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# ENERGY CONSUMPTION DURING OSMOTIC AND CONVECTIVE DRYING OF PLANT TISSUE

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Per-unit energy consumption during convection drying was 2-3 times higher than it was it the case with osmotic dehydration and syrup's reconcentration. The energy consumption in the osmotic-convection drying is mainly affected by two factors: drying rate and the initial water content after osmotic dehydration.

One of the methods of food preservation is drying. It is an important process which is often applied in the food technology and which is characterised by a considerable energy consumption.

One of research trends is an analysis of the currently used methods and the development of new means of the initial processing of plant material prior to drying, which would result in lower energy intensiveness of the drying process.

Osmotic dehydration of raw plant material in hypertonic solutions of osmoactive substances is used mostly for obtaining a 20-50% initial reduction of mass [2, 5]. Osmotically dehydrated food has a prolonged durability but at longer storage periods it calls for an additional preservation procedure. That is why the osmotic dehydration is mostly used as an initial processing prior to convection or vacuum drying, freeze drying, freezing and pasteurisation [1, 4].

During osmotic dehydration of plant tissue a considerable part of water is removed from the plant material. At the same time, its chemical composition undergoes a change the major cause of which is penetration of osmoactive substance into the plant tissue [2, 3]. Osmotically dehydrated plant materials differ as to their properties from the non-dehydrated ones what undoubtedly does effect the course of convection drying of those materials [1, 6]. Osmotic dehydration of food has been well researched in respect of its technology. There is a need, however, of studying of engineering and energetical aspects of the applied method of water removal. Especially important is the knowledge about energy consumption in the direct process of osmotic dehydration and the comparison between a per-unit energy consumption in this method with that of other methods of water removal, being in use in food technology.

The aim of this work was to obtain more information about energetical aspects of osmotic dehydration. Of the most significance is the comparing of a per-unit energy consumption during osmotic dehydration of plant tissue with that of the convection drying.

## METHODS AND MATERIALS

Apples of Boiken variety and carrots of Nantejska variety were used as a raw material. The analyses of dehydration kinetics and that of convection drying have been carried out on material cut up into cubes of a 10 mm size. Osmotic dehydration was carried out in a 60% saccharose solution, in a 50% saccharose with a 10% addition of sodium chloride and in a 25% solution of sodium chloride. The process was carried out at temperatures of 20, 30 and 40°C with the variable time range. The material was dried at a constant load of dryer of 6 kg/m$^2$ screen, at a temperature of 70°C and at a constant velocity of air being 1,5 m/s.

For the needs of osmotic dehydration a variant with the introduction of an evaporator into the technological line was considered. It was used for the concentration of sucrose syrup to its initial value.

## RESULTS AND DISCUSSION

The water content of the osmotically dehydrated plant tissue undergoes a rapid change during the first stage of the process, depending mostly on the kind of osmotic substance being used and on the process temperature. Changes in water content of apple tissue during osmotic dehydration as related to process temperature are shown in Fig. 1. A greatest loss of water content regardless temperature, takes following 3-4 hours of dehydration and this time interval is commonly assumed to be optimal time of the process. On the other hand, as it follows from Fig. 2, in case of the dehydration of carrots that time gets shortened. In carrots dehydrated in a 60% saccharose solution, and with addition of sodium chloride that time is 2-3 hours and in case of dehydration in a sodium chloride solution is not longer that 1 hour. For both plant materials being analysed here, in a given time interval, a 2-3 fold lowering of water content takes place down to a value not lower than 2-3 g $H_2O$/g d.m.

Further increase of the dehydration time is assisted (with a very slow rate of water removal) by a continuous increase of the dry substances contents being a result of the osmoactive substance's penetration. This relationship applies both for plant materials as well as for the investigated temperature changes and the kinds of osmoactive substance.

A per-unit energy consumption during osmotic dehydration of apples and carrots depends mostly on the process temperature and, in case carrots, on the

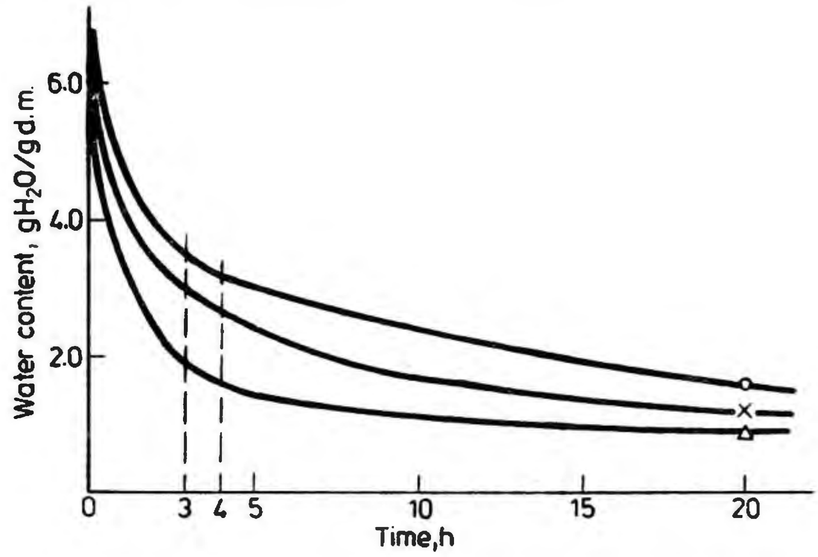


Fig. 1. Changes of the water content of apples during osmotic dehydration in dependence on the process temperature; o — 20°C, x — 30°C, △ — 40°C

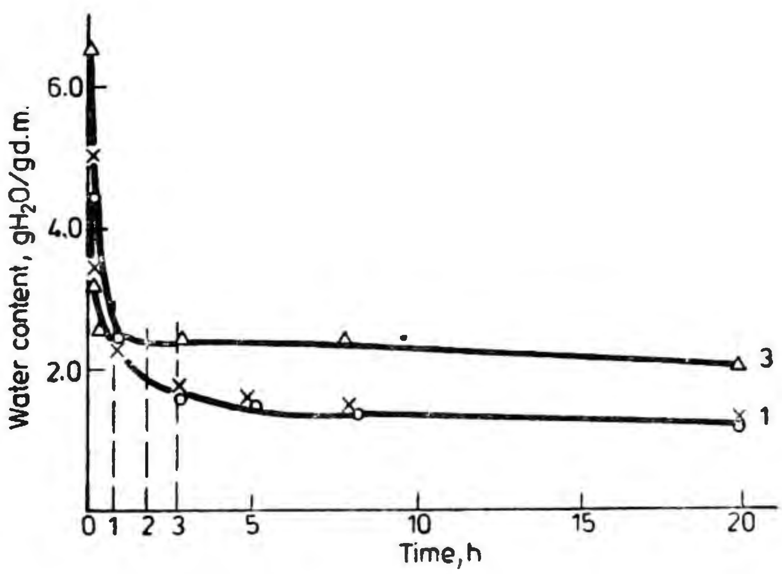


Fig. 2. Changes of the water content of carrots during osmotic dehydration in dependence on osmosis solution composition; o — 60% saccharose, x — 40% saccharose + 5% NaCl, Δ — 25% NaCl

kind of osmoactive substance as well. The per-unit energy consumption was calculated in from of a sum of energy used for heating up of plant material and syrup to a required temperature, the energy used by the pump for syrups pumping and the energy used for water evaporation. With a nearly two-fold decrease of water content down to about 4 g $H_2O$/g d.m. the osmotic dehydration time was up to 2 hours in case of apples and did not fall beyond 30 minutes in case dehydration of carrots. A further two-fold decrease of water content down to about 2 g $H_2O$/g d.m. resulted in the increase of apple's dehydration time up to about 3, 7 and 13 hours for temperature of 40, 30 and 20°C respectively. In case of the dehydration of carrots in a saccharose solution this time did not exceed 2 hours. The variable time of osmotic dehydration affects the first of all the energy consumption by the pump and the energy losses. The energetical demand of the pump was small and its effect on a per-unit energy consumption was negligible. The energy needed for heating up of plant material, on the other hand, makes more than 95% of the per-unit energy consumption in the case without syrup's reconcentration.

In practice, during dehydration at a room temperature both apples and carrots the energy cosumption did not surpass 2 kJ/kg removed water and was connected with the work of the pump. At a temperature of 30°C, on the other hand, and with a two-fold decrease of water content the energy consumption was about 700 kJ/kg, while at a temperature of 40°C it was higher than 1300 kJ/kg of removed water. In the case of carrots dehydration the energy consumption was about 20-30% lower what resulted from a considerably shorter time of the dehydration process. A further lowering of the water concent down to about 2 g $H_2O$/g d.m. decreased the per-unit energy consumption needed for the heating up of the plant material. At the same time, however, the share of heat losses increased. As a result a per-unit energy consumption remained on a similar level.

In the case when an evaporator was installed and the reconcentration of sugar was applied the energy consumption for water evaporation constituted a basic part in a per-unit energy consumption. Within a temperature range of 20-40°C, with dehydration carried down to about 2 g $H_2O$/g d.m. the energy consumption for water evaporation made about 70% of the per-unit energy consumption. For example: during dehydration at a room temperature of both apples and carrots the energy consumption was about 2800 kJ/kg of the evaporated water while during dehydration at 40°C it surpassed 4000 kJ/kg water (Table).

Table. Energy consumption (kJ/kg $H_2O$) during osmotic and convective drying of plant tissue. Water content decrease's range 8-4 kg $H_2O$/kg d.m.

| Process | Temperature (°C) | | | |
|---|---|---|---|---|
| | 20 | 30 | 40 | 70 |
| Osmotic dehydration | 2 | 700 | 1300 | — |
| Osmotic dehydration with syrup reconcentration | 2800 | 3400 | 4000 | — |
| Convection drying | — | — | — | 8000-9500 |

On the other hand, energy consumption of convection drying, amounted to 8000-9500 kJ/kg of the water evaportated, depending on the amount of water being evaported. More than 95% of the heat consumption was related to water evaporation. As a final result a per-unit energy consumption during convection drying was 2-3 times higher than it was in the case with osmotic dehydration and syrup's reconcentration.

The analysis carried out above concerned with comparing and evaluation of energy consumption of water removal during convection drying and osmotic dehydration. In practice, the osmotic dehydration is not an individual independent operation but most often it is used in connection with other methods such as convection drying for example.

On the basis of obtained results concerning convection drying of apples and carrots it has been stated that in a process of convection drying of the investigated material, following their initial osmotic dewatering no constant period of drying can be observed (Fig. 3). It is caused by the fact that water content of investigated materials following their osmotic dehydration falls below the critical water content. The drying time apples and carrots, those initially dehydrated and those non-dehydrated was almost independent on preparation procedure of the material in case of drying till obtaining the equilibrium water content. This effect results from the fact that during osmotic dehydration, the surface of dehydrated cubes became covered by a layer of concentrated syrup.

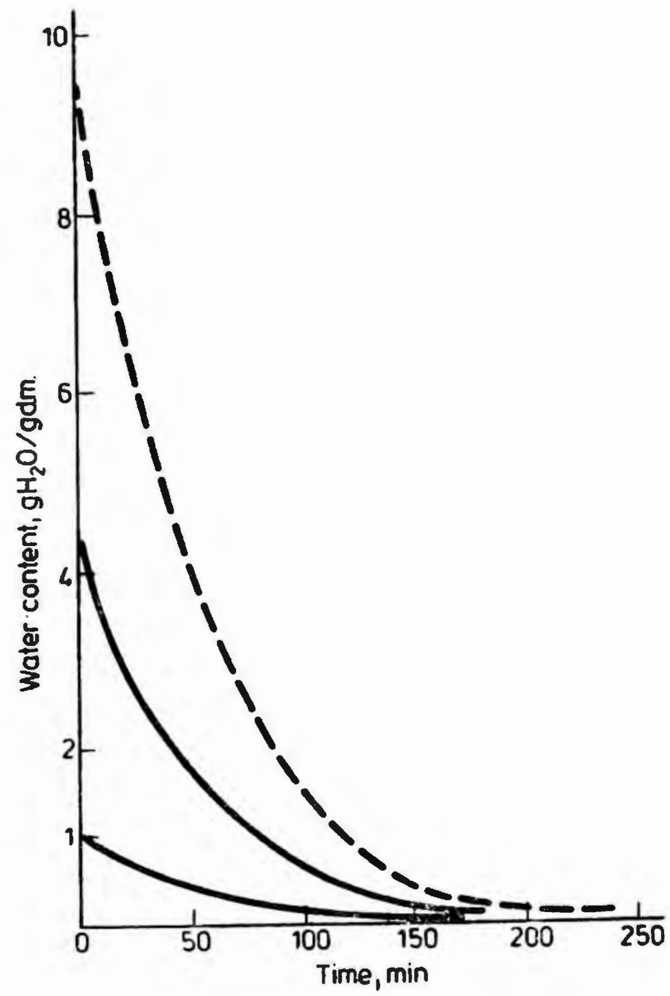


Fig. 3. Change of water content of apples during convective drying; --- — raw apples, ——— — after osmotic dehydration

Application of water rinsing of cubes following dehydration does considerably limits this phenomena. The above statement is supported by drying curves and those for $a_w$ changes. For samples without rinsing (Fig. 4) and that with rinsing (Fig. 5).

In the case of not rinsed samples, in spite of the long drying time, no significant lowering of $a_w$ (as it was in the case with samples not dehydrated osmotically) was found. The rinsed samples on the other hand, at the end of their drying process reached the $a_w$ value, similar to that of samples undergoing no initial processing. In spite of that, the osmotically dehydrated samples get dried much slower. For example: with the sample's water content of 0,5 g $H_2O$/g d.m. the drying rate of non-dehydrated apples was 0,021 g $H_2O$/(g d.m.·min) and of the osmotic dehydrated ones it was 0.009 g $H_2O$/(g d.m.·min).

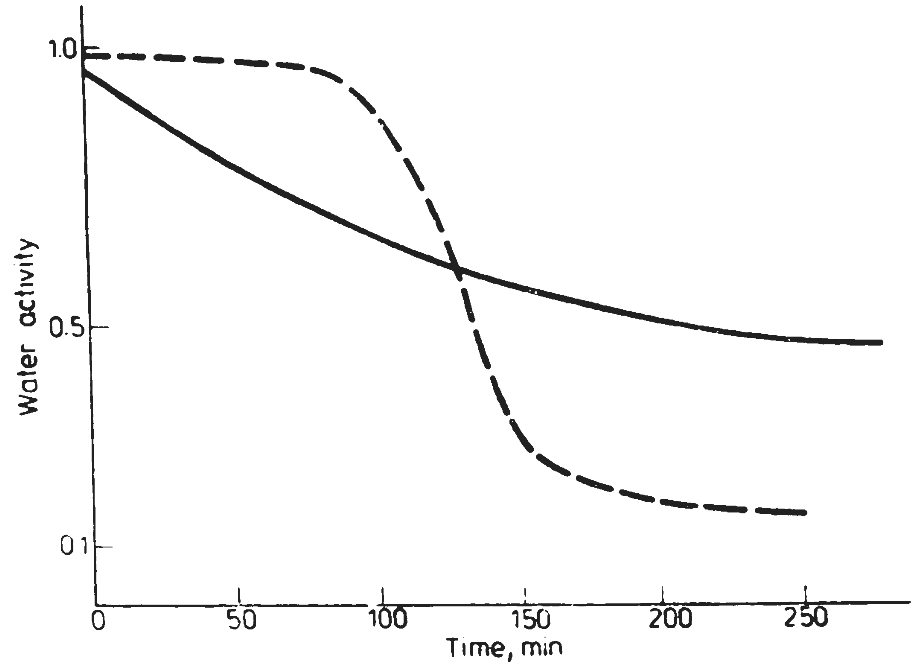


Fig. 4. Changes of water activity of aplles during convective drying; --- — raw apples, ——— after osmotic dehydration without rinsing

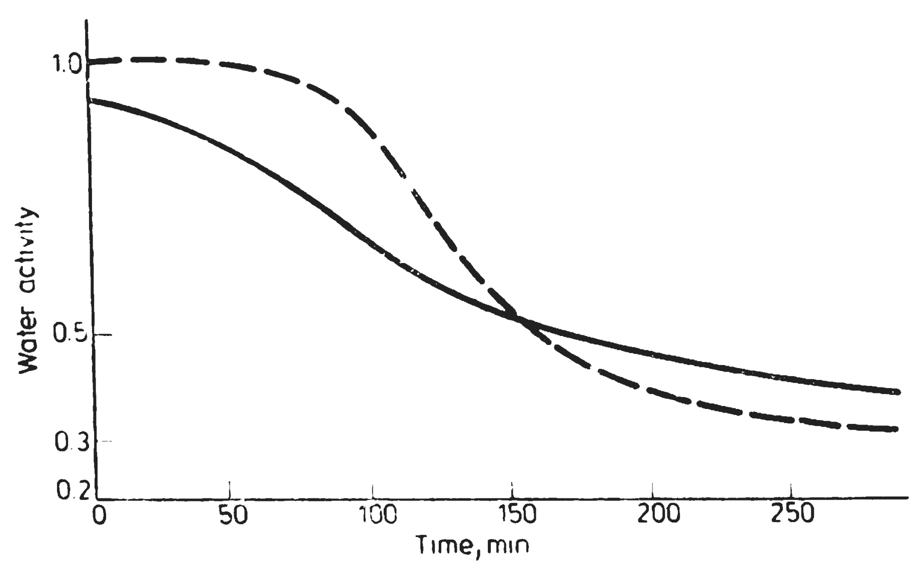


Fig. 5. Changes of water activity of aplles during convective drying; --- — raw apples, ——— after osmotic dehydration with rinsing

The initial osmotic dehydration resulted in shortening of the drying time, needed to obtain water content corresponding to $a_w$ = 0.70. For the raw apple with an initial water content of 7.6 g $H_2O$/g d.m. that time was 175 min, for the apple osmotically dehydrated to water content of 3.2 g $H_2O$/g d.m. it was 155 min. and for the apple initially dehydrated by osmosis to water content of 1.6 g $H_2O$/g d.m. it was 120 min. A more significant effect of the initial osmotic dehydration was stated in the case of carrots. For the raw carrots with water content of 9 g $H_2O$/g d.m. the drying time till $a_w$ = 0.70 was 300 min, whereas that for the saccharose-dehydrated carrots to water content of 1.2 g $H_2O$/g d.m. the time was 210 min. and for carrots dehydrated in the saccharose solution with additon of salt till the water content of 0.95 g $H_2O$/g d.m. the drying time was 105 min.

The shortening of the drying time at a constant parameters of the drying air resulted in a decreased per-unit energy consumption. During convective drying of apples and carrots following their initial dehydration in a saccharose solution a per-unit energy consumption was about 30% lower than that of raw material. The addition of NaCl (salt) to the saccharose solution influenced positively the further lowering of per-unit energy consumption.

Initial osmotic dehydration shortens by 10-65% the drying time, depending on the kind of material, that of osmotic substance and the time of osmotic pretreatment of the material. Besides, the loading of the dryer increases by 2-3 times expressed on raw material. The initial osmotic dehydration in a saccharose solution results in a 4-5 fold increase of the dryer's output with a 30% decrease of a per-unit energy consumption. The addition of salt to the saccharose results in a further significant increase of the dryer's output and the decrease of energy consumption.

Convection drying of plant material following initial osmotic dehydration is significantly more effective than the convection drying itself as regards energy consumption, only in ranges of certain final water contents of dried material. The final water content of material at which convection drying in conjunction with initial osmotic processing is more useful from convection one depends on dehydration degree and should contain itself in the range of 0.25-0.30 g $H_2O$/g d.m. for apples and 0.20-0.30 for carrots. Below the mentioned range of water content, osmotic-convection drying becomes less effective as regards energy consumption in relation to convection drying.

Summing up the obtained results one should state that the energy consumption in the osmotic-convection drying is mainly affected by two factors: drying rate which affects the drying time and the initial water content.

Initial osmotic dehydration does improve final energetical effect with proper utilisation of syrup assured. In the final stage of the drying process of osmotically dehydrated apples and carrots it is advised to considerably increase the screen load or to lower the velocity of the air flow.

## CONCLUSIONS

1. During osmotic dehydration of apples and carrots in concentrated solution of osmoactive substances water removal from the dehydrated material is associated by penetration of the osmotic substance into dehydrated tissue.

2. A highest dehydration rate of the osmotically dehydrated plant tissue is observed during short dehydration time. That drying period does not surpass 1 hour carrots 3-4 hours for apples.

3. Energy consumption during osmotic dehydration depends on the process temperature. Whith the increase of the temperature from 30 to 40°C — a per-unit energy consumption undergoes a 2-fold increase.

4. During osmotic dehydration of apples and carrots with sugar syrup reconcentration the per-unit energy consumption is 2-3 times lower than during convection drying.

5. Osmotic-convection drying of apples and carrots is energetically more effective as compared with the convection drying itself with the final water content not lower than 0.3 g $H_2O$/g d.m.

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## ZUŻYCIE ENERGII W PROCESIE SUSZENIA OSMOTYCZNEGO I KONWEKCYJNEGO MATERIAŁU ROŚLINNEGO

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S t r e s z c z e n i e

Odwodnienie osmotyczne materiału roślinnego w roztworach hypertonicznych substancji aktywnych osmotycznie jest wykorzystywane głównie do początkowej redukcji masy. Otrzymany w ten sposób półprodukt ma małą trwałość i powinien być dalej przetwarzany przez zamrożenie lub suszenie.

Celem pracy było zbadanie efektów energetycznych zastosowanej metody usuwania wody. Najbardziej istotne było porównanie zużycia energii pomiędzy suszeniem osmotycznym i konwekcyjnym. Zużycie energii na jednostkę produktu podczas suszenia jabłek i marchwi zależy głównie od temperatury procesu i rodzaju osmoaktywnej substancji. W praktyce, podczas odwodnienia w temperaturze pokojowej zużycie energii nie przekracza 2 kJ/kg usuwanej wody i związane jest z pracą pompy. Podczas gdy w temp. 40°C jest wyższe niż 1300 kJ/kg usuwanej wody.

W przypadku, gdy wyparka jest wykorzystywana do rekoncentracji syropu cukrowego zużycie energii na odparowanie wody wynosi ok. 70% energii jednostkowej i nie przekracza 400 kJ/kg odparowanej wody. Z drugiej strony zużycie energii w procesie suszenia konwekcyjnego wynosi 8000-9500 kJ/kg odparowanej wody (tab.). Tak więc zużycie energii suszenia konwekcyjnego jest 2-3 razy wyższe niż w procesie odwodnienia osmotycznego z rekoncentracją syropu.