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Rationalization of Sucrose Solution Using During the Fruit Osmotic Dehydration

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Summary

The model of sustainable energy production of dried fruit conducted by using combined technology – the model that has been developed at the Faculty of Agriculture in Novi Sad – includes osmotic dehydration of fruit in sucrose solution. During the process of dehydration the moisture content of the solution is increased due to mass transfer of moisture from fruit. This article examines different models of recycling and concentrating of the solution. Thus, the model for concentrating of the solution has been chosen according to this analysis, and it has been applied within its own technology. Evaporators of the low temperature solution have been used and they are based on the solar energy source. Two types of devices have been made on the basis of the heating process of evaporating. One type is filled with the stainless steel shavings, while the other type is based on the fillings by plates. The paper presents the evaluation model of the benefits of this concentrating manner as well as the evaluation criterion of the evaporators' fillings types. The energy support used here was an original solar air heater of semi-concentrated type.

Key words

osmotic drying, osmotic solvent, evaporating, fruit drying, solar energy

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Introduction

During the past decades a great number of researchers throughout the world have been examining different aspects of osmotic dehydrating of fruit, vegetables, meat, fish and other biomaterials. These authors state a number of advantages of this technology. The advantages are preserving the quality of products and low energy consumption (Stefanović and Urošević, 1995). With respect to fruit and vegetables, osmotic dehydration is most frequently combined with convective dehydration. In all these examples, osmotic dehydration is a preceding technology, thus it is also called osmotic pretreatment. Dehydration conducted in this way is based on the difference between the concentration potential of moisture in plant cell on one hand, and osmotic solution on the other hand.

In case of fruit dehydration, osmotic solution is most frequently a mixture of water and sucrose. During osmotic dehydration, this solution absorbs a certain amount of moisture, so concentration of sugar in the solution decreases in time. The decrease of sugar concentration results in decrease of moisture flux from fruit to the solution. Therefore, the solution becomes less efficient. Dissolved like this, the solution is problematic. It can be used as a raw material for alcohol production or some other technological or nutritional needs. However, the use of such osmotic solution is not efficient enough. The question is whether it is possible to use it more than once.

Thickening of osmotic solution can conventionally be realized by boiling or evaporation. Apart from sugar, during osmotic dehydration other dry substances transfer to the solution. Due to this fact, the technological operation of evaporation is required to be conducted at low temperatures, i.e. u vacuum. In other words, conventional solution re-circulating can be realized in vacuum evaporators.

At the Faculty of Agriculture in Novi Sad, different aspects of combined fruit and vegetables dehydrating have been examined intensively during the last couple of years. Special attention is drawn to osmotic dehydration kinetics and examination of technological parameters that provide high quality products (Babić et al., 2007). Furthermore, the same attention has been paid to the research of energy feasible model of dried fruit production using this technology. Energy feasibility was based on simple and efficient models of using renewable energy sources. The heat needed was provided through solar energy and biomasses from fruit. In order to achieve independence in terms of energy, the objective was to generate thickening of osmotic solution by a certain adequate method based on low potential of air which was heated by the solar energy.

A rational technical and technological way of thickening of used solution became a very significant factor of osmotic dehydration feasibility. Dalla Rosa and Giroux (2000) stress that osmotic solution regeneration is a critical factor due to its effects on environment, economy and the technology. There are a great number of different osmotic dehydrations of biomaterial. In case of fruit and vegetables dehydration, the solutions primarily used are sucrose or salt solutions (Romero Barranco et al., 2001). Combined fruit dehydration using osmotic and convective dehydration is predominantly based on sucrose solution (Giangiacomo, et al., 1987; Pan, et al., 2003). If one ensures that transfer of solid substance into osmotic solution is minimized (Matuska et al., 2004; Lazarides et al., 1995) the problems of osmotic solution management will be reduced. However, economical and environment-friendly solution of the problem requires high quality regeneration of the solution.

Development of different combined dehydration technologies became a widespread development trend in this field (Kudra and Mujumdar, 2002). Such development is a result of mass application of hi-tech technologies. Computers and cheap sensory equipment enable efficient and well-controlled management of dehydration. On the other hand, the problem of increasing prices of conventional energy-generating products is more and more apparent and it results in increasing usage of renewable sources. Together with the requirements arising from the Kyoto protocol, development of food technologies is to be more focused on using renewable energy sources.

Development of the osmotic dehydration technology at the Faculty of Agriculture in Novi Sad is based on the criterion of technological feasibility in terms of energy. The balance of mass and energy demands of combined technology (Babic et al., 2005a) can be observed in one general case, as presented in the Figure 1. We can see that there are three points of technology where heat energy is introduced. This energy is necessary for osmotic dehydration, convective dehydration and solution management. Vacuum evaporators, which can be applied in this technology, are relatively demanding regarding technical infrastructure. Primary water vapor and complex management of multilevel vacuum evaporation are required.

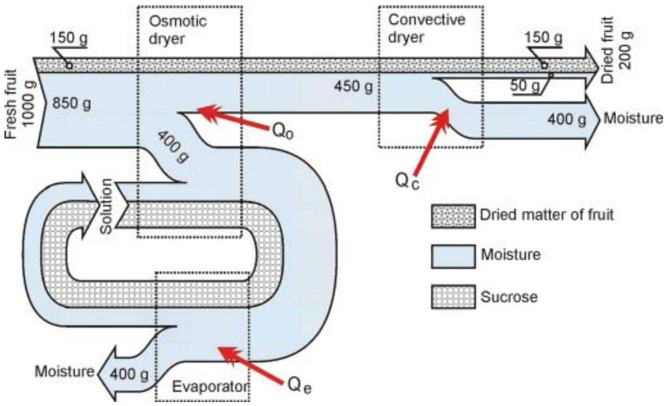

Figure 1.
Mass and heat balance of combined technology – a general case (Babić et al., 2005a)

Development of nanotechnology led to appearance of nanofilter. These filters are used also for thickening of juices and osmotic solution (Warczok et al., 2007; Courel et al., 2000). Special membranes allow water molecules to pass through, but they prevent passing of the solute. This method ensures good efficiency of thickening, but additional energy is required for further treatment of solution which passed through the nano-membrane (Vaillant et al., 2000).

Material and method

Prototype

A critical factor which determines feasibility of technical and technological concept is limiting the temperature of osmotic solution in the processes of regeneration of solution. Based on such approach in Laboratory of biosystem engineering, a prototype device for management was designed (Fig. 2). There are two options for fillings of this prototype. One possibility of filling is stainless steel shavings. The other alternative is plates which provide thin horizontal liquid films. In both cases, there is a large area for exchange of substances. Heated air, which is generated from the original solar air heater, flows from the bottom up. As the solution passes through the filling pulled by gravity, it reaches collector. Solution circulates through the system owing to the centrifugal pump. Air is heated in a special installation intended for examination of collective dehydration – the purpose of which is to control the level of the experiment (temperature and air flow).

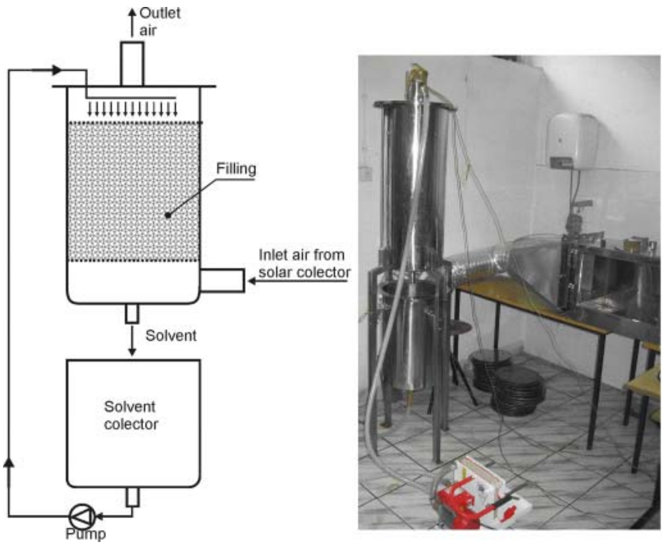

Figure 2. Solvent evaporator scheme and view

Experiment

Measuring the parameters of the process of evaporation on the device was conducted using a combined method. The data was partially collected by automatic computer acquisition: state of air when entering the heater, state of air when entering the device, state of air when leaving the heater and temperature of air when leaving the filling. Other parameters were measured periodically every 20 minutes. These parameters are: solution concentration, solution flow and air flow. Temperatures were measured by thermo-pairs of K type. Wet bulb temperatures were measured in the same way, with continual wetting of the outside with distilled water by a cloth. The condition of providing the air velocity fast enough was secured through sensors. Air flow was measured in the first section by a Prandt-tube. Solution flow was measured with a direct volume method using a vessel and chronometer. Sucrose concentration in the solution was measured by Omron refractometer. A Hewlett Packard device was used for computer acquisition.

The experiment was planned to measure the above stated parameters during six hours, i.e. until sugar concentration reaches 65 °Bx (Brix). The expected value of sucrose concentration at the beginning of the experiment was 46 °Bx. Two experiments were conducted at different temperatures of heated air 65 °C i 75 °C. After the experiment, the data was processed with MS Excel program.

Results and discussion

Two experiments were conducted on a prototype of the device with stainless steel fillings. The values that were constant during the process of evaporation are presented in the Table 1 for both experiments.

The parameters which changed during the experiment are presented in graphs (Fig. 3). It can be observed that the change of sucrose concentration in the solution during the evaporating process was significant. The influence of air on the velocity of the process is noteworthy, as well. Reaching the desirable concentration in case when air temperature was 75.59 °C at the entrance of the device took less than four hours, while it took almost six hours when the air temperature was 58.47°C. It is interesting to note that the tendency of increas-

Table 1. Results of measuring the process parameters

No	Title of parameter	Symbol	Unit	Average value during Exp 1	Average value during Exp 2
1	Inlet air temperature	t_{ai}	°C	58.47	75.59
2	Inlet air absolute humidity	x_o	kg/kg	0.0134	0.0138
3	Air flow	m_a	kg/h	251.5	230.7
4	Outlet air temperature	t_1	°C	32.20	33.56
5	Outlet air absolute humidity	x_1	kg/kg	0.0267	0.0322
6	Outlet air relative humidity	f_1	%	97.13	96.15
7	Solution flow	m_s	kg/min	18.044	19.81
8	Air velocity before filling (Air pseudo-velocity in filling)	v_1	m/s	0.871	0.848
9	Mass of solution on start process	M_s	kg	30.2	30.3

ing the concentration was almost a linear one. This fact can be accounted for by resemblance to dehydration in the period when dehydration velocity is constant. Phase change takes place on the free surface, which has the same value during the process so the mass transfer is approximately constant. End sucrose concentration in the solution almost reached the concentration of saturation for the temperature of 40 °C. Saturation at this temperature of solution is approximately 70 °Bx (Šušić et al., 1980).

The solution temperature increases quickly at the beginning, to be followed by continual increase. When about to reach the concentration of saturation temperature started changing more significantly. However, even in case of higher air temperature the concentration did not increase over 40 °C, which can be interpreted as a convenient process. Regarding the fact that in the combined technology of osmotic dehydration of fruit – which is applied at the Faculty of Agriculture in Novi Sad (Babić et al, 2005b) – temperature higher than 45 °C was not applied, the reached values of the solution were within the established limits.

Change of solvent flow during the process was also determined by the experiment. It was also possible to conduct the experiment by maintaining the constant flow, using a valve on the pipes. However, this option was rejected in order to determine the extent of the change. It can be seen that this change was significant. The decrease was almost 50 %. This was a direct consequence of change of viscosity due to concentration change (Babić et al., 2006). The dependency between viscosity change and concentration change is nonlinear, so the obtained result in the experiment is in compliance with this fact.

The experiment results confirmed the expectations regarding the convenience of this device for thickening of osmotic solution. Energy concept (Babić et al., 2005a), based on using renewable energy sources was applicable in this case, as well. It is possible to use solar energy or biomass energy, as well. In both cases it is required that the air temperature is 75 °C.

In order to compare this with other types of devices with the same purpose, one should use the same indicators as in case of dehydration – specific heat energy consumption. This is the amount of heat which needs to be included in the process for evaporation of 1 kg of water from the solution. It is defined in the following way:

$$q_e = \frac{Q_a}{W} \quad (\mathrm{kJ/kg_{ew}})$$

in which:

Q_a (kJ) – the amount of heat transferred to the air

W ($\mathrm{kg_{ew}}$) – the amount of evaporated water in evaporator.

For the two examined regimes of own prototype operation, the values are as follows:

q_{e1} = 5590 $\mathrm{kJ/kg_{ew}}$ and q_{e2} = 5122 $\mathrm{kJ/kg_{ew}}$.

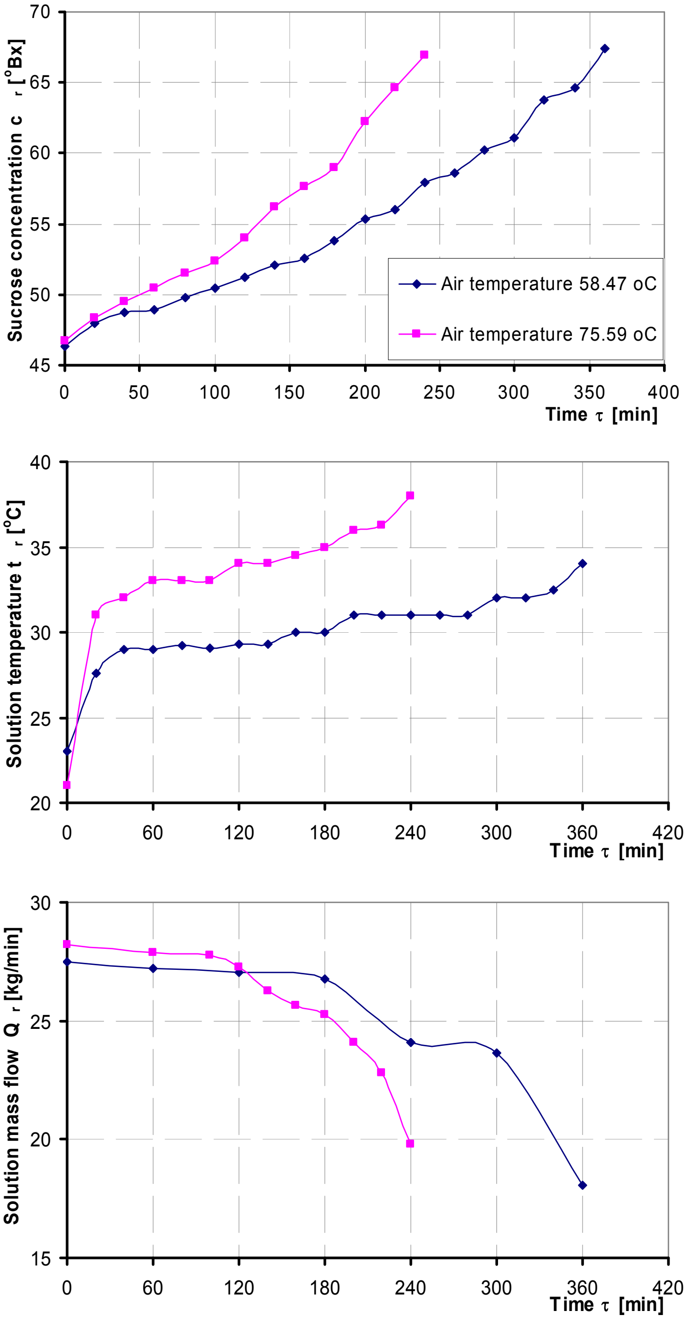

Figure 3.
Kinetics of concentration, temperature and solvent flow during the process

It can be concluded that in the second regime, energy consumption was lower. The following examinations should determine the regimes for which this indicator will have the lowest value. It is necessary to conduct optimisation of the process parameters, adhering to the criterion of minimal heat energy consumption. Regardless of how much this value is lowered, the advantage of this device is in using solar energy, which abounds in the period of fruit dehydration (summer and autumn). Apart from that, it is necessary to examine also the other means of evaporator fillings.

Conclusion

The research confirmed the hypothesis that regeneration of osmotic solution can be conducted on the basis of using solar energy. Thickening of sucrose solution in a prototype of technological device, which is presented in this paper, is technically and technologically feasible. The efficiency of evaporation is satisfactory. Further research is needed for optimization of process parameters regarding the criterion of minimum heat energy consumption. The process of solution thickening is to be terminated when it reaches 65°Bx.

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