

# Evaluation of a Mathematical Model of Dioctyl Phthalate Plasticizer Migration from PVC Discs into Colza Oil

Abd-el-Aziz Toubal, Nadia Fertikh, Salima Ali-Mokhnache, and Djelloul Messadi\*

Pollution Laboratory, Badji Mokhtar University, B.P. 12, 23000, Annaba, Algeria

Received 20 November; accepted 5 July 2005

## ABSTRACT

Results of long time tests are given for migration of dioctyl phthalate (DOP) from solid PVC discs into well-stirred colza oil. The following factors were examined: time, plasticization level (from 20 to 50 wt%), and temperature (30 and 50°C). The use of labelled DOP and radioactivity measurements in conjunction with weight loss give quantitative information on the mass exchanged (plasticizer migration and colza oil penetration) and lead to DOP concentration profiles that are developed through the bulk of polymer during the process. Mathematical model investigated in this study takes into account the following conditions: (1) the concentration of colza oil in the polymer matrix was neglected; (2) the diffusion in transient conditions through the PVC mass with DOP concentration-dependent diffusivity was considered. Statistical analysis shows that this self-consistent model is able to reproduce, to a good approximation for the DOP, the concentration profiles in the polymer, and the kinetics of transfer into the oil.

### Key Words:

matter transfer;  
plasticized PVC;  
edible oil;  
mathematical simulation.

## INTRODUCTION

Properties of poly(vinyl chloride) (PVC), an important commodity industrial polymer, are modified by compounding with a compatible plasticizer.

Generally, plasticizers are incorporated into plastic materials to

improve their workability through the decrease of the characteristic temperature of glass-to-rubber transition,  $T_g$  [1] and increase of flexibility.

Plasticized PVC is often used in the packaging industry for liquid foods [2]. In all applications, the

(\*) To whom correspondence should be addressed.  
E-mail: d\_messadi@voila.fr

plasticized PVC is in contact with the surrounding medium and the plasticizer may migrate with the following results [3-10]:

(i) Because of plasticizer loss, the polymer deteriorates its mechanical properties.

(ii) The surrounding medium is contaminated by the plasticizer. This problem is complicated by several factors:

(a) In a variety of contexts, there is a simultaneous transport of the liquid into, and the plasticizer out of the PVC. However, the amount of liquid transported into PVC often follows a more complex phenomenon. This amount increases rapidly to a maximum value; then, the liquid comes out partially (counterdiffusion) [11].

(b) For both these transfers, the diffusivity is concentration-dependent.

(c) Many factors may affect the migration process, including the nature of the polymer and plasticization process, the surrounding medium, the nature and amount of plasticizer, and the conditions of migration process, i.e., stirring, time, and temperature.

The migration is a slow process which can take several months at storage temperatures, thus shorter time tests at higher temperatures were proposed. On the other hand, the problem of identifying migrating species in the presence of chemically complex structures led very quickly to the simulation of real foodstuffs by pure products. However such simulations are, not conclusive.

Some authors[12] consider it better to derive mathematical models rather than change the conditions of the experiments. Sophisticated theoretical models, concerned with transfer of plasticizer into pure solvents, have been referred to in the literature and they must be adjusted to real foodstuffs.

In this paper, the results of long time tests are given for migration of the plasticizer (dioctyl phthalate: DOP) from solid PVC discs into well-stirred (Reynolds number is about 2000) colza oil, using a method based on labelled plasticizer and measurements of the radioactivity of the two in-contact phases. The following factors were examined: time, plasticization level (ranging from 20 to 50 wt%) and temperature (30 and 50°C). The transport kinetics in the liquid foodstuff are completed by the study of the migratory phenomenon developed through a particular disc matrix.

Low penetration advantage of the edible oil within

the PVC samples in order to test a simplified mathematical model is considered. Calculated and measured DOP concentrations in colza oil, as well as calculated and measured DOP concentration profiles that are developed through PVC matrix are compared by using the one-way analysis of variance.

## THEORY

The following assumptions were made:

(1) PVC discs are used and the case of one dimensional diffusion in a medium bounded by two parallel planes is considered, e.g., the planes  $x = \pm L$ .

(2) Concentration of colza oil in bulk polymer is neglected.

(3) The transfer of DOP through PVC mass is obtained by diffusion in unsteady state, as the diffusivity is dependent on the plasticizer concentration.

(4) The concentration of the plasticizer on the PVC surface reaches the equilibrium value as soon as the PVC sample is soaked in the colza oil.

It has been generally assumed that diffusion under transient conditions is as described by Fick's equation [13]:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \left( D \frac{\partial C}{\partial x} \right) \quad (1)$$

where  $t$ ,  $x$ , and  $D$  are the time, abscissa measured through the thickness ( $=2L$ ) of the disc, and diffusivity, respectively, the latter depends on the concentration of the diffusing plasticizer according to the relationship:

$$D(x,t) = D_0 \exp (-A/C) \quad (2)$$

The values of the coefficients  $A$  and  $D_0$  depend on the nature of the liquid foodstuff and the temperature.

## Mathematical Analysis of Short Tests

Equation (1) is analytically intractable with the above conditions. However, for very short times, the small amount of matter transferred at time  $t$  is very low, so that the concentration of the plasticizer is almost constant. In this case, the value of  $M_t$ , as a fraction of the quantity transported after infinite time  $M_\infty$ , can be expressed in terms of the square root of the time [12, 13]:

$$\frac{M_t}{M_\infty} = \frac{2}{L} \left( \frac{D_t}{\pi} \right)^{0.5} \quad (3)$$

This equation is very useful for determining the diffusivity which corresponds to the concentration of plasticizer in the PVC at the beginning of this short test.

### Numerical Analysis for Long Tests

In this case, the problem is solved using a numerical explicite method with finite differences. The numerical analysis [14] applied to eqn 1 leads to:

$$C(x, t + \Delta t) = \frac{1}{M} [C(x - \Delta x, t) + C(x, t)(M - 2) + C(x + \Delta x, t)] \quad (4)$$

with the dimensionless modulus M:

$$M = \frac{(\Delta x)^2}{\Delta t} \cdot \frac{1}{D(x, t)} \quad (5)$$

The concentration inside the disc is then computed at the abscissa  $x$  and time  $(t + \Delta t)$ , knowing the concentrations at time  $t$ , at the abscissa  $(x - \Delta x)$ ,  $x$ , and  $(x + \Delta x)$ . The total amount of plasticizer transferred at time  $t$  can be obtained by integrating the profile of concentrations with respect to time.

## EXPERIMENTAL

### Synthesis of Labelled DOP

Labelled phthalic anhydride [74mg,  $^{7-14}\text{C}$ ; 0.5mCi; CEA (Paris)] was transferred to a four necked flask and mixed with 5g of unlabelled phthalic anhydride dissolved in 50 mL of acetone. The flask is equipped with a thermometer, an inlet tube, a dropping funnel, a magnetic stirrer and a side condenser. The mixture is heated with continuous stirring until all the acetone is evaporated. 45g phthalic anhydride is added with 200 mL octanol, 60 mL toluene to promote the removal of water, and 0.6 mL conc.  $\text{H}_2\text{SO}_4$ . The mixture is heated in an oil bath for 200 min. while the temperature is gradually raised to 170°C. All the phthalic anhydride is dissolved after 80 min. After 110 min., the temperature of the vapor is stabilized at ca 82°C for 50 min., then

increases again to indicate the end of the reaction. During this period, a slow  $\text{N}_2$  stream is passed and an equimolecular mixture of octanol and toluene is periodically added.

At the end of the experiment, the mixture is cooled and diluted with  $2 \times 500$  mL (10%) aqueous sodium carbonate solution and dried for 12 h over anhydrous  $\text{CaCl}_2$ . The solution is then filtered and finally evaporated to remove diethylether, toluene and unreacted octanol. The diester is purified using vacuum distillation and yields 92%. Products with lower radioactivities are obtained by dilution with pure unlabelled DOP.

### Sample Preparation

Commercial PVC [Sicron 540 HV (Sonatrach Algeria); K70] is blended at 80°C with the calculated amounts of labelled DOP (20, 30, 40 and 50 wt%) and a fixed amount of barium-cadmium-zinc stabilizer [Irgastab BC 447 (ENPC-Algeria)]. The resulting dry blend is plasticized in a plastograph (Haake) working at 135°C, 35 rev/min, for 10 min. The plasticized mass is pressed using a steel mould operated by a power press at 150°C for 10 min. under 50 bars, to form a sheet of ca 3 mm thick. Several discs are cut, having nearly the same characteristics (18 mm in diameter, and 3 mm thick); those with a weight difference not exceeding 5% are selected for use and distributed into groups of 20 samples.

### Mass Transfer Study

All experiments were carried out with 20 PVC solid discs immersed in 200 mL of colza oil contained in a 250 mL flask, kept at a temperature fixed to 0.1°C, using a controlled rate of stirring. At intervals, PVC samples and colza oil were taken for analysis, so that the PVC-liquid ratio remains constant. Each PVC disc is weighted, and the concentration of the plasticizer in the oil is measured, so that the amounts of DOP and colza oil transferred can be determined. Then, each disc is peeled off into 15 slices of 0.200 mm thick using a lathe with a knife at the end of it. These slices are parallel to each other and to the flat faces of the discs (Figure 1). This operation works properly when the PVC disc is hardened with liquid  $\text{N}_2$ .

### Measurements

The variations of the DOP contents of the two phases in contact are monitored using the radioactive tracer tech-

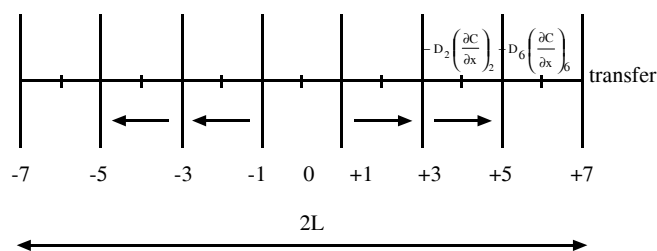


Figure 1. Diffusion of the DOP through the plane disk.

nique, with automatic quenching correction and the external standard technique. The method is proved simple and reproducible, and is, therefore, used to find the amounts of the DOP in complex mixtures prepared in the laboratory. The accuracy was 3% for the least successful test and the reproducibility was 0.25%.

The radioactivity of the liquid medium, removed at a given time after immersion, is measured by transferring 0.5 mL of colza oil to a plastic measuring vial containing 10 mL of the scintillation solution (Ready-solv. NA-Beckman). The mixture is shaken to ensure complete solubilization; the radioactivity is measured by means of a Beckman  $\beta$ -LS 2800 spectrophotometer over a period of 10 min. The analyses were carried out in duplicate; thus each quoted result represents the average of six measurements.

The following operations were carried out successively in order to measure the concentration of plasticizer mixture inside every PVC disc, for different  $x$  values of abscissa along the thickness of disc: (1) weighting of peeled slices; (2) dissolution of slices in 3mL of THF; (3) analysis on 0.5mL of the obtained solution as described previously.

## RESULTS AND DISCUSSION

### Study of DOP Transfer into Colza Oil

The curves in Figure 2 show the influence of temperature and the effect of initial DOP concentration in PVC discs on plasticizer migration into stirred colza oil. The operational conditions are respectively: (1) [DOP] = 50% for 30 and 50°C; (2) T=30°C for 20 and 50% DOP.

The curves indicate the importance of temperature for the migration rate. Any rise in temperature favours the physical process and increases drastically the amount of migrated plasticizer. On the other hand, the

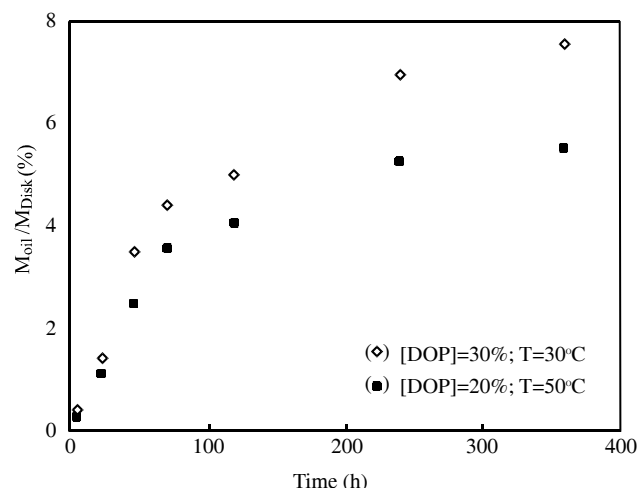


Figure 2. Variation in plasticizer migration (g/L) from PVC disk into colza oil vs. time under isothermal conditions (30 and 50°C) for various plasticizer concentrations in PVC, with the vegetable oil being stirred ( $Re=2000$ ).

initial DOP concentration influences strongly the migration process. The migration increases as a result of increasing PVC plasticization which involves both a greater DOP concentration gradient between the plastic disc and the liquid foodstuff (driving force of the transfer) and a reduction of the resistance to transfer. These two parameters (temperature and initial DOP concentration) affect the amount of the plasticizer transferred into colza oil at equilibrium ( $M_{\infty}$ ).

The effect of time in all the above cases indicates that there is no linear relation between the amount of migrated DOP and the square root of time. Generally, the desorption curves are sigmoid in shape with a point of inflexion at ca 50% equilibrium desorption. Such anomalous diffusion [13] occurs when the diffusion and polymer relaxation rates are comparable.

The influence of time was found to be of importance when it is < 120 h. For longer periods (>120 h), the migration process becomes practically unaffected by time. This behaviour is common for low migration rates and when the loss of plasticizer is coupled with a very low entry of liquid into the PVC samples (see below).

### Colza Oil Transfer in PVC Discs

Chemically, the used colza oil is a complex mixture of triacylglycerols which comprise ca 98% of the oil and other minor components such as sterols, ketones, alde-

hydes, hydrocarbons and pigments. The triacylglycerols with acyl groups containing 12 or more carbon atoms cannot diffuse into the plastic [15]. Thus, the role of the minor components may be important.

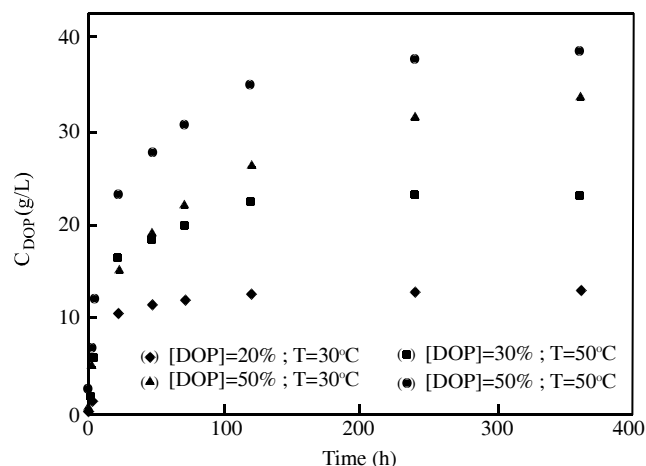
The curves on Figure 3, obtained under various experimental conditions, show a weak penetration of the colza oil into the PVC samples, at small rates.

### Profiles of DOP Concentration through PVC Discs

According to the process described above, PVC discs are removed from colza oil at different times, and every disc was peeled off in to fifteen layers of 200  $\mu\text{m}$  thick. The DOP concentration is measured in every layer and is referred to the position of the centre plane of every layer in the PVC disc. This position was expressed by the relative abscissa  $x$ , where  $-7 \leq x \leq 7$  (Figure 1). Point 0 on the abscissa is taken for the centre plane of the PVC disc, parallel to the faces, and  $\pm 7$  the abscissa at the centre plane of the two layers close to each disc face. The problem is symmetric with respect to  $x = 0$ , so the data are given only for  $0 \leq x \leq 7$ , when  $T = 30^\circ\text{C}$ ; [DOP] = 30% (Table 1), and  $T = 50^\circ\text{C}$ ; [DOP] = 20% (Table 2).

### Modelling and Simulation

The parameters  $D_0$  and  $A$  (equation (2)) are determined under isothermal conditions (30 and  $50^\circ\text{C}$ ) in the liquid in motion using PVC discs with plasticization levels ranging from 20 to 50 wt%. Diffusivities of DOP are calculated from the slopes of the straight lines obtained by plotting the DOP values transferred at short times



**Figure 3.** Amount of colza oil (%) transferred into a PVC sample referred to the initial disc weight.

against the square root of time. As the logarithm of diffusivities of the DOP are found to be related to the reciprocal of the initial plasticizer level, it is easy to obtain the following equations:

$$\text{For: } T = 30^\circ\text{C and [DOP] = 30\%} \\ D = 2.15 \times 10^{-7} \exp(-94.5/C) \quad (6)$$

$$\text{For: } T = 50^\circ\text{C and [DOP] = 20\%} \\ D = 2.15 \times 10^{-7} \exp(-63/C) \quad (7)$$

The amount of plasticizer transferred at equilibrium  $M_\infty$  is obtained from long test experiments (over 500 h)

**Table 1.** Measured (m) and calculated (th) DOP concentration profiles developed through a PVC disc vs. time;  $T=30^\circ\text{C}$ ; initial plasticizer concentration = 30%.

Relative abscissa $x$		0	1	2	3	4	5	6	7
PVC disc thickness (mm)		1.5	1.3	1.1	0.9	0.7	0.5	0.3	0.1
72 h	m	28.40	27.10	26.60	25.90	23.10	21.60	20.40	18.00
	th	29.08	29.07	28.18	27.26	25.35	23.41	20.71	18.00
120 h	m	26.60	25.30	24.00	22.50	21.90	20.10	18.60	16.50
	th	29.60	26.88	25.90	24.89	23.06	21.19	18.85	16.50
240 h	m	22.40	22.30	21.00	20.10	19.50	18.00	17.10	15.90
	th	22.48	22.45	21.83	21.15	20.00	18.81	17.36	15.90
360 h	m	18.90	18.60	18.30	18.00	17.40	16.80	16.20	15.30
	th	19.44	19.41	19.03	18.60	17.88	17.13	16.22	15.30

**Table 2.** Measured (m) and calculated (th) DOP concentration profiles developed through a PVC disc vs. time; T=50°C; initial plasticizer concentration = 20%.

Relative abscissa x		0	1	2	3	4	5	6	7
PVC disc thickness(mm)		1.5	1.3	1.1	0.9	0.7	0.5	0.3	0.1
72 h	m	19.30	18.60	18.00	17.60	16.50	15.40	13.60	13.00
	th	19.47	19.46	18.94	18.40	17.29	16.15	14.58	13.00
120 h	m	18.00	17.60	16.40	16.20	15.00	13.80	12.60	12.50
	th	18.28	18.27	17.72	17.16	16.14	15.11	13.80	12.50
240 h	m	15.70	15.40	15.00	14.80	14.00	13.40	12.30	12.00
	th	15.74	15.72	15.36	14.98	14.30	13.65	12.83	12.00
360 h	m	13.40	13.40	13.10	12.90	12.40	12.10	11.50	11.00
	th	13.53	13.53	13.28	13.02	12.58	12.12	11.56	11.00

that were made under the same conditions as for determining the diffusivities.

The profiles of the plasticizer concentration developed through the PVC discs are calculated at various times by using the model ( lines  $C_{th}$  in Tables 1 and 2).

The regression lines:

$$C_{th} = a + b C_m \quad (8)$$

fitting the pairs of values  $C_m$  and  $C_{th}$  were found by the method of the least squares. The calculation of parameters a and b and the subsequent variance analysis [16] were worked out for each experiment and considering the combined results (Table 3).

The standard deviations SE(a) and SE(b) measure the precision with which the parameters a and b have been obtained if one takes into account the number of degrees of freedom (N-2) where N is the number of paired values of  $C_m$  and  $C_{th}$ .

$$F_{obs.} = s_1^2 / s_2^2$$

$s_1^2$  is the variance due to the regression line ( variation of  $C_{th}$  with  $C_m$ ), and  $s_2^2$  is the residual variance about the regression line (measures the scatter of the  $C_{th}$  values about the regression line). The table gives for a confidence level of 99.9%, a limit  $F_{0.999}(1,N-2)$  in each case substantially less than the  $F_{obs}$  value (Table

**Table 3.** Determination of the parameters a and b (regression lines (8)) and variance analysis. (1): T = 30°C and [DOP] = 30%; (2): T = 50°C and [DOP] = 20%.

Time (h)		a	b	SE (a)	SE (b)	N	$F_{obs}$	$F_{0.999}(1,N-2)$
72	1	-1.008	1.094	1.969	0.082	8	177.873	5.041
	2	-0.473	1.068	5.103	0.307	8	286.270	5.041
120	1	-1.425	1.114	1.226	0.055	8	160.617	5.041
	2	1.182	0.979	1.454	0.094	8	107.419	5.041
240	1	1.521	1.014	1.332	0.074	8	224.538	5.041
	2	0.438	0.987	0.709	0.050	8	2536.569	5.041
360	1	-2.461	1.166	0.677	0.039	8	112.480	5.041
	2	-0.364	1.036	0.294	0.020	8	1349.398	5.041
combined results	1	-1.552	1.114	0.733	0.035	32	1467.917	3.646
	2	-0.825	1.088	1.153	0.078	32	1171.742	3.646

**Table 4.** Kinetics of transfer of DOP into colza oil. Measured (m) and calculated (th) masses (g).

Temperature (°C)	DOP (%)	Time (h)	6	24	48	120	240	360
30	30	m	0.0902	0.1290	0.1450	0.1690	0.1850	0.2050
		th	0.1172	0.1316	0.1412	0.1620	0.1796	0.1920
50	20	m	0.0604	0.1152	0.1202	0.1292	0.1322	0.1344
		th	0.0808	0.0966	0.0985	0.1030	0.1135	0.1239

**Table 5.** Determination of the parameters a and b (regression lines (9)) and variance analysis.

Temperature (°C)	DOP (%)	a	b	SE (a)	SE (b)	N	$10^4 \times S_2^2$	$F_{obs}$	$F_{0.999}(1, N-2)$
30	30	0.056	0.636	0.017	0.035	6	1.121	33.30	4.60
50	20	0.039	0.551	0.012	0.100	6	0.322	30.14	4.60
Combined data.		0.020	0.802	0.017	0.116	12	2.267	48.03	3.17

3). Hence, calculated profiles of DOP concentration correlate well with the measured ones.

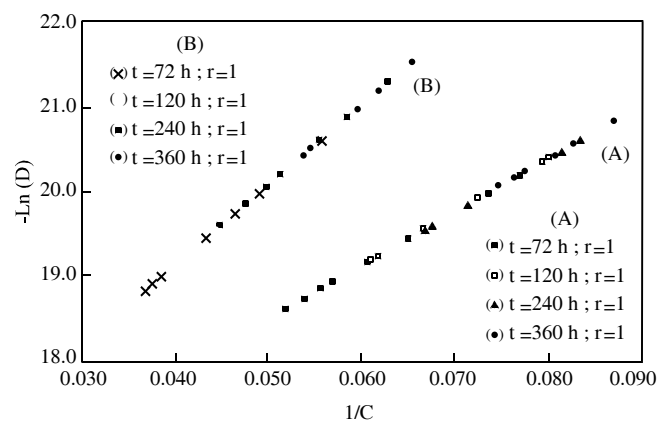
Figure 4 shows that the model is self-consistent (that is, the diffusion is well concentration-dependent as indicated above), since the logarithm of DOP diffusivities are related to the reciprocal of local concentration of plasticizer according to a linear relation, with a regression parameter equal or close to unity.

The integration of the concentration profiles provide the quantities of DOP transferred into colza oil at different times for the following condition:

$$[DOP] = 20\% \text{ and } T=50^\circ\text{C}$$

$$[DOP] = 30\% \text{ and } T=30^\circ\text{C}$$

Table 4 compares the theoretical masses ( $M_{th}$ ) and the measured ones ( $M_m$ ).

**Figure 4.**  $\ln(D)$  As a function of  $(DOP \text{ local concentration})^{-1}$ .

(A)  $T=30^\circ\text{C}$ ; initial plasticizer concentration = 30%.

(B)  $T=50^\circ\text{C}$ ; initial plasticizer concentration = 20%.

The parameters a and b for the regression line:

$$M_{th} = a + b M_m \quad (9)$$

are calculated for each experiment and considering the combined data (Table 5). The statistical results show that the calculated masses correlate with measured ones (with a P-value  $\leq 0.01$ ).

## CONCLUSION

When plasticized PVC discs are immersed in colza oil, two phenomena take place simultaneously: plasticizer migration and liquid penetration. DOP transfer is strongly enhanced when the initial plasticizer concentration and/or the test temperature increases. The influence of time is of importance when it is lower than 120 h. The transport kinetics in the liquid food were completed by the study of the migratory phenomenon in PVC itself, leading to the profiles of the DOP concentration developed through the polymer bulk during the process. Colza oil penetrates into PVC discs with difficulty, resulting in weak rates of sorption and small amounts of sorbed oil.

A mathematical analysis was undertaken by neglecting the small amounts of colza oil transferred into the polymer matrix. The simplified model was found (analysis of variance for one-way) to be available for determining the DOP concentration profiles, which integration provided correct values for transferred mass DOP into colza oil (P-value  $\leq 0.01$ ).

The model is self-consistent; that is, the data obtained verify the assumption of an exponential concentration-dependent diffusivity.

## REFERENCES

- Pizzoli M., Scandola M., *The Polymeric Encyclopedia*, CRC Press, Cleveland, 1-8 (1996).
- Pira and ICI. Symposium: Plastics for packaging food, GenÈve (1994).
- Messadi D., Gheid A., Etude des transferts de matiÈre entre un plastifiant dispersØ dans un disque de PVC et des liquides alimentaires, *Eur. Polym. J.*, **30**, 167-173 (1994).
- Gheid A., Messadi D., Influence des principaux paramÈtres sur les Øchanges entre des PVC plastifiØs au DOP et des liquides alimentaires, *J. de la SociÈte AlgÈrienne de Chimie*, **6**, 151-159 (1996).
- Messadi D., Vergnaud J.M., Evolution des profils de concentration dans la matrice d'un disque de PVC plastifiØ au DOP et trempØ dans l'alcool benzylique, *Eur. Polym. J.*, **33**, 1167-1171 (1997).
- Papaspyrides C.D., Tingas S.G., Comparison of isopropanol and isooctane as food simulants in plasticizer migration tests, *Food Add. Contam.*, **15**, 681-689 (1998).
- Tawfik M.S., Huyghebaert A., Interaction of packaging materials and vegetable oils: Oil stability, *Food Chem.*, **64**, 451-459 (1999).
- Djilani S.E., Bouchami T., Krid F., Boudiaf N., Messadi D., Comparaison des simulations chimique et mathØmatique de la migration du DOP ¶ partir de disques de PVC plastifiØ plongØs dans des huiles comestibles, *Eur. Polym. J.*, **36**, 1981-1987 (2000).
- Scholler D., Vergnaud J.M., Bouquant J., Vergallen H., Feigenbaum H., Safety and quality of plastic food contact materials. Optimization of extraction time and extraction yield, based on arithmetic rules derived from mathematical description of diffusion. Application to control strategies, *Pack. Tech. Sci.*, **16**, 209-220 (2003).
- Scotter M.J., Castle L., Chemical interactions between additives in foodstuffs: A review, *Food Add. Contam.*, **21**, 93-124 (2004).
- Messadi D., *Nouvelle mØthode d'Øtude du transfert de matiÈre entre le PVC plastifiØ et des liquides*, ThÈse de Doctorat Ès-Sciences, Saint-Etienne, NØ25 (1981).
- Vergnaud J.M., *Liquid Transport Processes in Polymeric Material, Modelling and Industrial Applications*, Printice Hall, Englewood Cliffs, New Jersey, Ch. 8 (1991).
- Crank J., *The Mathematics of Diffusion*, Clarendon Press, Oxford, 37, 105, Ch. 11 (1975).
- Smith G.D., *Numerical Solution of Partial Differential Equations*, Oxford University Press, Glasgow, Ch. 2 (1975).
- Figge K., Migration of components from plastics packaging materials into packed foods. Test methods and diffusion models, *Polym. Sci.*, **6**, 187-252 (1980).
- Minitab reference manual, Release 12.21 for windows-PA state College, Minitab (2000).