient numeric simulation, making possible workmanship economy, of time and of energy and, for consequently increase of the gain. This is explained by the fact of the oil concentration in the micela to be larger and that can be reached in less time.
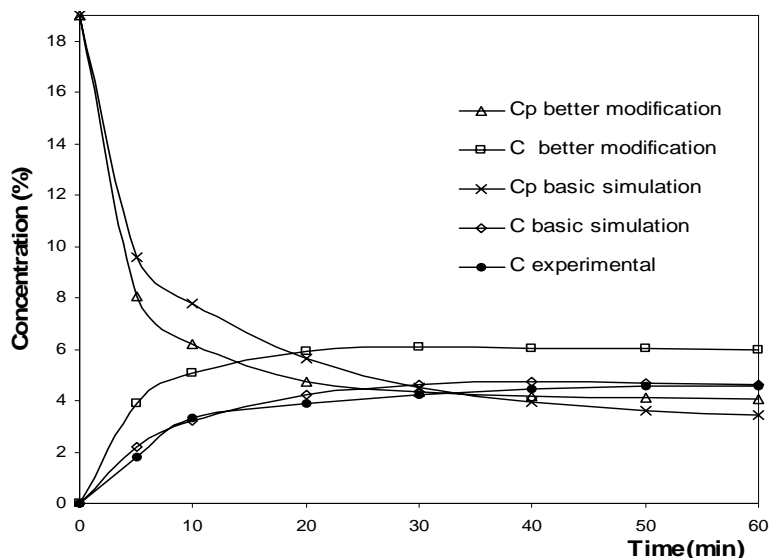


Figure 10. Variation of the concentrations $C^p$ and $C$ by time for several regimes: experimental, basic and for the most efficient simulation of extraction.

## 5. CONCLUSION

In this work was presented the experimental determination of some characteristic of the oleaginous sunflower, that can be used so much for production of vegetable oil as for biodiesel, used in the mathematical models of the vegetable oil extraction. These data are inexistent in the literature, or incomplete.

The built equipment, that simulates a real extractor of fixed bed, is important for the determination of characteristics of the raw material and in the extraction simulation. The obtained results using that equipment can be used as information for mathematical models of equipments of great load and used by the industries of the vegetable oil extraction.

The results obtained by the numeric simulations are in agreement with the experimental results and that allows to use the employed mathematical model to simulate the extraction process. The results show that the largest extraction gradient happens in the first ten minutes of the process, because of the difference of existent concentration between the raw material and the micela.

It is observed by the results obtained that the extraction can be executed in an approximated time of 50 minutes and they show that the efficiency of the extraction process of the sunflower oil for solvent can be improved in the industry with adjustments in the preparation of the raw material that result in reduction of the "bulk" porosity, in the decrease of the diameter of the particles, with the consequent increase of the contact area between the pore phase and "bulk".

## 6. ACKNOWLEDGEMENTS

## 7. REFERENCES

Abraham, G., Horn, R. J., Koltin, S. P., 1998, "Modeling the solvent extraction of oilseeds", *JAOCS*. Vol. 65, Nº 1, Champaing, pp. 129-135.

Majumdar, G. C. et al., 1995, "Modeling solvent extraction of vegetable oil in a packed bed", *JAOCS*, Campaing, Vol.1, Nº 9, pp. 971-979.

Moreira, L. G., 1998, "Modelagem matemática do processo de extração de óleo vegetal por solvente em extrator de leito fixo", *Dissertação de Mestrado*. Unijuí, Ijuí, Brazil, pp. 83

Thomas, G. C., Krioukov, V., Vielmo, H. A. 2005, "Simulation of vegetable oil extraction in counter-current crossed flows using the artificial neural network", *Chemical engineering and processing*, Elsevier, Vol. 44, pp. 581-592.

Veloso, G. O., Kriukov, V., 1999, "Mathematical model for extraction of vegetable oil in a industrial installation of the type 'De-Smet'", Proceedings of the 15th *Brazilian Congress of Mechanical Engineering*, Águas de Lindóia, Brazil, pp. 435-444.