A C T A A L I M E N T A R I A P O L O N I C A
Vol. XIV (XXXVIII), No. 1 1988

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ENERGY SAVING IN THE DRYING OF VEGETABLES OBTAINED BY THE INTRODUCTION OF A NEW DICE FORM

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The drying experiment was performed on a 10 mm carrot cube with croscuts on each side and a plain form carrot cube. The results showed a substantial drying time reduction reaching 40 to 50% obtained for the crosscut cube in comparison with the plain cube.

Although new drying techniques have been applied recently, the majority of drying operations performed on vegetables are still convection-type, using air as the heating medium. Air-drying the simplest one and in comparison with the newer techniques, a less expensive one [2]. Convection-type drying of vegetables is an essential and most widespread method in the Polish Food Industry and it is not likely to be replaced by freeze-drying in the near future. While a significant progress has been made in such fields as improving the equipment by the use of heat pumps [3], modification of air operating conditions [6] and the use of waste heat [4] and solar energy [5] for drying, the raw material itself has rarely been looked at as a possible source of energy saving.

The size, the form and particularly the specific surface of vegetable dice are the most important factors influencing the drying time and thus the energy consumption. For this reason, small vegetable dice should be preferred. However, the pressure drop of the air passing through the bed of small particles will increase, causing air leaks around the edges of the dryer tray or belt and uneven material drying [1]. Additional problems occur when small vegetable dice clog the belt or tray openings or when the dried particles are lifted into the air and blown out of the dryer with the air stream.

This paper looks at the possibility of saving energy in the drying process by the introduction of a new vegetable dice form. The objective was to establish a vegetable dice form of a relatively low size reduction factor and a high specific surface which would result in high porosity of the material layer and a substantial drying time reduction.

EXPERIMENTAL

MATERIAL

Fresh, commercial variety carrot was utilized. The vegetable was washed, peeled, sliced into 10 mm slices, and then cut into 10 mm cubes. Half of the carrot cubes was crosscut on each side while the other half was left unchanged and is referred to in this paper as plain form cubes. The 3 mm deep crosscuts did not change the initial shape and size of a cube. Characteristic size of carrot cubes utilized in the drying experiments are shown in Fig. 1.

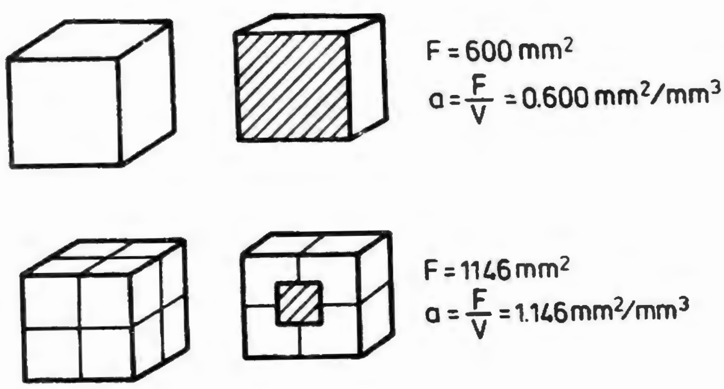

Fig. 1. Charasteristic sizes of carrot cubes; F — total surface, a — specific surface, V — volume

The calculation of the specific surface already included the increase of the cube area caused by the deformation of the crosscut cube in drying. It was previously observed that in the early stage of drying, shrinkage of vegetable tissue deforms the cube causing the outer segments to come apart [7]. Thus, the drying area of a single crosscut cube was 1146 mm^2 as compared to 600 mm^2 of a plain cube. At the same time, the specific surface increased from 0.6 mm^2/mm^3 to 1.146 mm^2/mm^3.

METHODS

The drying experiments were performed under through-flow conditions in an experimental dryer shown in Fig. 2. The air passed through a gas volumeter, a heater and an air stream equilizer to a drying chamber. A sample was placed on a screen tray and periodically weighed by means of a laboratory balance. The temperature of the drying air was measured with a thermocouple located close to the sample with the fan and heater outputs were controlled by means of a multichannel variable power supply.

Five separate experiments were conducted at temperatures of 333, 343, 353, 363 and 373 K using constant mass velocity of the air of 1.4 kg/s m^2. The initial

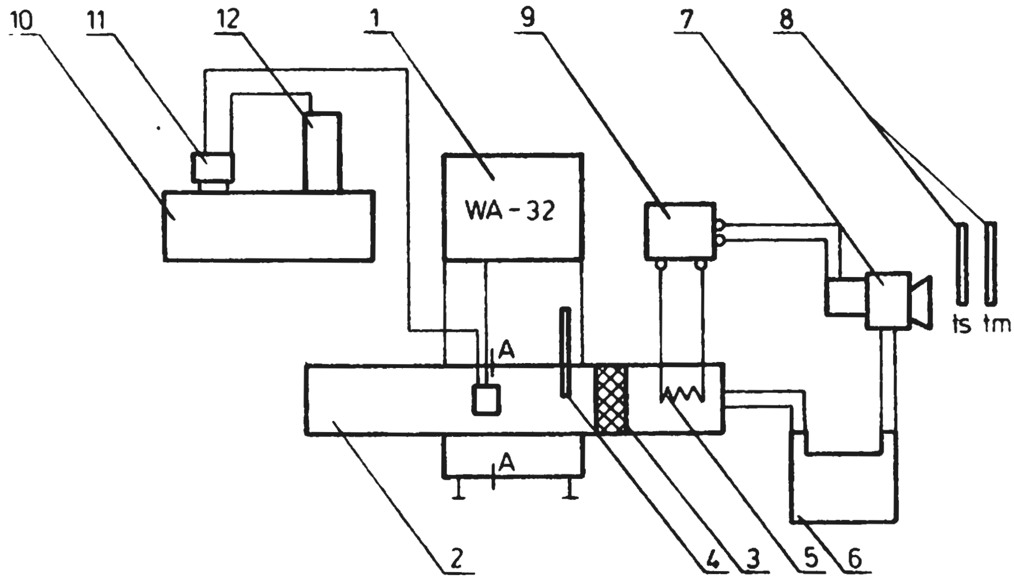

Fig. 2. Schematic diagram of the experimental dryer; 1—analitical balance, 2—drying chamber, 3—air stream equilizer, 4—thermometer, 5—electric heater, 6—gas volumeter, 7—fan, 8—psychrometer, 9—power supply, 10—temperature recorder, 11—switch, 12—ice bath

moisture content of fresh carrot was determined by drying in an oven at 378 K to the constant weight.

RESULTS AND DISSCUSION

Results of the experiments are shown in the form of the drying curves on semilog paper as logX vs time (where X is the moisture content of carrot) in Fig. 3 and Fig.4.

During the drying experiments both crosscut cubes and plain cubes were dried up to a final moisture content of 0.1 kg H_2O/kgDM (9.1% wet basis).

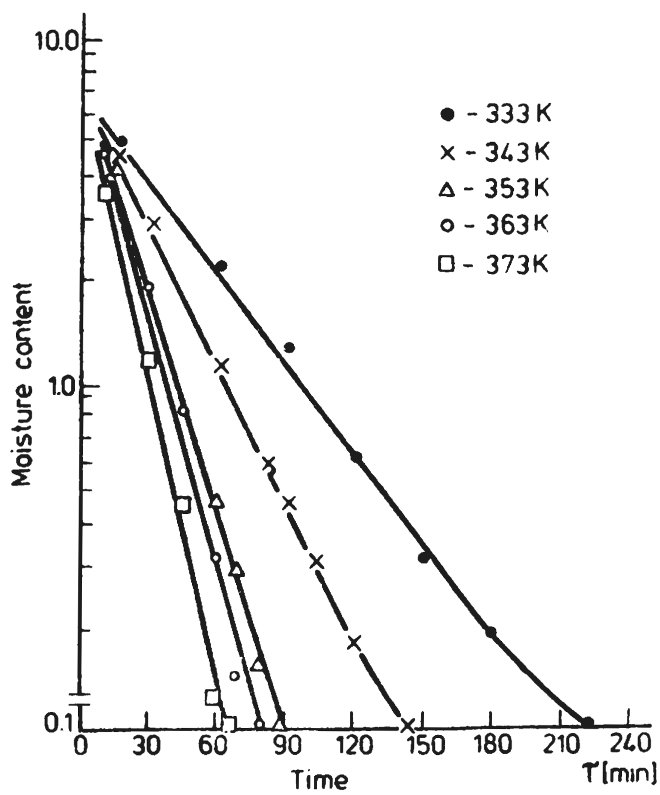

Fig. 3. Effect of temperature on the drying rate of crosscut carrot cubes

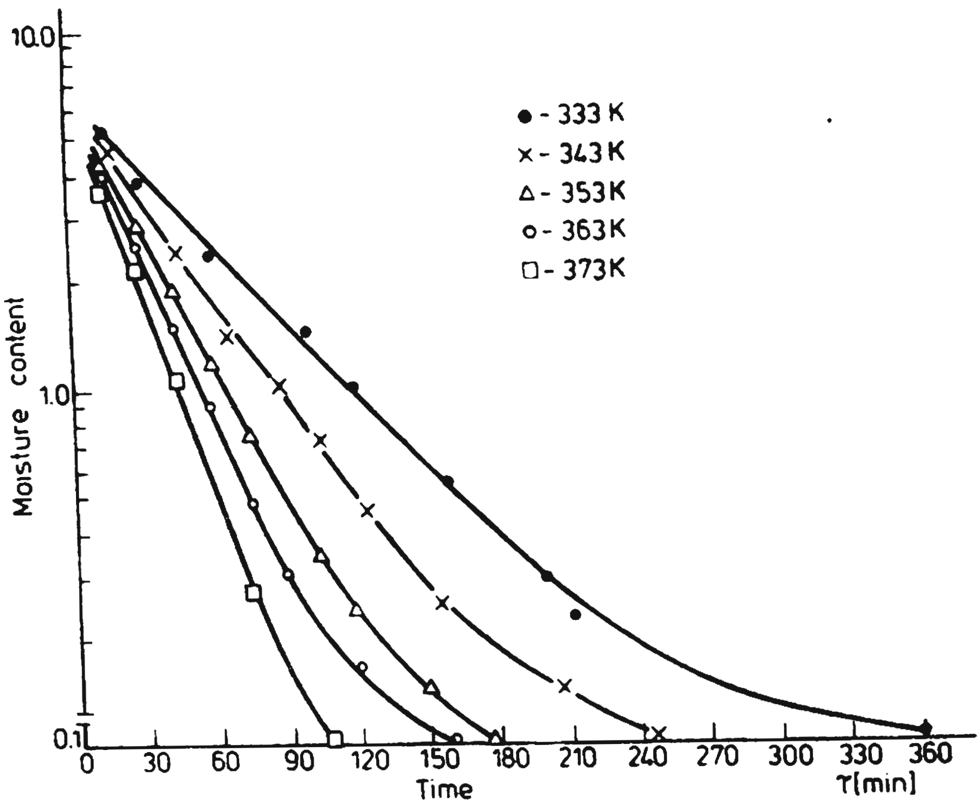

Fig. 4. Effect of temperature on the drying rate of plain carrot cubes

Critical moisture content (X_c), time of constant-rate drying period (τ_c), and total drying time (τ_t) were calculated from the drying curves for five separate experiments and are summarized in Table. In addition, time ratio expressed as

Table. Results of the drying experiments on crosscut and plain carrot cubes

Parametr	Temperature (K)									
	333		343		353		363		373	
	c	p	c	p	c	p	c	p	c	p
X_o	6.5	6.9	6.5	6.4	6.0	5.9	6.3	6.5	6.5	6.5
X_c	5.2	5.6	5.0	5.4	4.7	5.0	4.6	5.5	3.9	4.5
τ_c	11	11	10	7	7	6	8	5	11	9
τ_t	223	360	145	246	90	178	80	160	66	107
$\frac{\tau_{tc}}{\tau_{tp}} 100\%$	61.9		58.9		50.6		50.0		61.7	

X_o — initial moisture content (kg H_2O/kg DM), X_c — critical moisture content (kg H_2O/kg DM), τ_c — time of the constant-rate period of drying (min.), τ_t — time of drying to the final moisture content of 0.1 kg H_2O/kg DM (min.); c — reffers to the crosscut cube, p - reffers to the plain cube

the relation of the total drying time of the crosscut cubes to the total drying time of the plain cubes were calculated.

Upon examining the results in Table, it is evident that the drying time of the crosscut cubes was substantially shorter than that of the plain cubes. Drying time reduction, reaching 40 to 50% was the highest for temperatures of 353 and 363 K and the lowest for 333 and 373 K. As it was mentioned before, shrinkage of vegetable tissue deform the crosscut causing outer segments to come apart thus significantly increasing the drying area. This resulted in the increase of water evaporation from the carrot surface and shortened the distance of internal water migration within the sample. The effect of the drying surface increase of the crosscut cubes was not as evident at the constant-rate drying period as at the falling rate period. The values of critical moisture and the time of constant-rate period were essentially similar for both forms of carrot cubes at a given air temperature. This suggests that during the constant-rate drying period surface cuts on crosscut cubes remained closed and the drying rate was similar to that of plain cubes. Thus, the internal stresses caused by the moisture gradients giving access to shrinkage of vegetable tissue and opening of the surface cuts, probably developed in the falling-rate period of drying.

The effect of the surface cuts on carrot cubes is well documented in the falling-rate period of drying where the drying rate is influenced by the internal moisture movement and the shortest dimension of the sample appears to be the critical factor. A comparison of the drying times for the crosscut and plain carrot cubes shows and almost 50% time reduction for the former at some temperatures. This indicates remarkable importance of surface cuts during drying to a low final moisture content.

Although the tests in this study were performed on carrot cubes, the results appear to indicate that using — in the process of drying — of a regularly shaped piece of any vegetable — as long as it has multicuts on its surface — could result in significant energy savings.

CONCLUSIONS

The drying behaviour of crosscut carrot cubes is characterized by a short drying time, specifically in the falling-rate period of drying, in comparison to the commonly used plain carrot cubes.

The introduction of crosscut cubes as a vegetable dice form allows for its use in commercial through-flow dryers and can result in significant energy savings by reducing the drying time by up to 50%.

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The research described in this paper was supported in part by the Central Programme of Research and Development in Food Industry under Grant No 10-16/3.2.7.
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OSZCZĘDNOŚCI ENERGII W SUSZENIU WARZYW UZYSKANE PRZEZ ZASTOSOWANIE NOWEGO KSZTAŁTU KRAJANKI

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

Suszenie w strumieniu powietrza (konwekcyjne) należy wciąż do najbardziej rozpowszechnionych metod odwadniania warzyw korzeniowych. W ostatnich latach uzyskano znaczny postęp w ulepszaniu konstrukcji suszarek, modyfikacji przepływu i parametrów powietrza suszącego i użyciu traconego ciepła, lecz surowiec i jego przygotowanie do suszenia nie było rozpatrywane w aspekcie oszczędzania energii podczas suszenia.

W tej pracy badano możliwości oszczędzania energii podczas suszenia przez zastosowanie nowego kształtu krajanki. Porównano suszenie 10 mm kostki marchwi mającej nacięcia na każdej stronie z tradycyjną 10 mm kostką bez nacięć. Materiał suszono w doświadczalnej suszarce do zawartości wody 0.1 kg/kg s.m. Wyniki wykazały 40 do 50% skrócenie czasu suszenia dla kostek z nacięciami w porównaniu z kostkami bez nacięć. Skrócenie czasu suszenia było większe w temperaturze 353 i 363 K niż w 333, 343 i 373 K i bardziej wyraźnie w drugim okresie suszenia. W trakcie suszenia, nacięcia na kostkach, wskutek skurczu tkanki rozchylały się, znacznie zwiększając powierzchnię suszenia.

W tej pracy doświadczenia wykonano wprawdzie na kostkach marchwi, lecz wydaje się, że podobne oszczędności energii wynikające ze skrócenia czasu suszenia, można by uzyskać podczas suszenia dowolnych, regularnych kawałków warzyw korzeniowych mających nacięcia na powierzchni.