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Effect of Temperature on the Model for Blanching Potatoes and other Vegetables

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(Received March 11, 1983; Accepted March 29, 1983)

This study expands the leaching model for blanching potatoes, previously reported, to include the effect of blanch temperature. Although the diffusivity coefficient varies with temperature, we found it more accurate and practical to correlate the equilibrium constant in the model with temperature and hold the diffusivity constant. With the adjustment, the model applies not only to the hot water blanching of potatoes, but also to water cooling.

Introduction

Increasing shortages of utilities and stricter waste treatment standards have amplified the need for optimization studies of food processing by systems analysis. Systems analysis of food processing encompasses the study and computer simulation of processes as a whole, accounting for the simultaneous interactions of the individual unit operations or processing steps. A critical component is a process simulator, which is a steering or master program interfacing and coordinating all subroutines and data banks. It mimics or simulates the real process and controls iterative process design and optimization. The subroutines are generally mathematical models of individual unit operations which calculate the steady state mass and energy balances and process costs.

KOZEMPEL *et al.* (1, 2) have studied and developed a predictive mathematical model for hot-water blanching. Applying the model to the potato flake process, they found leaching to be the main cause of component loss from potatoes in blanching. They found that the model they developed, Eqn. [1], predicts the change in concentration of solute with time in the effluent process water:

$$\frac{dS}{d\Theta} = PMC_1\psi - PMS\psi + W(S_1 - S)]/[v_\varrho + \frac{PM\tau}{2}\psi] \quad \text{Eqn. [1]}$$

where

$$\psi = 1 - \frac{8}{\pi^2} \exp(-\pi^2 D\tau/L^2)$$

This equation, derived in KOZEMPEL *et al.* (1), is the truncated solution for the fraction of a solute diffused in one dimension assuming the diffusion coefficient and surface concentration are constant. At steady state $dS/d\Theta = 0$ and BEqn. [1] becomes

$$S = \frac{PMC_1\psi + WS_1}{PM\psi + W} \quad \text{Eqn. [2]}$$

By mass balance, the model calculates the concentration of solute in the potato leaving the blanch unit. Soluble solids, potassium, magnesium, phosphorus, glucose, total sugars, ascorbic acid, thiamine, riboflavin, and niacin are the solutes for which the model is predictive. All variables in the equation are process parameters and known in a given situation except for the two constants, C_1 and D. C_1 is the equilibrium solute concentration in the model which is the leachable solute concentration in the juice of the potato. D is the diffusivity of the solute within the potato. Both constants are temperature dependent. The objective of this study is to develop a temperature dependent model for hot-water blanching and for water cooling of soluble solids, potassium, and glucose.

Experimental

Fig. 1 shows the process equipment and streams flow for studying hot-water blanching of potatoes. The Rietz Thermoscrew*, Rietz Manufacturing Company, model TJ-12-K3312 was used as the blancher. Tap water entered the process through a central valve and rotameter to control and measure the water feed rate. Tap water had an average potassium concentration of 3 ppm and an average soluble solids concentration of 0.04 wt./wt. An Eastern centrifugal pump, model U-34-C, recycled sufficient blanch water to maintain a uniform temperature in the blanch. A steam-heated exchanger maintained the blanch water at the desired temperature. The feed water flow rate was either 163 or 204 kg/h and the blanch system contained 128 kg of water.

We used Maine and Idaho Russet Burbank and Maine Kennebec potatoes throughout the study. The processing steps preceding blanching were: lye-peeling at 71°C for 15 min (20% NaOH), trimming, sulfite rinse (¼% $NaHSO_3$), cutting with an Urschel cutter Model G-A, sulfite rinse, screen-

* Agricultural Research Service, U.S. Department of Agriculture

* Reference to brand or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

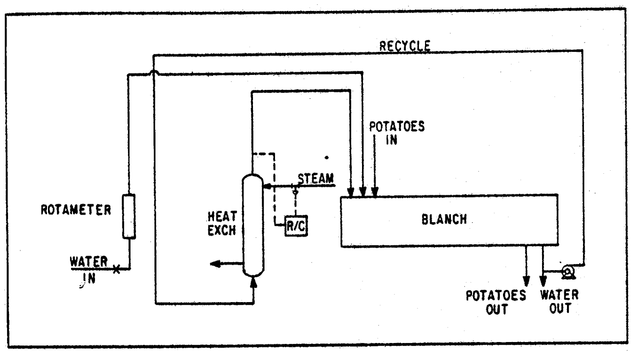

Fig. 1 Flow diagram of hot-water blancher

ing/washing, and sulfite rinse. We used 0.95-cm French fry cut potatoes at rates ranging from 21 to 29 kg/h. The potatoes remained in the Thermascrew for a nominal residence time of 16 min which was sufficient to blanch the potatoes and gelatinize the starch (3).

The cooler consisted of a small tank operated with full recycle of cooling water using an Eco gear pump. A heat exchanger maintained the desired temperature. The cooler system, including a surge tank, ranged from 122 to 139 kg of water. The residence time was 8 min. Potatoes from the hot-water blancher were processed in the cooler in perforated metal baskets, 48 cm×6 cm×15 cm. The cooler held four baskets. The potato flow rate was established by the potato flow rate in the blancher which, as stated above, was 21 to 29 kg/h. The residence time was set by putting another basket in every 2 min until four baskets were in the cooler, then simultaneously adding and removing one basket every 2 min.

Analyses

Water. Water samples from the blanching stream contained insoluble potato solids. These samples were filtered through 2 V folded filter paper prior to analysis. The samples removed from the cooling bath were essentially clear water solutions which did not require filtration. Potassium was determined directly on potato water samples acidified with HNO_3, in an Atomic Absorption Spectrophotometer, Perkin Elmer 306.

Glucose. Potatoes were extracted and analyzed as described by DELLAMONICA *et al.* (4). Potato water samples were analyzed with a YSI Model 27 Industrial Sugar Analyzer, all analyzed within 4 h to minimize loss of the glucose.

Solids were determined by thermal evaporation on a steam bath to remove the bulk of water, then finally dried to a constant weight in a forced air oven set at 105°C.

Potatoes. For the "soluble" components in potato juice the sample was treated as follows: The potato was ground in a Waring Blender cup and the juice pressed through cheese cloth, then filtered through Whatman 2 V folded filter paper. The filtrate was then sampled for "soluble solids and soluble potassium." However, before determining soluble glucose the filtrate was clarified with PbAc to remove possible interfering reducing substances. Lead was removed from the clarified juice with sodium oxalate. The sample was filtered. The filtrate was diluted, and subsequently analyzed for glucose utilizing the YSI sugar analyzer. Results are reported as solubles.

Moisture. Moisture content of potato was determined by AOAC Method 7.003 (5).

Results and Discussion

From our previous study (1) we have values for D and C_1 for soluble solids, potassium, and glucose at 77°C. D is the diffusivity and C_1 is the equilibrium constant or leachable solute concentration in the potato juice. Both constants vary with temperature. We need to modify the model to account for these variations. We tried several variations. In the first modification we held C_1 constant and varied D according to Eqn. [3] (6)

$$D = Do\, e^{-\left(\frac{E}{R_o}\right)\left(\frac{1}{T}\right)} \qquad \text{Eqn. [3]}$$

Using a series of experiments in which the temperature of the hot-water blanch varied from 43°C to 88°C and all other parameters were held constant, we made a pattern optimization search to determine the best values of Do and E/R. This modification was unable to correlate the data satisfactorily as listed in **Tab. 1, 2,** and **3.** There must be another factor which has a temperature effect and order of magnitude greater than D. This factor must be C_1, the soluble solids concentration or solubility of soluble solids in the water phase of the potato. In the second modification we chose to consider D constant and varied C_1.

We determine the potato solute concentration, C_o, analytically but C_o is not necessarily equal to the leachable solute concentration in the water phase of the potato, C_1, at the

Tab. 1 Comparison of calculated values of various modified models with experimental potassium concentration data for seven different experiments

Steady state K concentration, ppm			
Experimental	Parameter varied		
	D	k	D & k
228	200	228	238
221	197	224	234
228	194	221	230
117	195	123	129
221	192	178	184
86	209	87	91
263	200	251	261

Tab. 2 Comparison of calculated values of various modified models with experimental glucose concentration data for seven different experiments

Steady state glucose concentration, ppm			
Experimental	Parameter varied		
	D	k	D & k
466	369	453	447
443	361	443	437
439	357	439	433
225	357	225	235
374	355	344	345
133	379	141	160
441	374	508	499

Tab.3 Comparison of calculated values of various modified models with experimental soluble solids concentration data for seven different experiments

Steady state soluble solids concentration, wt./wt.			
Experimental	Parameter varied		
	D	k	D & k
.00330	.00260	.00322	.00323
.00310	.00252	.00314	.00315
.00318	.00258	.00318	.00320
.00160	.00262	.00169	.00172
.00250	.00245	.00240	.00242
.00108	.00253	.00089	.00092
.00350	.00257	.00353	.00354

blanch temperature. However, C_l should be related to C_o. If we assume a direct relationship then $k = C_l/C_o$ and k should vary with temperature. We tested this hypothesis using the same series of experiments and calculated the values of k. Eight values of k for soluble solids (SS), potassium (K), and glucose (GLU) are plotted vs temperature in **Figs.2–4.** One would expect an asymptotic upper limit for k. Leaching has no practical significance at temperatures near the freezing point of the blanch water. The value of k should approach an asymptotic lower limit. A sigmoid type curve should be able to fit the data and satisfy the two boundary conditions.

We chose Eqn. [4] as the sigmoid curve with which to empirically fit the data.

$$y = 1/2\,[1.0 + \mathrm{Tanh}(x)] \qquad \text{Eqn. [4]}$$

where

$$x = 6\left[\frac{T + 1.11}{122.22}\right] - 3 \qquad \text{Eqn. [5]}$$

The value of k at any temperature for soluble solids, potassium, or glucose can then be calculated from the following equations:

$$k_K = 0.13 + 0.621\ Y \qquad \text{Eqn. [6]}$$
$$k_{SS} = 0.01 + 0.848\ Y \qquad \text{Eqn. [7]}$$
$$k_{GLU} = 0.047 + 0.362\ Y \qquad \text{Eqn. [8]}$$

Figs.2–4 show the curves corresponding to these equations. The multivariable correlation coefficients, R, for Eqns. [6–8] are 0.959, 0.991, and 0.976, respectively. Such high coefficients indicate the equations correlate the data with a high degree of accuracy.

Using this modification of the model we calculated concentrations for the three solutes as listed in **Tab.1, 2,** and **3.** The model gave good agreement to the experimental data with R values of .959, .972, and .994 for K, GLU, and SS, respectively.

Next we combined both model versions, a variable D and a variable C_l, and repeated the above calculations. This added complexity in the model gave essentially no improvement in the fit. The E/R and Do values were 8 and 0.000295 for SS, 182 and 0.00137 for GLU, and 12 and 0.000556 for K, respectively. The R values were .965 for K, .973 for GLU, and .995 for SS. These multivariable correlation coefficients increased only .006, .001, and .001 for K, GLU, and SS, respectively, by varying D as well as C_l not enough to justify the increased complexity. Since there is no practical advantage using a variable D as well as C_l, we chose to use as the temperature dependent model a variable C_l, with D held constant.

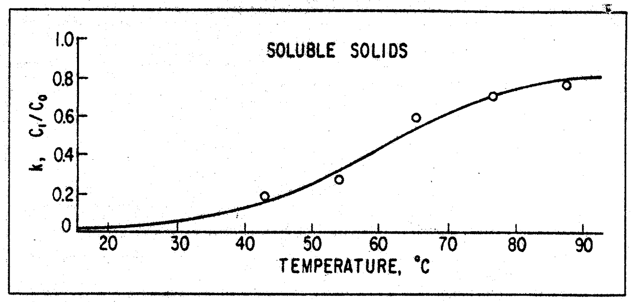

Fig. 2 Effect of temperature on the equilibrium constant for soluble solids plotted as $k = C_l/C_o$ vs temperature

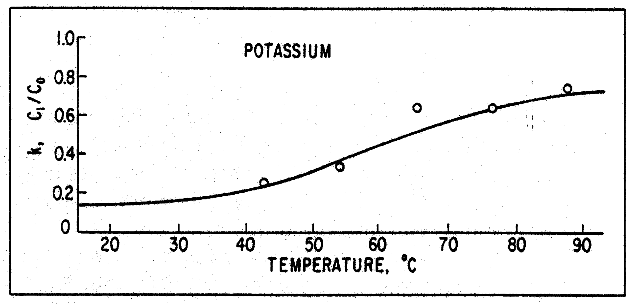

Fig. 3 Effect of temperature on the equilibrium constant for potassium plotted as $k = C_l/C_o$ vs temperature

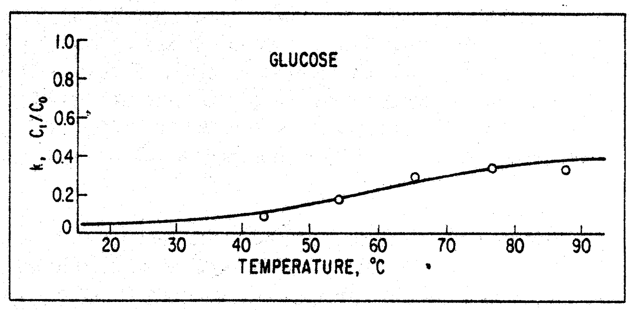

Fig. 4 Effect of temperature on the equilibrium constant for glucose plotted as $k = C_l/C_o$ vs temperature

Cold-water cooling is the next unit operation after hot-water blanching in potato flake production. We would expect to be able to apply the temperature-dependent model for hot-water blanching to cold-water cooling. We made a series of experiments from 13 °C to 21 °C to determine how accurately the model predicts leaching in the cooler.

The solute concentration of the feed potatoes entering the cooler varies as the solute concentration of the potatoes leaving the hot-water blanch. We were unable to run the blanch and cooler to steady state within the time limitations of one experiment so we used unsteady state data. To use unsteady state data we used the Runge-Kutta approximation (7) to integrate the differential equation in the leaching model for hot-water blanching Eqn. [1] to determine the blanch water effluent concentration. We calculated the concentration in the potatoes by mass balance. This established the solute concentration of the feed potatoes entering the cooler. To determine the solute concentration in the exit cooler water with time, we again used the Runge-Kutta approximation to integrate the differential Eqn. [1] for the cooler.

The blancher and cooler are a continuum so that the integration of differential Eqn [1] applied to the blancher and the cooler should be done simultaneously to simulate exactly transient or unsteady state processing. To approximate a simultaneous solution, we compound this sequence of steps in small increments. To each increment the Runge-Kutta approximation used 20 iterations to calculate the change in concentration due to a time increment of 0.2 h. Time was incremented to 6.0 h. **Fig.5** presents the results for K.

We made a null hypothesis (8) to determine if the predicted values were significantly different from experimental. At the 95% confidence level ($p<0.05$) the mean of the differences was not significantly different from zero and we conclude the model applies to leaching losses of K in cooling.

However, making the same test for SS and glucose (data in **Tab.4**) we had to reject the null hypothesis. This suggests the physical changes due to blanching alter the leachable concentration of glucose and the component(s) of the SS. We hypothesize that when amylose is retrograded, some of the amylopectin in the granule is dissolved in the water in the potato. This leachable starch component greatly increases the leachable soluble solids. Since amylopectin consists of α-D-glucose units, it may reduce the leachable glucose concentration in the potato liquid. In effect, during retrogradation, starch greatly increases leachable soluble solids and suppresses glucose.

Conclusions

We have extended the leaching model of hot-water blanching to include the effect of temperature on the loss of soluble solids, K, and glucose in blanching. The model also predicts

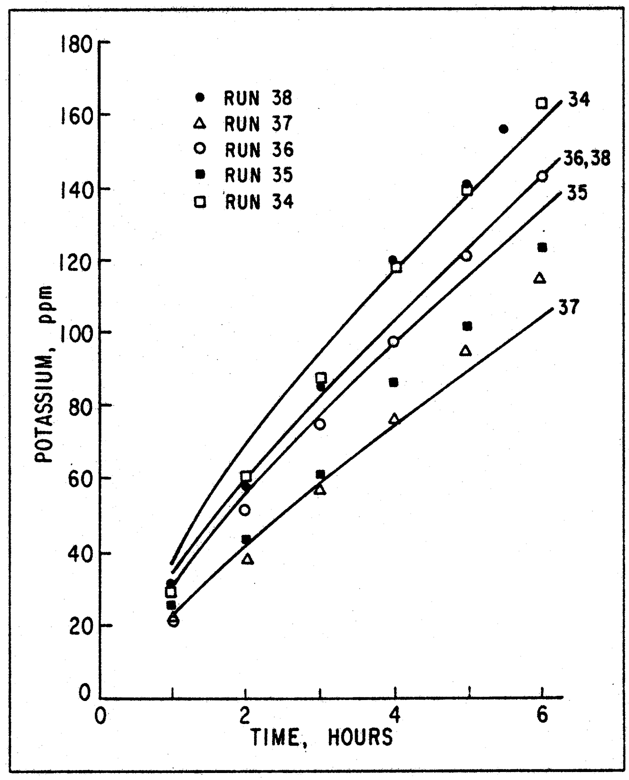

Fig.5 Plot of potassium concentration, experimental value, and prediction curve vs residence time in the cooler

Tab.4 Concentration of glucose and soluble solids in cooler water

Blanch	Temp, C	78	77	63	66	77
	τ, min	16	16	16	16	16
	P, kg/h	28.6	22.0	22.1	16.4	24.2
	W, kg/h	163.3	204.1	163.3	163.3	163.3
	Potatoes	MRB*	MRB	MRB	MK**	MK
Cooler	Temp, C	13	16	17	15	21
	τ, min	8	8	8	8	8

Cooler glucose concentration, ppm

Time, h	Exp	Pred	Exp	Pred	Exp	Pred	Exp	Pred	Exp	Pred
1	55	92	30	76	50	76	40	46	35	71
2	115	161	80	135	90	137	60	85	80	126
3	165	217	120	186	147	190	93	120	125	172
4	235	264	180	229	193	236	127	151	185	211
5	290	303	215	267	233	276	157	179	215	245
5½									240	261
6	340	336	250	299	277	312	190	205		

Cooler soluble solids concentration, wt./wt.

Time, h	Exp	Pred	Exp	Pred	Exp	Pred	Exp	Pred	Exp	Pred
1	.066	.0063	.067	.0058	.068	.006	.046	.004	.052	.0077
2	.092	.011	.080	.010	.089	.011	.061	.007	.072	.0139
3	.119	.016	.095	.015	.102	.016	.071	.010	.091	.0194
4	.138	.020	.118	.019	.125	.021	.087	.013	.114	.0194
5	.170	.023	.128	.022	.150	.025	.101	.016	.136	.0292
5½									.140	.0314
6	.202	.027	.148	.026	.175	.029	.115	.018		

MRB = Maine Russet Burbank, MK = Maine Kennebec, Exp = Experimental, Pred = Predicted by model the loss of K in cooling. Due to suspected physical changes during cooling, it does not hold for soluble solids or glucose in cooling.

Nomenclature

C_o = solute concentration in the juice within the potato, wt./wt., analytical value
C_l = initial solute concentration in the juice within the potato, wt./wt.
D = diffusivity, cm^2/h
Do = collision factor
E = Activation energy
k = ratio of C_l/C_o
L = nominal thickness of cut pieces, cm
M = potato moisture content, wt./wt.
P = potato flow rate, wt./h
R_o = gas constant
R = multivariable correlation coefficient, $[1-\Sigma(Yi-\hat{Y}i)^2/(\Sigma Yi^2-(\Sigma Yi)^2/n)]^{1/2}$
S = solute concentration in the blanch water; also, solute concentration in the exit blanch water, wt./wt.
S_l = solute concentration in the inlet water to the blanch, wt./wt.
T = degrees Celsius
V = volume of the blanch water
W = water flow rate, wt./h
ϱ = density of the blanch water, wt./vol.
Θ = time, h
τ = extraction residence time, h

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