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Continuous On-Line Control of Degree of Cook for Potatoes

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Abstract

On-line computer control of degree of cook or texture force of mashed potatoes in the flake process is demonstrated with a recently developed electronic cookness tester and ricer (ECT). The computer program uses shear force measurements from the ricer to calculate degree of cook and compares it to a setpoint that represents optimally cooked potatoes. The dwell time of a steam cooker is then automatically adjusted based on the difference in these values and with the aid of a cooking model.

Potatoes are cooked to the desired setpoint limits regardless of changes in upstream processing conditions. The ECT, in conjunction with this control system, eliminates the need for operator intervention in the production of mashed potato products.

Keywords. Food processing, Potatoes.

Introduction

In the mashed potato flake process, potatoes are precooked or blanched to deactivate enzymes, eliminate off-colors and flavors, and to gelatinize the starch; cooled to retrograde the starch and firm the cells for further processing; and then steam-cooked to soften the cell walls sufficiently for subsequent mashing and drum-drying (Talburt and Smith, 1987). The steam-cooking step determines the texture of the flaked product. Willard et al. (1987) state that overcooked potatoes are characterized by cell wall breakage and result in a product of poor texture even though higher production rates for drum drying are achieved. Undercooked potatoes cause reduced drum dryer production rates and loss of mash from the spreader rolls. In the narrow range where potatoes were considered sufficiently cooked, Kozempel et al. (1990) showed that drum-drying production rates decrease with increasing cooking times, and only for potatoes that have been in storage for less than eight weeks. After this storage time, cooking has little effect on drum-drying rate in this range. All studies show that cooking time affects the texture of the final product and in certain cases the yield. An optimum degree of cook here assures a product of good texture (Kozempel, 1988).

Potatoes of a single cultivar stored and processed under the same conditions, may result in significant variation in textural quality. Operators manually adjust steam-cooker dwell time to compensate for changes in texture. Potatoes are evaluated as cooked at the steam cooker based on the experience of the operator. A method in which texture is measured on-line at the steam cooker and used to automatically adjust dwell time would aid the operator in producing potatoes cooked to optimum texture.

Harada et al. (1985) presented correlations for 21 cultivars of potatoes, specific for a Zwick universal testing machine, which permit the use of shear force measurements to evaluate sensory texture and taste at the optimal cooking time. Kozempel (1988) developed a model based on new data, the data of Harada et al. (1985) and Kiyoshi et al. (1978), for the prediction of degree of cook of potatoes independent of potato cultivar or instrument used to measure shear force. The model relates the ratio of cooked potato texture to that of raw potato texture versus the cooking time. The ratio, defined as the degree of cook, of 0.15 ± 0.01 was found to represent potatoes that are optimally cooked as determined from subjective evaluations. Values greater than 0.16 indicate undercooked potatoes and those less than 0.14 indicate overcooked potatoes. An operator can measure off-line the texture of potatoes leaving the steam cooker and calculate degree of cook. If this value is not equal to 0.15 ± 0.01 or a value the processor deems representative of perfectly cooked potatoes, the processor can continually adjust dwell time until repeated measurements result in a desired degree of cook.

Measurements can also be made on-line using an electronic cookness tester and ricer (ECT) developed by Kozempel and Heiland (1990). Once the ECT is standardized against a conventional texture tester, it can be used in a computer control scheme along with a model for degree of cook to automatically adjust dwell time. The objective of this article is to demonstrate the control of degree of cook of potatoes using ECT values in a computer algorithm of the cooking model to regulate the dwell time of a steam cooker. By using the ECT and the computer control strategy presented here, operator intervention is eliminated and the quality of potato flakes, and possibly of any other processed product that is cooked and then mashed, is consistent regardless of changes in processing conditions before cooking or of the feed commodity.

MATERIALS AND METHODS

Maine Russet Burbank potatoes, harvested in October 1989 and stored at 3-4° C for five months, were peeled in a DSA 45 Kunz 45 L high pressure steam peeler at 1750 kPa for 15 s, washed in a rod/reel washer to remove loosened peels, cut into nominal 1×1 cm French fries with an Urschel slicer Model G-A, and spray-washed (Robins Vibro-Flo washer) to remove surface sugars and starch. The potatoes were blanched at 81° C for dwell times of either 5.5, 8.5, 18, or 27 minutes, respectively, in a Rietz thermoscrew hot-water blancher, Model TL-36-K2210. The potatoes were then cooled in an Abbott screw conveyor for 6.5 minutes at 22° C and cooked in a Robins Model 20283 continuous atmospheric steam cooker. Finally, the potatoes were mashed in a ricer and continuous electronic on-line cookness tester (Kozempel and Heiland, 1990). The ECT is a motorized screw press with three equally spaced load cells to measure the screw's reactive force on a solid end plate. The end plate is positioned about 4 mm from the end of the barrel portion of the screw press housing and forms a radial extrusion slot. Applied load force is linear with respect to millivolt reading. The potato flow rate was 200 kg/h.

Figure 1 shows the process loop for texture and control of degree of cook. Texture is controlled by manipulating the dwell time of the steam cooker. Three load cells at the ECT and a thermocouple at the blancher exit are interfaced to an EXP-16 analog input multiplexer board which, in turn, is interfaced to a Model DAS-16 analog-digital (A/D) board (Omega Engineering, Inc., Stamford, CT). A COMPAQ Deskpro 386 personal computer was used. The computer algorithm directs the output signal to a MSTEP-5 stepper motor controller board and stepper motor (Superior Electric Motor Model M061-FD02) to adjust the steam-cooker motor for a desired dwell time.

Force measurements were made on samples of potatoes entering the blancher and exiting the steam-cooker with a Model TP-2 (Food Texture Corp., Rockville, MD) back-extrusion tester (FTC) using the methods described by Kozempel (1988).

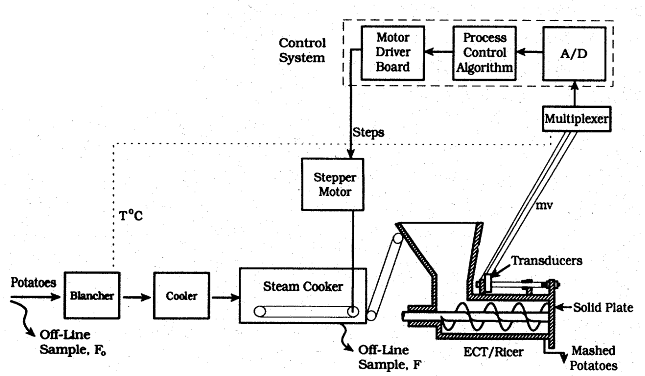

Figure 1–Partial process diagram with the Electronic Cookness Tester/Ricer and Control System.

COMPUTER ALGORITHM

The program for control of degree of cook utilizes a proportional feedback control strategy and is written in Microsoft QUICKBASIC 4.5. Proportional control was chosen for demonstration purposes because it is the easiest to implement in pilot plant tests using a minimum of feed potatoes. Proportional plus integral control or proportional plus integral plus derivative control may also be implemented, although it is not recommended for this case. The textural variability of the potatoes may cause noisy signals making the constants difficult to determine.

The program collects data via the A/D board from the load cells and thermocouple every 4 seconds. The millivolt reading for each load cell is converted to force and summed to calculate the force exerted by the screw to extrude the cooked potatoes. Every 2 minutes the force values are averaged, converted to degree of cook (degree of cook = C_E/C_o), where C_E is the ECT texture force of the cooked potatoes and C_o is the ECT texture force of the raw potatoes, and compared to a setpoint value of degree of cook. If the difference in these values is within ±0.01, no change in dwell time is made. If not, a new dwell time is calculated and converted to the number of steps to turn the stepper motor and adjust the dwell time accordingly. Experimental and calculated values of force and degree of cook are displayed on the monitor.

RESULTS AND DISCUSSION

The cooking model presented by Kozempel (1988) is a first order model:

$$- \ln F/F_o = k_c\,\theta_c + k_b\,\theta_b \qquad (1)$$

where F is the measured FTC texture force of the cooked potato, F_o is the FTC texture force of the raw potato, and F/F_o is defined as degree of cook. k_c and k_b are rate constants for cooking and blanching, respectively, and are independent of cultivar and texture test used. θ_c and θ_b are the dwell times of the steam cooker and blancher, respectively. Blanched potatoes are defined as those that are precooked in a hot-water blancher at temperatures less than boiling to gelatinize the starch. An Arrhenius-type equation is used to represent k_c and k_b:

$$k = k_o\,e^{-E/RT} \qquad (2)$$

For steam cooking, values of $k_o = 7.813\times10^{16}$ min^{-1} and E/R = 15269 K were used. For blanching, values of $k_o = 1.21\times10^{23}$ min^{-1} and E/R = 19918 K were used. The correlation is valid from 74 to 100° C for cooking and from 74 to 85.5° C for blanching. Solving equation 1 for θ_c gives:

$$\theta_c = \frac{- \ln F/F_o - k_b\,\theta_b}{k_c}. \qquad (3)$$

Equation 3 may be used as a guide by the operator to calculate the ideal steam-cooker dwell time at an optimal degree of cook. Equation 3 gives an estimate or starting point for θ_c for a desired degree of cook when applied to a pilot-plant or commercial plant situation. For the ECT, the degree of cook corresponding to F/F_o is represented by C_E/C_o.

C_o could not be experimentally determined in this study, because the required force is outside the load cells range. Because the clearance between the ricer plate and the barrel portion of the screw press housing varies slightly in assembly from run to run, nominally 4 mm, and the temperature of the ricer is uncontrolled, the values of C_E and C_o must be defined using measurements obtained from a standard laboratory texture testing device.

Kozempel and Heiland (1990) have shown that the relationship between texture force measurements for cooked potatoes on the ECT and FTC are linear. In this study, the following relationship between the devices was used for ECT initialization:

$$C_E/C_o = F/F_o - 0.03. \quad (4)$$

While a degree of cook of 0.15 from laboratory or bench texture instrument measurements indicates optimally cooked potatoes, preliminary ECT experiments done in this study showed that potatoes are optimally cooked when C_E/C_o is 0.12 ± 0.01. (The discrepancy is probably due to a difference in temperature measurement. The laboratory test was performed at 27° C whereas the ECT measurements were made with hot potatoes from the cooker.)

Before control action was initiated, values of F_o and F were measured off-line and values of C_E were collected by the computer program. The average of these values were used in equation 4 to calculate C_o.

Proportional feedback control was used to adjust cooker dwell time to $\theta_c'{}_{set}$ for a setpoint degree of cook, $C_E/C_{o\,set}$, of 0.12 ± 0.01. The equation for proportional feedback control is:

$$\theta_c' = K_c\,(C_E/C_{o\,set} - C_E/C_o) + \theta'_{c\,set} \quad (5)$$

where the error between the setpoint and experimental values of the degree of cook, $C_E/C_{o\,set} - C_E/C_o$, is used to adjust the dwell time of the steam cooker to θ_c'. An error of ≤ 0.01 was considered as agreement between θ_c' and $\theta'_{c\,set}$ The proportional constant, K_c, is defined by the following equation:

$$K_c = \frac{(\theta_c' - \theta'_{c\,set})}{(C_E/C_o - C_E/C_{o\,set})}. \quad (6)$$

K_c may be estimated using data from plant tests and conventional controller tuning methods or from on-line tuning methods. However, it is best to estimate K_c from equations 2 and 3 to eliminate the need for extensive pilot-plant tuning tests.

The ability of equations 2 and 3 in representing pilot-plant conditions was tested first. Maine Russet Burbank potatoes were blanched, cooled, and then cooked. Blancher and steam-cooker dwell times were varied and degree of cook was measured for each run. The results are shown in

TABLE 1. Comparison of cooking model with cooking data

Blancher dwell time, θ_b	Steam cooker dwell time, $\theta_{c\,exp}$	Degree of Cook, $\frac{F}{F_o}$	Calculated Steam Cooker dwell time, $\theta_{c\,cal}$	abs (diff)*
8.5	14.5	0.07	17.1	2.6
8.5	11.5	0.10	14.4	2.9
8.5	12.9	0.17	10.4	2.5
18	9.1	0.11	10.4	1.3
18	7.0	0.16	7.5	0.5
18	5.4	0.22	5.1	0.3
27	7.3	0.13	6.3	1.0
27	9.1	0.15	10.4	1.3
27	11.3	0.17	9.1	2.2

*diff = $\theta_{c\,exp} - \theta_{c\,cal}$

Table 1 and indicate that the model adequately predicts cooker dwell times for a desired degree of cook, in this case, at cooker dwell times of less than 11 minutes. However, it is not the predicted values of dwell time which are used in the control scheme, it is the change in degree of cook with dwell time which is of interest.

K_c was estimated by substituting a range of values of F_e/F_o at fixed experimental blancher dwell time and temperature and steam temperature, into equations 2 and 3 to calculate the corresponding θ_c. The range of θ_c and C_E/C_o values were then plotted for equation 6 with θ_c equal to θ'_c and equation 4 used to obtain C_E/C_o, and K_c was obtained from the slope. $\theta'_{c\,set}$ is determined during a run.

Figure 2 demonstrates one way the ECT and control system may be used in a control loop. The objective was to bring and maintain potatoes to a degree of cook of 0.12. At the beginning of the run, the setpoint dwell time of the cooker, $\theta'_{c\,set}$, was set to 8.0 min. This dwell time is generally adequate for newly harvested potatoes and a blancher temperature of 81° C and blancher dwell time of 18 minutes. Initial potato degree of cook was 0.10 ± 0.01. Once the control system was activated, corresponding to time = -0.5 h in the figure, equation 6 was used to automatically and continuously reset $\theta'_{c\,set}$ until the value of $\theta'_{c\,set}$ that gave a degree of cook of 0.12 was reached.

This occurred approximately 15 min (time = -0.25 h) into the run at $\theta'_{c\,set}$ = 3.6 min. For time ≥ 0 h, degree of cook was maintained in the range 0.12 ± 0.01. An offset in

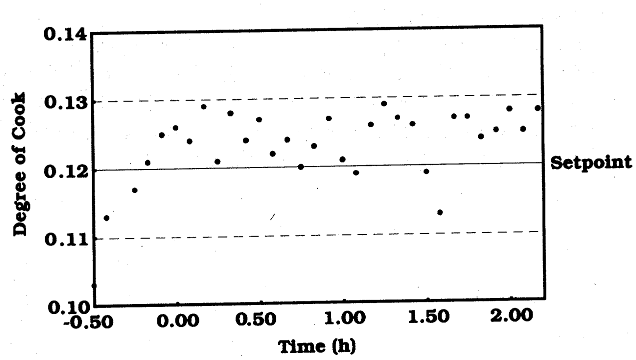

Figure 2–Control of cooking of potatoes.

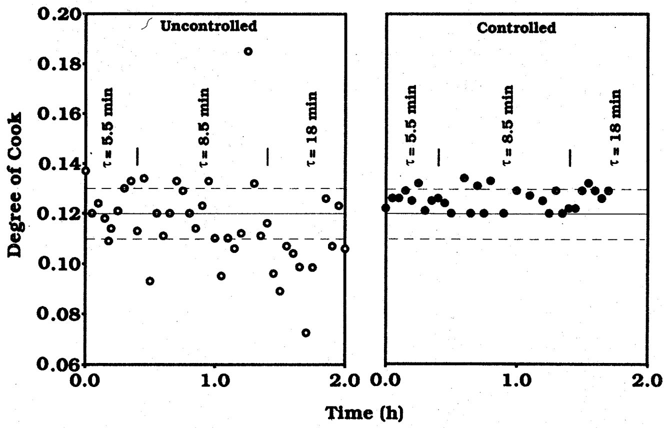

Figure 3– Controlled and uncontrolled cooking response to step changes in blancher dwell time.

the controlled variable from the setpoint is indicative of proportional control, and can be adjusted by varying K_c.

The advantages of using the ECT in controlling the dwell time of the steam cooker is shown in figure 3. In the first run, manual control was used; i.e., the control system was not activated. The steam cooker dwell time was set to 8 minutes and the blancher dwell time was changed from 5.5 to 8.5 and then to 18 minutes, respectively. This shows the response of the system to changes in potato texture. The results show that degree of cook decreased slightly when blancher dwell time was increased from 5.5 to 8.5 min, but most dramatically when changed from 8.5 to 18 min, because more cooking was taking place in the blancher.

The reaction of the control system to changes in the dwell time of the blancher was examined next and the results are also shown in figure 3. The experiment above was repeated but the dwell time was adjusted automatically to cook the potatoes to a setpoint degree of cook of 0.12 ± 0.01. The control system kept the potatoes within the range of the setpoint by adjusting the steam-cooker dwell time downward.

Conclusion

The use of an electronic cookness tester (ECT) in controlling the degree of cook of potatoes has been demonstrated. Values from the ECT were used in a computer algorithm of the cooking model to regulate the dwell time of a steam cooker. Values of K_c and $\theta'_{c\,set}$ were generated on line to control degree of cook to less than ± 0.01 units of a setpoint value.

This method eliminates the need for long on-line parameter determination which can result in a product that cannot be used. Although not shown in this study, it is possible that the ECT may be used for cooking control in any food process requiring cooking then mashing.

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Symbols

cal	=	calculated (subscript)
C_E	=	ECT texture force of cooked potato (texture units)
C_o	=	ECT texture force of raw potato (texture units)
C_E/C_o	=	degree of cook from ECT measurements
ECT	=	electronic cookness tester
E/R	=	activation energy/gas constant (K)
exp	=	experimental (subscript)
F	=	FTC texture force of cooked potato (texture units)
F_o	=	FTC texture force of raw potato (texture units)
F/F_o	=	degree of cook from FTC measurements
K_c	=	proportional control constant
k	=	rate constant (min^{-1})
k_o	=	frequency factor (min^{-1})
k_b	=	rate constant for blanching (min^{-1})
k_c	=	rate constant for cooking (min^{-1})
set	=	setpoint (subscript)
T	=	temperature (K)
θ_b	=	dwell time of blancher (min)
θ_c	=	dwell time of steam cooker (min)
θ_c'	=	controlled output dwell time for steam cooker (min)