ANALYSIS OF OSMOTIC DEHYDRATION VARIABLES: INFLUENCES ON TOMATO (*Licopersicon esculentum*) DRYING

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This work presents a study of tomato osmotic dehydration in a NaCl solution. Solution temperature and concentration, immersion time and agitation had their influences evaluated. Kinetics of moisture content and solid gain were obtained. After the osmotic treatment, the fruits were dried (tray dryer) in a range of 40 to 60ºC in 10 hours. It was observed that temperature and agitation increases moisture reduction, but those variables are more influential on solid gain, what is not interesting. Osmotic treatment was responsible for increasing drying rate in a subsequent convective tray drying. The mathematical model used here was statistically coherent.

KEY-WORDS: OSMOTIC DEHYDRATION; TOMATO; Licopersicon esculentum.

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1 INTRODUCTION

Tomato is an important source of Vitamin A and C, magnesium, calcium and beta-carotene. It is largely consumed in Brazil, *in natura* and processed. Among processed tomato, dehydrated tomato has become more used nowadays. Besides being a conservation method, dehydration process aggregate commercial value to the product.

A product with pour aspect and coloration is usually the result of drying at high temperature. Osmotic dehydration is an interesting drying pre-treatment that maintains biologic product characteristics and also makes the whole process cheaper because, in this process, water is removed without spending energy (BERISTAIN *et al.,* 1990). Osmotic treatment is a way to obtain intermediate moisture products with good sensorial characteristics (HERRERA, GABAS and YAMASHITA, 2001).

Osmotic treatments had become a common procedure in tomato drying. SILVA & CORRÊA (2005) presented an extensive review of Brazilian thesis and dissertations concerned about drying and published between the years 1970-2003. Osmotic dehydration was used in every work about tomato dehydration listed by those authors. The osmotic processes and the final product are function of variables like kind of dehydration agent, dehydration solution concentration and temperature, immersion time and agitation.

Tomato, like other fruits, presents a waxy impermeable pellicle that compromises osmoses. KROSS *et al.* (2004) presented a tomato osmotic treatment that emphasized the great resistance of the fruit epidermis. Any kind of processes that removes the pellicle or it is waxy, or exposes the fruit interior greatly improve osmotic processes.

TONON, BARONI and HUBINGER (2007) studied the influence of temperature, solution composition and agitation on the mass transfer kinetics of dehydrated tomato. Those authors also analyzed Caratenoid retention. They observed the directly influence of temperature, concentration and agitation on the overall mass transfer coefficients. It was reported that the osmotic process did not change the Caratenoid content. This suggests that osmotic dehydration is an efficient method of water remove because it does not change the fruit nutritive value. AZOUBEL and MURR (2004) also observed a positive influence of solution concentration on mass transfer coefficients. SHI *et al.* (1999) studied several dehydration processes and observed that the osmotic was the one that presented the smaller lycopene losses.

McMINN and MAGEE (1999) and Rodrigues and Fernandes (2007) used osmotic dehydration before a convective drying of potatoes and melons, respectively, and reported that the osmotic treatment was responsible for increasing drying rates. DOYMAZ (2007) investigated drying characteristics of tomatoes in a convective tray drying and observed a strong and directly proportional relationship between drying rate and air temperature (range of 55 to 70ºC). It was also observed on that work that a pre-treatment by dipping the tomatoes in alkaline ethyl oleate solution increased drying rates.

The aim of this present work was the study of the influence of temperature and concentration of the osmotic solution, agitation and time on osmotic dehydration of tomatoes and the influence of the osmotic pretreatment on a subsequent convective tray drying.

2 MATERIAL AND METHODS

2.1 OSMOTIC DEHYDRATION

The tomatoes used here were bought in the market of João Pessoa, Paraíba – Brazil, and the experiments were carried out in the Unit Operations Laboratory of Chemical and Food Technology Department of the Federal University of Paraíba. The fruits were selected one by one based on their aspect, coloration, absence of physic damage and uniform maturation degree. The more uniform samples were chosen. After this, the selected fruits were washed to remove skin dirt.

The experiments were carried out with pieces of tomatoes. The upper part of the tomatoes (the one that links the fruit to the tree) was removed. After this, the remaining part was cut in four parts based in its geometric axis (cuts perpendicular to each other). The samples were weighted and immersed in an osmotic solution, following the methodology bellow (COSTA, 2003). The relation between tomato and solution ratio in weight basis was 1 of tomato to 4 of solution. After osmotic treatment, tomatoes in pieces were dried in a tray dryer. All the experiments were done in triplicate and the reported results are an average.

Samples were taken at every 30 minutes. The solution was drained. Superficial moisture was removed with absorbent paper. The samples were weighted to determine moisture content, X, in wet basis (w.b.), and Solid Gain (SG) during osmosis, according to Equations 1 and 2.

$$X(\%) = \frac{m_w}{m_i} \cdot 100 \quad (1)$$

$$SG(\%) = \frac{m_s - m_{si}}{m_i} \cdot 100 \quad (2)$$

Where m_w means mass of water; m_i is the initial mass of the sample; m_s is the mass of solids; and m_{si} is the initial mass of solids.

2.2 OSMOTIC DEHYDRATION WITHOUT AGITATION

Tests without agitation were carried out at 5ºC, 30ºC and 40ºC. The concentrations of the osmotic solutions used at 30ºC were 5, 10, 15, 20, 25 and 30% (w/w). The procedure of washing and weighting, described above was used for all the tests in which Equations 1 and 2 were applied (COSTA, 2003).

2.3 OSMOTIC DEHYDRATION WITH AGITATION

Tests with agitation were carried out at 30ºC, 45ºC e 60ºC with solutions of 5, 10, 15, 20 and 25% (w/w). Procedure of washing and weighting described above was used for all the tests in wich Equations 1 and 2 were applied (COSTA, 2003).

2.4 TRAY DRYING

The drying system was composed by a centrifugal blower of 1HP, electrical resistances (2 of 1000W, 3 of 500W and 1 of 150W) and the tray dryer. The isolated tray dryer was composed by stainless steel trays of 0.40 m x 0.40 m, like a mesh, used to allow perpendicular flow of the air. Drying experiments were carried out at temperatures of 40, 50 and 60ºC and air velocity of 2.0 ms^{-1}. During the experiments, samples were periodically weighted and the drying kinetics was obtained.

After the tray drying, tomatoes were dried in an oven at 105ºC and weighted to obtain final moisture content, according to AOAC (1984).

Drying was carried out with tomatoes cut in 4 parts without the upper part (as described before). All the conditions were tested with tomatoes with and without previous pretreatment with an osmotic solution of 10% (w/w) (COSTA, 2003).

2.5 MATHEMATICAL MODEL

The mathematical model used here was proposed by AZUARA *et al.* (1992). Such model was used in several osmotic works, like SINGH, KUMAR and GUPTA (2007) about dehydration of cubes of carrot and SUTAR and GUPTA (2007) about dehydration of slices of onion. It is based on mass balance and corresponds to a two-parameter equation. It was formulated to predict the kinetics of dehydration during the osmotic process and to determine the final equilibrium point (Equation 3).

$$WL = WL_{\infty} - WS \tag{3}$$

where WL is fraction of water lost by the foodstuff at time t; WL_{∞} is the fraction of water lost by the foodstuff at equilibrium; and WS is the fraction of water that can diffuse out, but which remains inside the foodstuff at time t.

Such equation can be developed to give Equation 4.

$$\frac{t}{WL} = \frac{1}{S_1(WL_{\infty})} + \frac{t}{WL_{\infty}} \tag{4}$$

In a similar way, for Solid Gain (SG):

$$\frac{t}{SG} = \frac{1}{S_2(SG_{\infty})} + \frac{t}{SG_{\infty}} \tag{5}$$

where S_1 and S_2 are model constants.

Equations 4 and 5 are linear ones. They relate to t and to t, respectively. These equations can predict the kinetics of dehydration during the osmotic process, the kinetics of solid gain and determine the final equilibrium points.

3 RESULTS AND DISCUSSION

3.1 OSMOTIC DEHYDRATION OF TOMATOES CUT IN 4 PIECES

Figures 1 and 2 present moisture content ratio and solid gain variation obtained in osmotic treatment with NaCl solution at concentrations from 5 to 30% at 30ºC. Moisture reduction and solid gain increased with time. Tomato waxy epidermis works as a barrier to mass transfer. However, in this work, this was by-passed by exposing the interior of the fruit. The final moisture obtained was up to 85.07% of the initial value and the solid gain was up to 14.05%. Profiles of moisture reduction and solid gain according to solution concentration were coherent, i.e., moisture reduction and solid gain increase with solution concentration, but until the concentration of 25% (Figures 1 and 2). Curves obtained with 30% solution were very near of 25% solution curves. This fact indicates concentration is not influential above 25%. It should be also noted that solution saturation occurs between concentrations of 25 and 30%.

FIGURE 1- MOISTURE CONTENT RATIO DURING OSMOTIC DEHYDRATION AT 30ºC

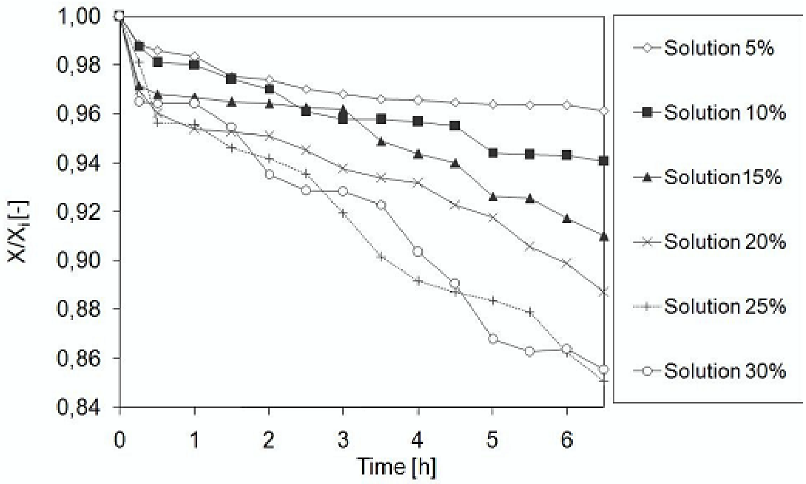
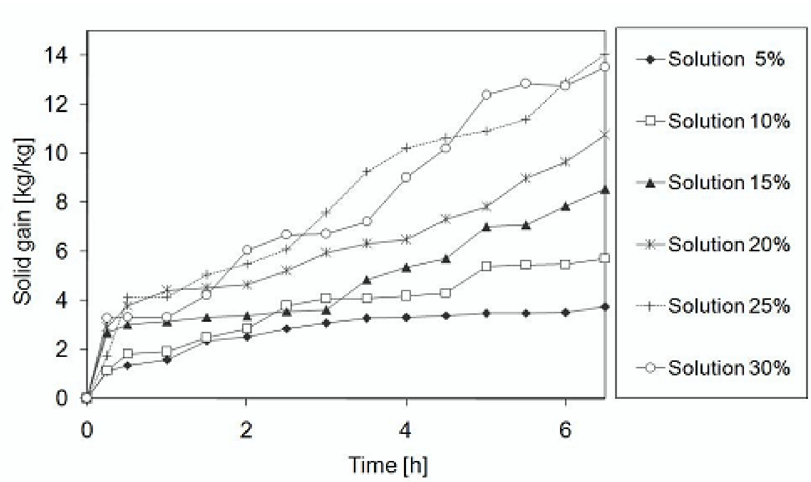


FIGURE 2 - SOLID GAIN DURING OSMOTIC DEHYDRATION AT 30ºC



It is important to note that osmotic processes should not be carried out for too long because the time influence is greater for solid gain than for moisture reduction. According to Figures 1 and 2, moisture reduction from 2 to 6,5 hours was up to 8.4% and solid gain in the same period was from 49% (5% NaCl solution) to 155% (25% NaCl solution). RAOULT-WACK (1994) observed that osmotic dehydration is almost concluded in the first two hours of treatment and in a subsequent period, solid gain is the most important phenomenon.

Figures 3 and 4 show profiles of moisture content ratio and solid gain in a 15% NaCl solution at different temperatures. Both figures show that there is no significant difference for moisture reduction and solid gain in the first one hour of immersion. However, temperature becomes relevant from the second hour on. After 4 hours of immersion, the 5 and 30ºC curves present a tendency to become horizontal, what suggests an equilibrium tendency. The curves of moisture content and solid gain obtained at 45ºC (Figures 3 and 4) showed a different aspect from the others. The fruits become softened at 45ºC, what makes osmotic process easier. It can be seen that at 45ºC, moisture reduction is greater, but this was not desirable because the solid gain was also greatly increased.

Even with the greatest moisture reduction at 45ºC, by comparing moisture content curves obtained with solutions of 15% at 45ºC and of 25% at 30ºC, one can see that moisture reduction is almost the same (Figure 5). This suggests that the use of more concentrated solutions is the best alternative. Commercial NaCl is a cheap product and the process was at room temperature, without heating requirements. Another relevant aspect is that operation at 30ºC delivers a harder product. It is important to note that solid gain is also very similar in such cases (Figure 6).

FIGURE 3 - MOISTURE CONTENT RATIO DURING OSMOTIC DEHYDRATION IN A 15% NACL SOLUTION AT SEVERAL TEMPERATURES WITHOUT AGITATION

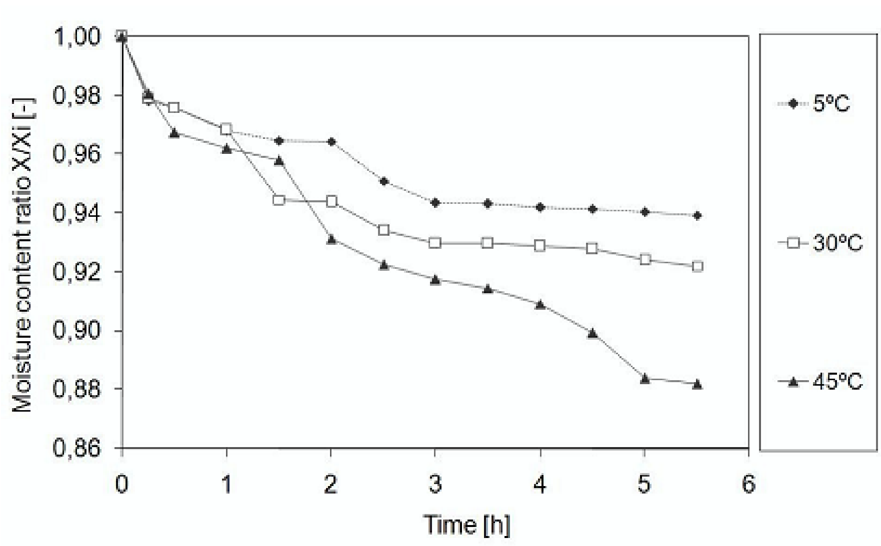


FIGURE 4 - SOLID GAIN DURING OSMOTIC DEHYDRATION AT SEVERAL TEMPERATURES WITHOUT AGITATION

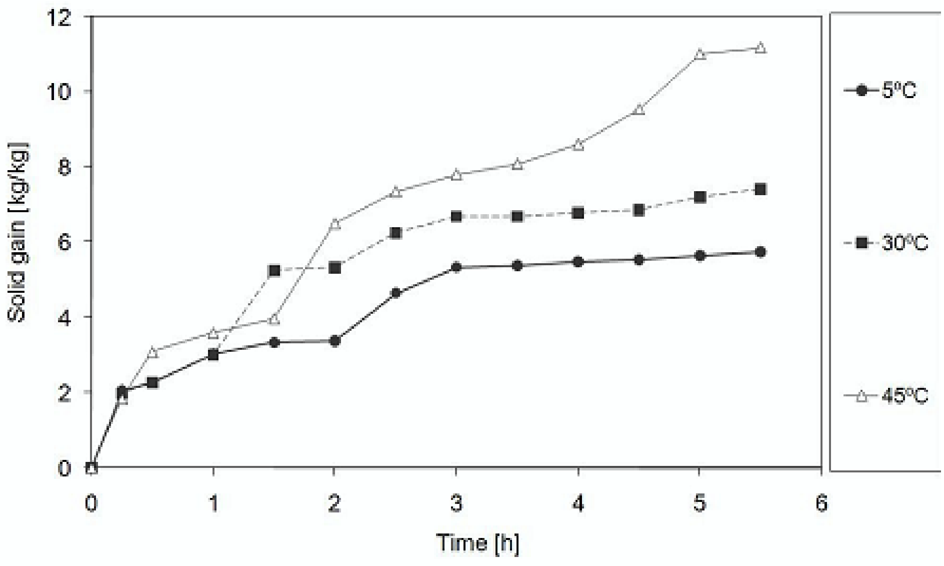


FIGURE 5 - MOISTURE CONTENT RATIO DURING OSMOTIC DEHYDRATION AT DIFFERENT CONDITIONS

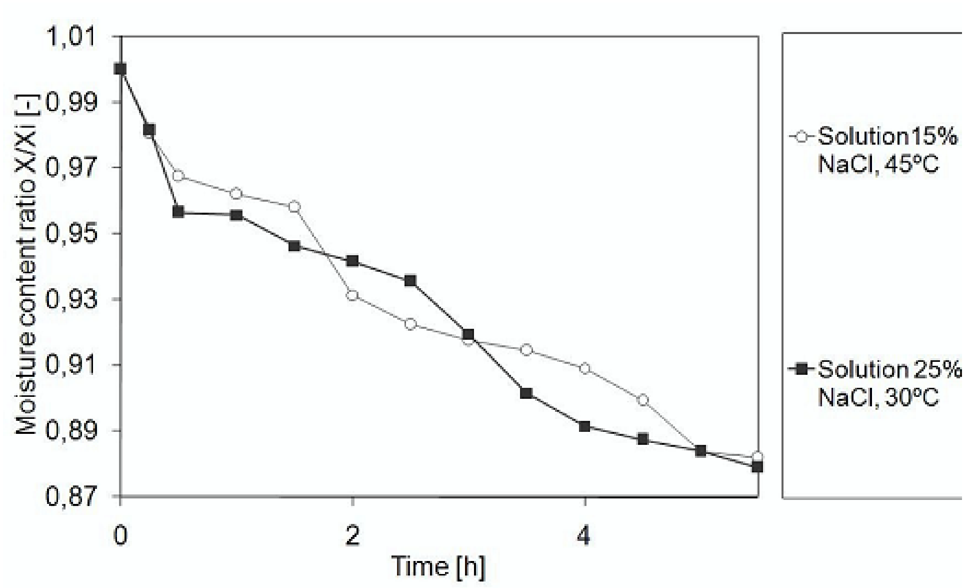
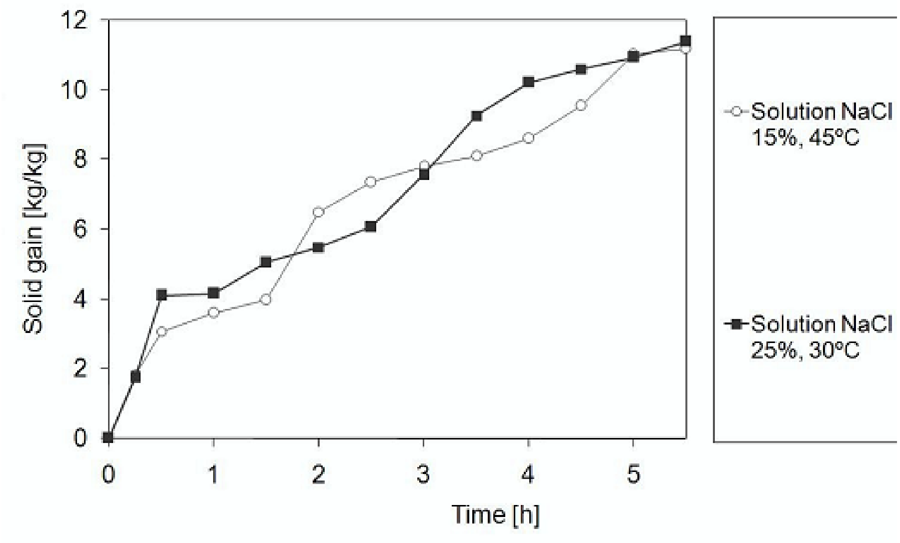


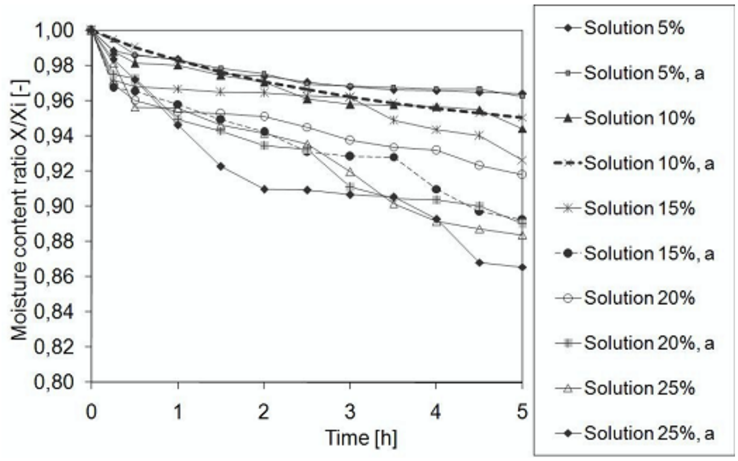
FIGURE 6 - SOLID GAIN DURING OSMOTIC DEHYDRATION AT DIFFERENT CONDITIONS



Experiments with agitation at different concentrations were also performed. Figures 7 and 8 present moisture reduction and solid gain with agitation at 30ºC, respectively. It can be seen that moisture reduction and solid gain were again proportional to the solution concentration and that agitation becomes significant for moisture reduction when solution concentration was greater than 10% and for solid gain when solution concentration was greater than 15%. However, one can see that the influence of agitation is greater for solid gain than for moisture reduction.

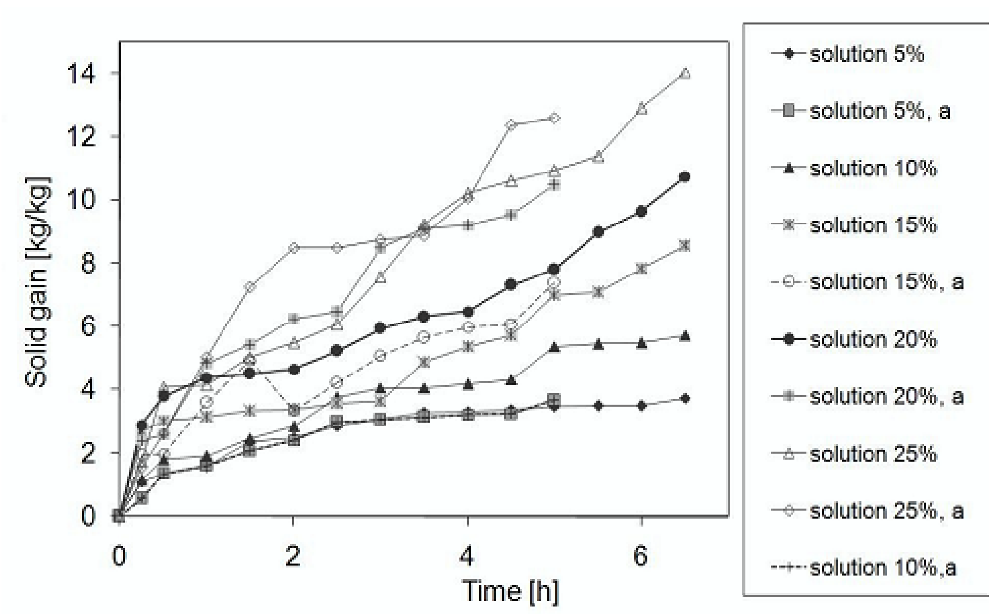
Considering sensorial aspect, this is an inconvenient. A product with great salt concentration is usually rejected.

FIGURE 7 - MOISTURE CONTENT RATIO DURING OSMOTIC DEHYDRATION AT 30ºC WITH AND WITHOUT AGITATION



“a” means agitation.

FIGURE 8 - SOLID GAIN DURING OSMOTIC DEHYDRATION AT 30ºC WITH AND WITHOUT AGITATION



“a” means agitation.

Figures 9 and 10 show the influence of agitation and temperature together. As mentioned before (Figures 7 and 8), the influence of agitation was greater in high concentrations. Because of this, the curves shown in Figures 9 and 10 are related to 20% NaCl experiments. These figures show that there is a much greater moisture reduction and solid gain at 60ºC. As mentioned before, the soft product obtained in higher temperatures improves moisture reduction and solid gain. Higher temperatures change tomato texture and increases solid gains. Due to these facts, temperature is not interesting for the osmotic dehydration of tomatoes. The same influence of temperature, agitation, concentration and time of osmosis on osmotic dehydration of tomato observed here, were reported by other authors (AZOUBEL and MURR, 2004; KROSS, 2004; RODRIGUES and FERNANDES, 2007).

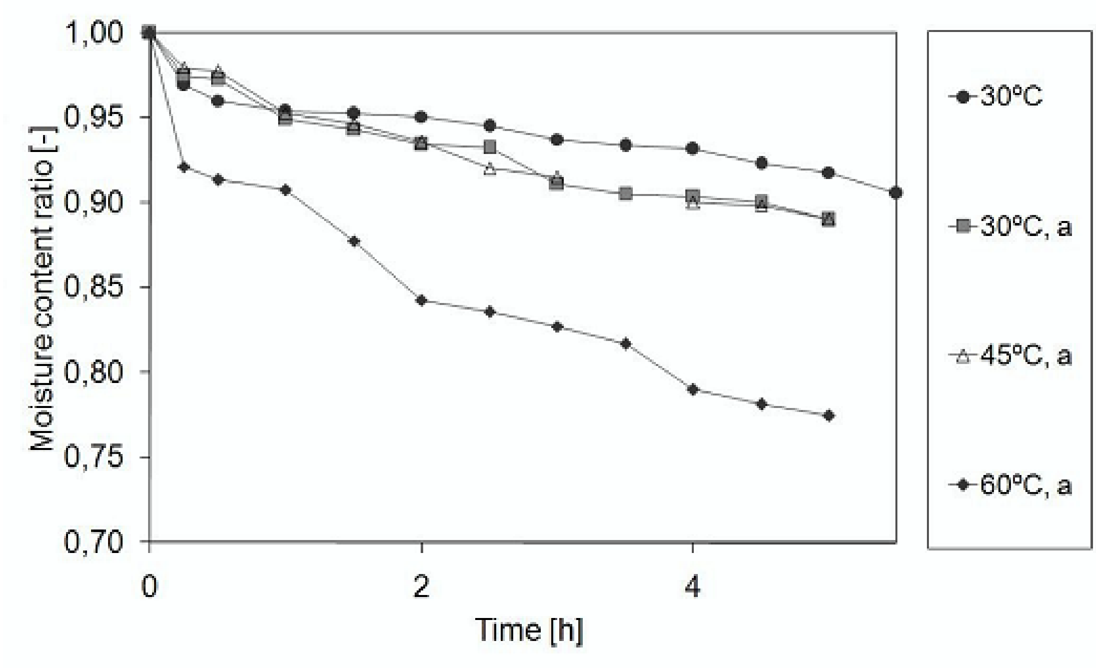
The WL results obtained here were adjusted with Equation 4. Table 1 shows the agreement parameters obtained with Equation 4. R^2 parameter was not so good for all the cases, but p was always smaller than 0.05, suggesting some statistically coherence. Data of WL_∞ and final WL (Table 1) show that, in the major part of the cases, there was little difference between then. This suggests that the period of immersion used was near the one necessary to reach equilibrium. Figure 11 and 12 show the fitness of Equation 4 according to Table 1. One can see from these figures that Equation 4 predicts very well the experimental data.

TABLE 1 - RESULTS OF EQUATION 4 COEFFICIENTS

Case	Condition	Angular coefficient[A]	Linear coefficient[A]	R^2	F	p	Predict WL_∞ [%]	Final WL [%]	Immersion time [h]
1	5% *	0.23244	16.8270	0.9873	1010.906	0.0000	4.302	3.75	6.5
2	10% *	0.13420	19.8161	0.9134	126.533	0.0000	7.452	5.72	6.5
3	15% *	0.09826	16.8292	0.6847	26.056	0.0025	10.177	8.55	6.5
4	20% *	0.08476	11.0327	0.8270	53.343	0.0010	11.798	10.75	6.5
5	25% *	0.05075	11.6304	0.8029	48.815	0.0000	19.704	14.05	6.4
6	30% *	0.04866	12.7142	0.6627	23.580	0.0001	20.551	13.50	6.5
7	5% §	0.21375	21.6546	0.9768	378.6079	0.0000	4.678	3.67	5.0
8	10% §	0.11036	30.0288	0.9999	103268.1	0.0000	9.061	4.75	5.0
9	15% §	0.11963	11.6413	0.8475	50.01860	0.0038	8.359	7.38	5.0
10	20% §	0.072258	8.718046	0.9319	123.1658	0.0000	13.839	10.49	5.0
11	25% §	0.054857	9.040052	0.9130	94.4166	0.0000	18.229	12.61	5.0
12	10% 45ºC, agitation	0.17191	2.007369	0.9505	172.6684	0.0000	5.817	7.67	5.0
13	10% 60ºC, agitation	0.078013	9.10025	0.89808	79.31121	0.0000	12.818	11.2	5.0

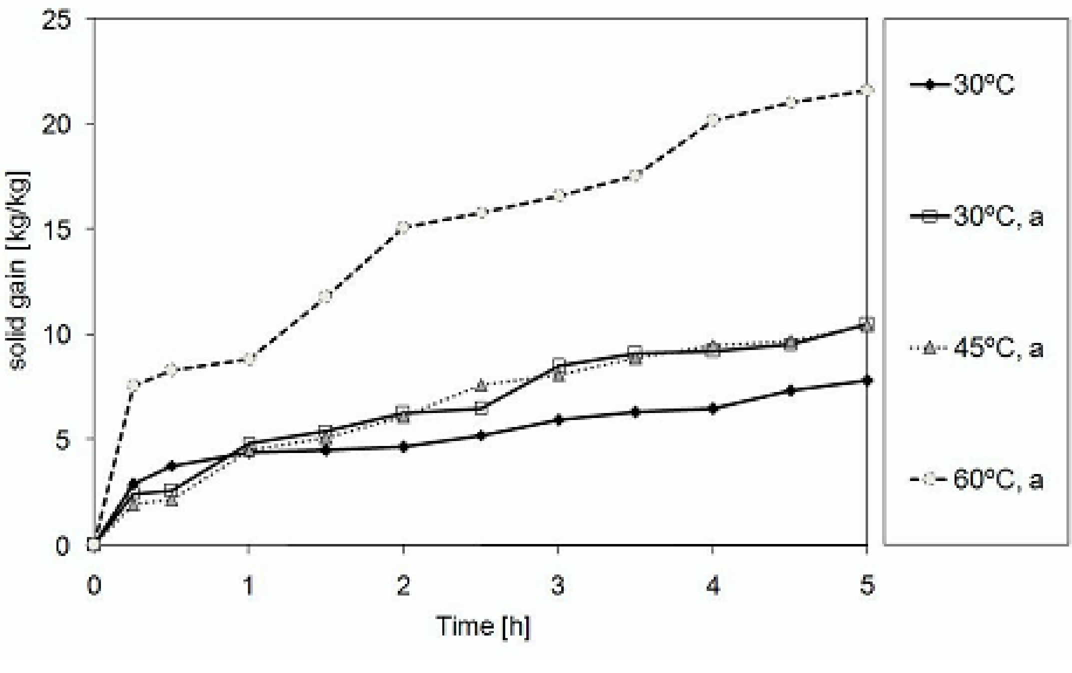
[A] the coefficients were determined by using t in minutes, * without agitation, 30ºC, § with agitation, 30ºC, WL is fraction of water lost by the foodstuff at time t, WL_∞ is the fraction of water lost by the foodstuff at equilibrium.

FIGURE 9 - MOISTURE CONTENT RATIO DURING OSMOTIC DEHYDRATION AT SEVERAL TEMPERATURES WITH AND WITHOUT AGITATION



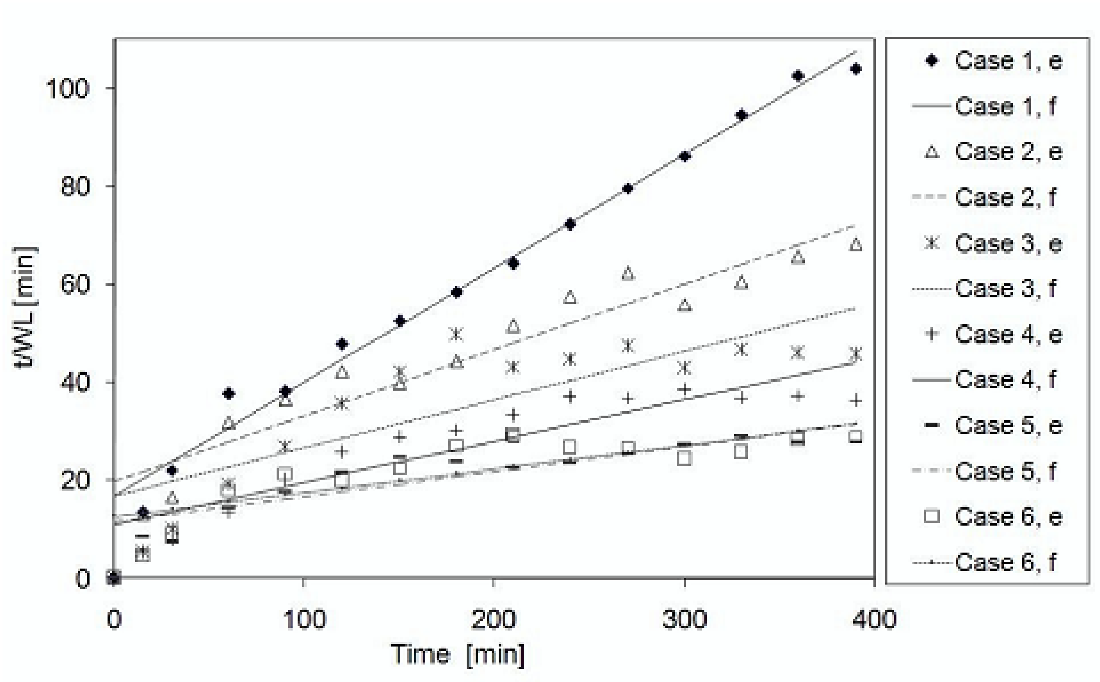
"a" means agitation.

FIGURE 10 - SOLID GAIN DURING OSMOTIC DEHYDRATION AT SEVERAL TEMPERATURES WITH AND WITHOUT AGITATION



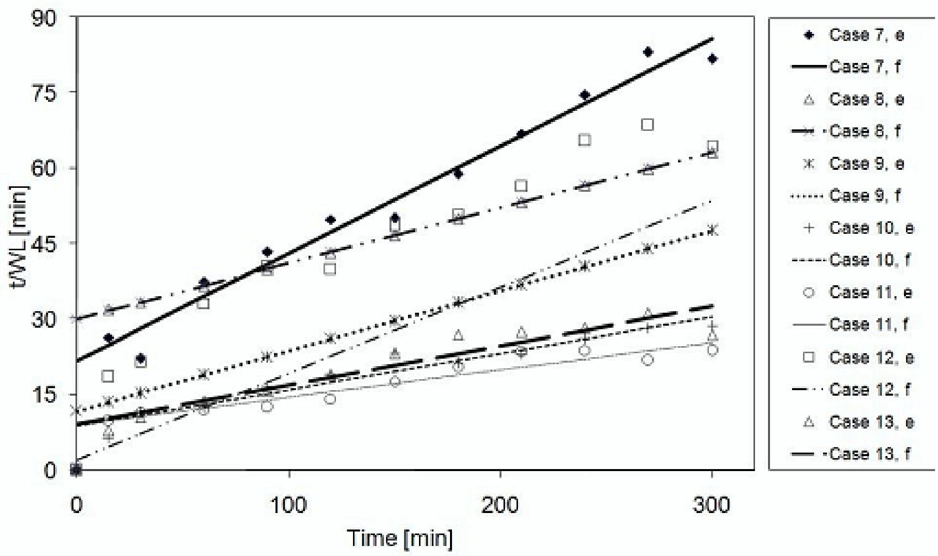
"a" means agitation.

FIGURE 11 - RATIO TIME/WATER LOSS DURING OSMOTIC DEHYDRATION FITNESS



The cases are according to Table 1, “e” means experimental, and “f”, fitness.

FIGURE 12 - RATIO TIME/WATER LOSS DURING OSMOTIC DEHYDRATION

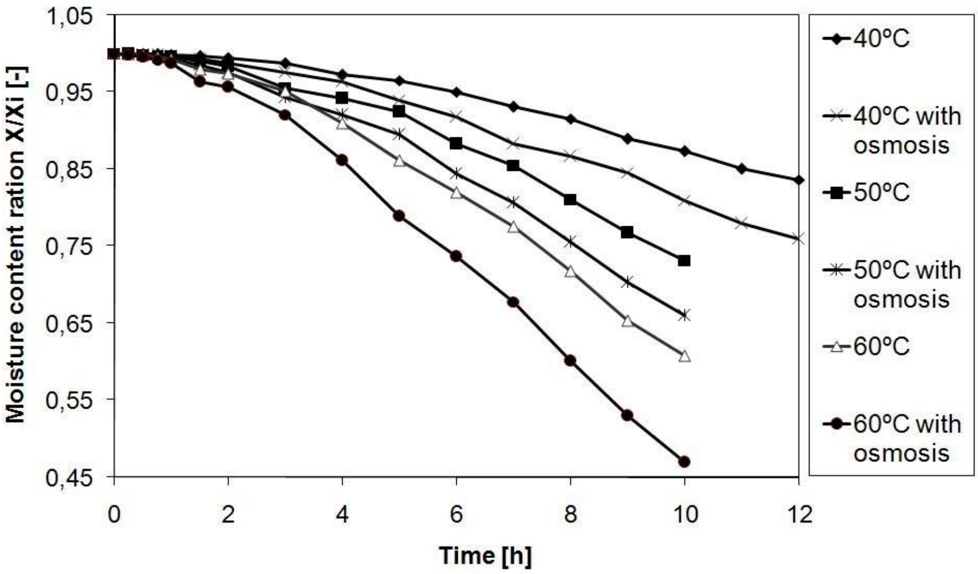


The cases are according to Table 1, “e” means experimental, and “f”, fitness.

3.2 TRAY DRYING

Figure 13 shows the moisture content ratio for the experiments carried out in the tray dryer at 40, 50 and 60ºC, with and without previous osmotic treatment.

FIGURE 13 - MOISTURE CONTENT RATIO DURING DRYING AT SEVERAL TEMPERATURES WITH AND WITHOUT PREVIOUS OSMOTIC TREATMENT



According to Figure 13, osmotic treatment causes a greater moisture removal in a subsequent drying. The osmotic treatment increases drying rates. Greater drying rates due to osmotic pretreatment was also obtained on the works of McMINN & MAGEE (1999) and RODRIGUES & FERNANDES (2007).

The rate established by the relation was about 10% for the experiments done at 40 and 50 ºC and about 22% for the experiments done at 60ºC. This causes, in a practice way, in an energy reduction on the dryer and, considering the same moisture reduction, a reduction of processing time.

4 CONCLUSION

Agitation, temperature and time were more influential on solid gain than on moisture reduction. Because of this fact, these parameters were not interesting for tomato osmosis dehydration. The best results were obtained at 30ºC and without agitation within a period shorter than 2 hours.

In the first two hours of dehydration, temperature does not present any significant influence.

Agitation does not promote a significant difference to have its use justified.

The mathematical model proposed in this work is statistically coherent.

Besides maintaining tomato characteristics and saving energy, the osmotic treatment increased moisture removal in a subsequent drying.

RESUMO

ANÁLISE DA INFLUÊNCIA DE VARIÁVEIS DE DESIDRATAÇÃO OSMÓTICA NA SECAGEM DE TOMATE (*Licopersicon esculentum*)

Estudou-se a desidratação osmótica de tomate em solução de NaCL, avaliando a influência da temperatura, da concentração da solução, do tempo de imersão e da agitação. Também foram obtidas as cinéticas do teor de umidade e ganho de sólidos. Após o tratamento osmótico, os frutos foram secos (secador de bandejas) na faixa de 40 a 60ºC durante 10 horas. A temperatura e a agitação contribuiram para a redução do teor de umidade, no entanto exerceram maior influência sobre o ganho de sólidos o que não é interessante. Os melhores resultados foram obtidos com solução de NaCL a 25%, sem agitação e a 30ºC, durante período inferior a 2 horas. O tratamento osmótico aumentou a taxa de secagem em secador de bandejas e o modelo matemático usado mostrou-se estatisticamente coerente.

PALAVRAS-CHAVE: DESIDRATAÇÃO OSMÓTICA; TOMATE; Licopersicon esculentum.

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