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ESTIMATION OF ENERGY EFFICIENCY OF THE PROCESS OF OSMOTIC DEHYDRATION OF PORK MEAT

PROCENA ENERGETSKE EFIKASNOSTI PROCESA OSMOTSKE DEHIDRATACIJE SVINJSKOG MESA

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ABSTRACT

Osmotic dehydration is a low-energy process since water removal from the raw material is without phase change. The goal of this research is to estimate energy efficiency of the process of osmotic dehydration of pork meat at three different process temperatures, in three different osmotic solutions and in co- and counter-current processes. In order to calculate energy efficiency of the process of osmotic dehydration, convective drying was used as a base process for comparison. Levels of the saved heat energy in the process of osmotic dehydration in comparison to convective drying were from 1.40 MJ to 1.97 MJ per 1 kg of fresh meat. Based on the presented results it can be concluded that the optimization of the process of osmotic dehydration from the aspect of energy efficiency has to include: choosing molasses as an osmotic solution; process temperature of 20°C; choosing counter-current process due to higher energy efficiency.

Key words: *osmotic dehydration, energy efficiency, pork meat, molasses.*

REZIME

Smanjenje količine utrošene energije po jedinici uklonjenje vode iz namirnica je neophodno u cilju povećanje ukupne efikasnosti procesa, smanjivanja troškova proizvodnje, kao i smanjivanja uticaja visoke potrošnje energije na životnu sredinu. Osmotska dehidratacija je proces niske energetske zahtevnosti pošto se proces uklanjanja vode iz sirovina biljnog i animalnog porekla odvija bez fazne transformacije. Cilj ovog istraživanja je procena energetske efikasnosti procesa osmotske dehidratacije svinjskog mesa na tri različite temperature procesa, u tri različita osmotska rastvora i pri isto-strujnim i protiv-strujnim izvedbama procesima. Da bi se izračunala energetska efikasnost procesa osmotske dehidratacije, konvektivno sušenje je uzeto kao bazni proces za poređenje. Nivoi ušteđene tolotne energije u procesima osmotske dehidratacije u poređenju sa procesima konvektivnog sušenja kretali su se od 1.40 MJ do 1.97 MJ po 1 kg svežeg mesa. Modifikacijom tehnološkog postupka iz isto-strujnog u protiv-strujni proces, energetska efikasnost se povećala za 13%. Povećanjem temperature procesa osmotske dehidratacije, nije se u dovoljnoj meri povećala tehnološka efikasnost procesa, da bi kompenzovala dodatni utrošak energije za zagrevanje sistema svinjsko meso/osmotski rastvor u energetskom bilansu. Na osnovu prikazanih rezultata može se zaključiti da optimizaciju procesa osmotske dehidratacije svinjskog mesa sa aspekta energetske efikasnosti treba voditi u smeru: odabira melase kao osmostkog rastvora, procesne temperature od 20°C i protiv-strujnog procesa osmotske dehidratacije.

Ključne reči: *Osmotska dehidratacija, energetska efikasnost, svinjsko meso, melasa šećerne repe.*

INTRODUCTION

Out of the total industrial energy consumption in food production 15% is used for the process of thermal drying, with relatively low thermal efficiency of 20 to 50%. Hence, reducing the amount of consumed energy per unit of removed water from the food material is necessary in the effort to increase the total efficiency, reduce the costs of production, as well as reduce the effects of high energy consumption on the environment (*Chua et al., 2001*).

OD is a low energy demanding process (*Panagiotouet al., 1999; Waliszewiskiet al., 1999*) due to its ability to remove water from food material without phase change, hence without energy consumption on latent heat of evaporation of water (*Della Rosa et al., 2001; Torreggiani, 1993*).

In order to investigate and estimate energy efficiency of the OD process, convective drying is taken as a base treatment for comparison.

Comparison of the efficiencies of OD process and convective process is possible only by choosing the adequate response of both processes, one that is not affected by secondary mass flow from the osmotic solution to the food material being dehydrated, causing solid gain of the food material that is specific for osmotic dehydration (*Koprivica et al., 2010*). From all investigated responses of the process of OD (*Pezo et al., in press*), only WL is not affected by solid gain and it is comparable between different types of dehydration.

Due to big complexity of meat composition (*Stamenković et al., 2007*) direct calculation of quantity of heat needed for removing the equivalent quantity of water from meat by convective drying is not precise enough, since the calculation cannot take into account the phenomena that characterise biological material, such as meat. Water in meat is located in myofibrils, meat cell functional organelles, and also in inter-cellular space between myofibrils and sarcoplasm (*Barat et al., 2009*). The goal of this research was to estimate energy efficiency of the process of OD of pork meat at three different process temperatures, in three different osmotic solutions and in co- and counter-current processes, with the comparison to the convective drying through a simple experiment of following dynamics of water evaporation in parallel runs of meat and water samples.

Nomenclature:

A – ash mass fraction of shoulder blade pork meat: 0.0011 kg/kg i.s.
c_p– specific heat capacity of the sample, (kJ/kg·C)
c_{p1} – specific heat capacity of pork meat, (kJ/kg·C)
c_{p2} – specific heat capacity of osmotic solution, (kJ/kg·C)
c_{pa}– ash specific heat capacity: 1.14 kJ/kg·C
c_{pm} – fat specific heat capacity: 1.67 kJ/kg·C
$c_{p(NaCl)}$ – crystal NaCl specific heat capacity: 0.85 kJ/kg·C
$c_{p(OS1)}$ – OS_1 specific heat capacity: 2.34 kJ/kg·C
$c_{p(OS2)}$ – OS_2 specific heat capacity: 2.22 kJ/kg·C
$c_{p(OS3)}$ – OS_3 specific heat capacity: 2.09 kJ/kg·C
c_{pp} – protein specific heat capacity: 0.84 kJ/kg·C
c_{pv}–ash water specific heat capacity: 4.19 kJ/kg·C
$c_{p(succrose)}$ – sucrose specific heat capacity: 1.24 kJ/kg·C
$c_{p(water)}$ – water specific heat capacity: 4.19 kJ/kg·C
d.m. - dry matter content
L – latent heat of water evaporation, (kJ/kg)
M – fat mass fraction of shoulder blade pork meat
MBE - Mean bias error
meat: 0.0031 kg/kg i.s.
m_i – mass of evaporated water from the sample, (kg)
m_s – sample mass, (kg)
m_{s1} – pork meat mass, (kg)
m_{s2} – osmotic solution mass, (kg)
N – NaCl mass fraction of OS_1: 0.1372 kg/kg i.s.
OD – osmotic dehydration
OS_1 - Osmotic solution 1
OS_2 - Osmotic solution 2
OS_3 - Osmotic solution 3
Q – quantity of heat needed for heating and evaporation of determined mass of water, (kJ)
Q_z – quantity of heat needed for heating meat/osmotic solution system, (kJ)
R^2 – coefficient of determination
RMSE - Root mean square error
S – sucrose mass fraction of OS_1: 0.4706 kg/kg i.s.
T_1 –initial sample temperature, (°C)
T_2 – final sample temperature, (°C)
V – water mass fraction of shoulder blade pork meat: 0.75 kg/kg i.s.
W – water mass fraction of OS_1: 0.3922 kg/kg i.s.
WL – water loss
χ^2 - chi-square test

MATERIAL AND METHOD

Pork meat (*M. triceps brachii*) was purchased just before use. Initial moisture content of the fresh meat was 72.83%. Osmotic solutions used in this research were:

OS_1:

Aqueous osmotic solution of sodium chloride and commercial sucrose (350 and 1200 g/kg of distilled water, respectively) (*Qi et al., 1998; Collignan et al., 2001*);

OS_2:

Mixture of OS_1 and sugar beet molasses of dry matter content of 80% in mass ratio of 1:1;

OS_3:

Sugar beet molasses obtained from the sugar factory Pećinci, with initial dry matter content of 85.04 %, diluted to mass concentration of 80% dry matter content.

Preparation of the pork meat and the treatment of co-current process of OD are described in *Pezo et al. (in press),* with the only difference that mass ratio of material to osmotic solution was 1:2.

Counter-current process of OD differed from co-current process in changing concentrations of osmotic solutions during every hour of 5 hour process, Table 1. In this way conditions of counter-current process are simulated. Mass ratio of material to osmotic solution was 1:2, since this low mass ratio better expresses the difference between co- and counter-current process than the usual mass ratio of 1:5, which reduces decreases in concentration gradient in co-current processes.

Table 1. Concentrations of three osmotic solutions in every hour of five hour process of counter-current osmotic dehydration

	1st h	2nd h	3rd h	4th h	5th h
OS_1:	45% d.m.	48.75 % d.m.	52.5% d.m.	56.25% d.m.	60% d.m.
OS_2:	52.5% d.m.	56.88 % d.m.	61.25% d.m.	65.63% d.m.	70% d.m.
OS_3:	60% d.m.	65% d.m.	70% d.m.	75% d.m.	80% d.m.

Dynamics of water evaporation is experimentally determined by parallel convective drying of the same quantities of meat cube samples (dimensions of 1x1x1 cm) and water of 100 g in the same glass trays, placed in a convective heater, preheated at 100°C. The samples of meat and water were at the same room temperature before the experiment. In equal time intervals (15 min, 30 min, 45 min, 60 min, 90 min, 120 min and 150 min) meat and water sample mass is measured.

Calculation of WL values used for calculation of quantity of saved energy is described in *Pezo et al. (in press).*

Quantity of heat needed for increasing the temperature of water samples and evaporation of determined mass of water is calculated from the following equation (*Toledo, 2007*):

$$Q = c_p \cdot m_s \cdot (T_2 - T_1) + L \cdot m_i \qquad (1)$$

Quantity of heat needed for heating meat/osmotic solution system to process temperatures is calculated according to (*Toledo, 2007*):

$$Q_Z = (c_{p1} \cdot m_{s1} + c_{p2} \cdot m_{s2}) \cdot (T_2 - T_1) \qquad (2)$$

Specific heat capacity of pork meat, c_{p1}, is calculated based on chemical composition of pork meat shoulder blade used in process of osmotic solutions (*Nićetin et al., 2012*) from following equation (*Toledo, 2007*):

$$c_{p1} = P\cdot(c_{pp}) + M\cdot(c_{pm}) + A\cdot(c_{pa}) + V\cdot(c_{pv}) \qquad (3)$$

Specific heat capacity of osmotic solutions c_{p2} is calculated based on modified equation (3), where mass fractions and specific capacities of components of osmotic solutions are used.

(*Specific heat capacity; Water – thermal properties; Olbrich, 1963*).

Statistical analysis of experimental data was performed using StatSoft Statistica 10.

RESULTS AND DISCUSSION

The results of the dynamics of evaporations are shown in Figure 1, where the dependence of time needed for certain levels of WL and values of WL for meat and water samples is formed. In Table 2 values of R^2, χ^2, MBE and RMSE are shown.

Table 2. Statistical indicators of experimental data fitting to model

Statistical indicators	Meat	Water
R^2	0.991	0.994
χ^2	6.47E-04	7.37E-04
MBE	8.97E-03	2.49E-03
RMSE	1.37E-03	1.56E-03

In both cases for meat and water samples high values of R^2 and low values of χ^2, MBE RMSE indicate that experimental data have good fittings to the proposed models (*Menges and Ertekin, 2006*).

Considering that meat and water samples were dried at the same time in parallel runs, under the same conditions, the same absorbed quantity of heat by both samples can be assumed.

Time of convective drying needed for achieving the same WL levels as for different processes of osmotic dehydrations presented in Table 3 is determined from the equations of dependence of time and WL for meat samples, presented in Figure 1. Then, for the same determined time of convective drying, WL values for water samples are determined. These WL values of water samples are used for calculating the quantity of absorbed heat using equation (1). This quantity of heat is also absorbed by meat samples for achieving observed WL levels. In this way, the connection between WL values achieved in OD process and the assumed and calculated quantity of heat "saved" by using osmotic process instead of convective drying is accomplished.

In OD processes at increased temperatures (35°C and 50°C), the values of "saved" quantity of heat are adjusted to heat losses for heating meat/osmotic solution system, calculated by equations (2), (3). In this way, "saved" quantity of heat for all ODs are comparable and indicate energy balance of the total process.

All values of WL and "saved" quantity of heat for all ODs are presented in Table 3.

Table 3 shows values of quantity of heat needed for removing 1kg of water from meat in co- and couner-current OD processes at different temperatures.

Analysis of energy balance of OD in comparison to convective drying

Based on the results shown in Table 3, it can be seen that the levels of "saved" energy in OD process in comparison to convective drying ranged from 1.40 MJ to 1.97 MJ per 1kg of fresh meat. OD processes at 20°C – which were undemanding in terms of energy – achieved equivalent energy savings from 1.63 MJ to 1.86 MJ per 1kg of fresh meat. By modification of the technological procedure from a co-current to counter-current process, energy efficiency increased up to 13% (for example: OD in OS_3, at 35°C).

Heat energy required for removing 1kg of water from pork meat in OD was affected by applied technological parameters and ranged from108.92±3.05 kJ/kgH_2O to 1023.23±5.99 kJ/kgH_2O, Table 4. In comparison to the quantities of heat needed in convective drying for removing the same amount of water, which ranged from 8000 to 9500 kJ/kgH_2O (*Lenart and Lewicki, 1988*), energy efficiency of OD processes was from 8.55 to 80.28 times higher.

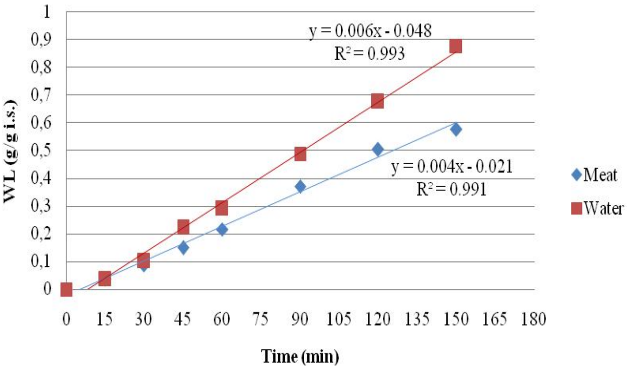

Fig. 1. Dependence of water loss by evaporation from meat and water samples and duration of convective drying

Table 3. Mean values and standard deviations of quantities of heat needed for the same level of WL in convective drying of 1kg of pork meat

	OS_1			OS_2			OS_3		
Temp.	20°C	35°C	50°C	20°C	35°C	50°C	20°C	35°C	50°C
Co-current OD									
WL$(g/g_{i.s.})$	0.4231 ±0.0136	0.4657 ±0.0243	0.4950 ±0.0029	0.4280 ±0.0035	0.4980 ±0.0058	0.5487 ±0.0004	0.4703 ±0.0025	0.5207 ±0.0115	0.5843 ±0.0090
Q (kJ/kg$_{meat}$)	1631.3^{a} ±49.45	1529.17^{a} ±82.47	1402.23^{b} ±9.84	1627.54^{a} ±11.97	1647.64^{a} ±19.77	1602.32^{a} ±1.42	1770.94^{c} ±8.51	1734.34^{ac} ±39.04	1742.54^{c} ±30.51
Counter-current OD									
WL$(g/g_{i.s.})$	0.4365 ±0.2311	0.4451 ±0.0108	0.4881 ±0.0015	0.4768 ±0.0061	0.4907 ±0.0085	0.5288 ±0.0027	0.4967 ±0.0139	0.5614 ±0.0045	0.5698 ±0.0031
Q (kJ/kg$_{meat}$)	1656.3^{a} ±73.97	1564.61^{a} ±36.67	1589.51^{a} ±5.10	1793.01^{c} ±20.74	1722.83^{ac} ±28.84	1734.64^{ac} ±9.24	1860.44^{cd} ±47.13	1966.31^{d} ±15.34	1881.40^{d} ±10.50

^{abc} Different letters in superscript in the table indicate statistically significant difference between values, at significance level of $p<0.05$

Table 4. Mean values and standard deviations of quantity of heat needed for removal of 1 kg of water from pork meat

	OS_1			OS_2			OS_3		
Temp.	20°C	35°C	50°C	20°C	35°C	50°C	20°C	35°C	50°C
Co-current OD									
Q (kJ/kgH_2O)	127.87^{a} ±4.12	601.8^{b} ±31.51	1023.23^{c} ±5.99	126.40^{a} ±1.03	544.75^{bd} ±6.35	890.29^{e} ±0.65	115.03^{a} ±0.62	502.40^{d} ±11.10	804.38^{f} ±12.39
Counter-current OD									
Q (kJ/kgH_2O)	123.94^{a} ±9.53	393.17^{g} ±9.55	606.23^{bd} ±1.86	113.46^{a} ±1.45	349.30^{g} ±6.05	545.95^{bd} ±2.79	108.92^{a} ±3.05	298.36^{f} ±2.39	492.98^{d} ±2.68

Analysis of the effect of the type of osmotic solution on the energy balance of OD process

Based on the presented results in Table 3 it can be seen that there were no statistically significant differences between the results of quantities of "saved" heat energy of co-current processes in OS_1 and OS_2, at 20° and 35°C, while at the temperature of 50° there were statistically significant differences between results of all three osmotic solutions. This indicates that the type of osmotic solution statistically significantly affects the levels of quantities of "saved" heat energy, and also that the highest values are achieved in OS_3 (molasses). The same statistical significances are present in analysis of the values of the quantity of heat needed for removal of 1kg of water from the meat at the same temperatures, but in different osmotic solutions, Table 4.

In the cases of counter-current processes, significant statistical differences are noticeable between values in different osmotic solutions at all temperatures, indicating that the type of osmotic solution statistically significantly affects quantities of "saved" heat energy in counter-current process, as well, Table 3. The highest values are once again achieved in OS_3.

Analysis of the effect of temperature on the energy balance of OD process

The values of “saved” quantity of heat during co-current process in OS_1, Table 3, indicate that there were significant statistical differences between values at 20°C and 35°C in comparison to values at 50°C. The increased temperature of the process statistically significantly affected the reducing quantities of “saved” energy. This can also be noticed for WL values, since the increase of the technological efficiency, due to the increase of the temperature of the process, was not high enough to compensate for heat consumption in the energy balance for extra heating of the meat/osmotic solution system.

In case of co-current OD in OS_2, there was no significant statistical difference between the values of the quantities of “saved” heat, indicating that extra input of energy led to significant increase of WL values and technological efficiency, so the energy balances of tested samples were similar, Table 3.

Co-current OD in OS_3 has shown the same trends of energy balances as the process in OS_2, Table 3.

Counter-current ODs in all osmotic solutions have shown the same trends of energy balances as co-current processes in OS_2 and OS_3, Table 3.

Based on the results of significant statistical influences of the temperature of the process on the quantity of heat energy required for removing 1kg of water from pork meat, Table 4, it can be noticed that in all cases the increase of the temperature statistically significantly increased the needed quantities of heat energy.

Analysis of the effect of the type of process on the energy balance of OD process

Based on the presented results in Table 3 it can be seen that there were no statistically significant differences between the results of quantities of “saved” heat energy of co-current and counter-current processes in OS_1, at 20°C and 35°C, while at the temperature of 50° there were statistically significant differences between results. At the highest temperature, the counter-current process resulted in statistically significant increase of the energy efficiency in comparison to the co-current process.

In case of OD in OS_2, statistically significant differences between values of quantities of “saved” heat of co- and counter-current processes were observed only at 20°C, Table 3.

In case of OD in OS_3, statistically significant differences between the values of quantities of “saved” heat of co- and counter-current processes were observed at 35°C and 50°C, indicating that at higher temperatures the type of the process statistically significantly influenced the energy balance, Table 3.

From the results presented in Table 4, it can be noticed that the type of the process statistically significantly influenced the quantity of needed heat energy for removing 1kg of water in most cases (in all osmotic solutions at 35°C and 50°C), where lower values of heat were needed for counter-current processes.

CONCLUSION

Based on statistically significant effects of the technological parameters on energy balance of the process of osmotic dehydration of pork meat, optimisation of the process from the aspects of energy efficiency should include:

Choosing molasses as an osmotic solution, since it exerted the best energy saving in comparison to other two osmotic solutions.

Increasing the temperature from energy undemanding 20°C to 35°C did not always increase WL high enough to justify extra input of energy, while the temperature of 50°C has shown as too energy demanding on final energy balance.

Choosing counter-current process since it has shown better combined technological and energy efficiency.

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REFERENCES

Barat, J., Alino, M., Fuentes, A., Grau, R., Romero, J. B. (2009). Measurement of swelling pressure in pork meat brining. Journal of Food Engineering, 93, 108-113.

Chua, K. J., Mujumdar, A. S., Hawlader. M. N. A., Chou, S. K., Ho, J. C. (2001). Batch drying of banana pieces - effect of stepwise change in drying air temperature on drying kinetics and product colour. Food Research International, 34, 721–731.

Collignan, A., Bohuon, P., Deumier, F., Poligne, I. (2001). Osmotic treatment of fish and meat products. Journal of Food Engineering,49, (2-3), 153-162.

Della Rosa, M. Giroux, F. (2001). Osmotic Treatments (OT) and Problems Related to the Solution Management. Journal of Food Engineering, 49 (2-3), 223-236.

Koprivca, Gordana, Mišljenović, Nevena, Lević, Lj., Jevrić Lidija (2010). Mass transfer kinetics during osmotic dehydration of plum in sugar beet molasses. Journal on Processing and Energy in Agriculture (former PTEP), 14 (1), 27-31.

Lenart, A., Lewicki, P. P. (1988). Energy consumption during osmotic and convective drying of plant tissue. Acta Alimentaria Polonica, 1, 65-72.

Menges, H. O., Ertekin, C. (2006): Mathematical modeling of thin layer drying of Golden apples. Journal of Food Engineering , 77 (1), 119-125.

Nićetin, Milica, Ćurčić, Biljana, Filipović, V., Koprivica, Gordana, Lević, Lj., Milašinović, Lj. (2012). Changes in Nutritive Quality of Osmodehydrated Pork Meat in Sugar Beet Molasses. International Conference On Science and Technique in the Agri-Food Business, ICoSTAF, Szeged, Hungary, Review of Faculty of Engineering, Analecta Technica Szegedinensia, (3-4), 112-118.

Olbrich, H. (1963). The Molasses, Institut für Zuckerindustrie, Berlin (Germany).

Panagiotou, N. M., Karanthanos, V. T.,Maroulis Z. B. (1999). Effect of Osmotic Agent on Osmotic Dehydration of Fruits. Drying Technology, 17 (1-2), 175-189.

Pezo, L., Ćurčić, Biljana, Filipović, V., Nićetin, Milica, Koprivica, Gordana, Mišljenović, Nevena, Lević, Lj. (in press): Artificial neural network model of pork meat cubes osmotic dehydration. Hemijska Industrija, doi: 10.2298/HEMIND120529082P

Qi, H., LeMaguer, M., Sharma, S.K. (1998). Design and Selection of Processing Conditions of a Pilot Scale Contactor for Continuous Osmotic Dehydration of Carrots, Journal of Food Process Engineering, 21,75-88.

Specific heat capacity:
http://www.diracdelta.co.uk/science/source/s/p/specific%20heat%20capacity/source.html

Stamenković, T., Živković, D., Perunović, M., Jovanović, M. (2007). Proizvodnja i odlike suve svinjske plećke, Tehnologija mesa, 48, 5-6.

STATISTICA (Data Analysis Software System), v.10.0 (2010). Stat-Soft, Inc, USA (www. statsoft.com)

Toledo, R.T. (2007). Fundamentals of Food Process Engineering, University of Georgia, Athens, Georgia, USA.

Torreggiani, D. (1993). Osmotic Dehydration in Fruit and Vegetable Processing. Food Research International, 26 (1), 59-68.

Water – thermal properties:
http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html

Waliszewski, K.N., Cortés, H.D., Pardio, V.T., Garcia, M.A. (1999). Color Parameter Changes in Banana Slices During Osmotic Dehydration, Drying Technology, 17 (4-5), 955-960.

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