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COMPUTER CONTROL OF BLANCHER FOR FRENCH FRY COLOR

Abstract

Computer control of color development of potatoes through regulation of glucose/reducing sugar content in the blancher is demonstrated for french fry production. Color was controlled using two methods. In the first, anticipatory-feedback control was used to adjust glucose concentration in the potatoes leaving a hot-water blancher. Because the relationship between concentration and color was not defined through the mathematical model, operator intervention was required to control color. In the second, anticipatory-feedback control was combined with some simple rules for adjusting setpoints and color. Results indicate that the second scheme is preferable because it eliminates operator intervention to effect color control.

Introduction

Nonenzymatic browning in potatoes, a result of the Maillard reaction between amino acids and reducing sugars, causes off-colors and flavors in products such as french fries, mashed potato flakes, and potato chips. Control of browning is essential in potato processing because off-colored products must be discarded or sold at a lower grade.

Factors affecting reducing sugar content have been discussed by Talburt and Smith (8) with the most significant being storage history. Reducing sugar content increases when potatoes are stored at low temperatures.

Processors control browning in fried products using hot-water blanching to leach reducing sugars and amino acids (8). Operating conditions of the blanchers and fryers are selected subjectively and continuously adjusted based on evaluations of the color, moisture, and oil contents of finish-fried or par-fried samples from the processing line (5). Color evaluations may be made on-line (1) using a colorimeter that gives continuous numerical readings or off-line by comparing the color of fried product to a standard chart (2). Moisture and oil contents are determined off-line.

Brown and Morales (3) and Califano and Calvelo (4) have developed guidelines and mathematical models from laboratory data for the purpose of aiding the processor in predicting the color of french fried potato products from blanching temperature and residence time. Marquez and Anon (7) suggested that the optimum color of potato chips is obtained when the concentration of reducing sugars is in the range 120-240 mg/100 g (1200-2400 ppm). These studies were not extended to pilot-plant or commercial operations where up to 4500 kg/hr of potatoes are processed.

Laboratory studies, which are generally conducted using non-flow processes, are often used to predict processing parameters for unit operations on the pilot-plant or commercial level. In commercial settings, potatoes are continuously fed to two or more hot-water blanchers. The first blancher leaches reducing sugars and amino acids from the potato surfaces. The second blancher is for additional leaching if the potatoes are high in reducing sugars. Alternatively, the second unit may be a cooler, set to a lower temperature to adjust the surface concentrations of the reducing sugars. This unit generally serves to rinse the reducing sugars and other leached components from the surfaces of the potatoes carried over from the first blancher. It is rarely used to put reducing sugars back on the surfaces of the potato. A buildup of reducing sugars and other potato components in the water of both units approaches a steady-state value (6, 10). Buildup of reducing sugars in the blanch water is not observed to the same extent in laboratory studies because few potato strips are blanched in a comparatively large volume of water. Therefore, in laboratory studies, potatoes fried after hot-water blanching may exhibit less browning than in a commercial situation because the reaction components that diffused to the surface of the potato are rinsed from the surface by the dilute blanch water. Laboratory studies frequently neglect the subsequent cooling step, where the starch of the potato is retrograded, changing the diffusion matrix of the potato and thereby slowing diffusion of the reactive components to the potato surface. Browning upon frying is due to surface sugars that are not rinsed off in the cooling step and in the case of potatoes insufficiently blanched, due to additional diffusion to the surface while frying.

Tomasula, *et al.* (10) have shown control of glucose concentration in potatoes during hot-water blanching in a pilot-plant unit. Controlling glucose concentration at the blancher effects control of color at the fryer. Glucose was monitored because it is easily measured on-line. An anticipatory-feedback control strategy was used based on an extension of a model developed by Kozempel *et al.* (6) for the prediction of glucose in the blanch water and potato. The control program requires the average initial glucose concentration of the feedstock potatoes for satisfactory control but does not relate the glucose concentration of the potato to color of the finish-fried product.

It is the objective of this study to extend the previous study (10) and show that an anticipatory-feedback control system may be used to control the color of fried potato products.

Materials and Methods

Two hundred kg/hr of Maine Russet Burbank potatoes that were harvested 10/89 and stored at 3-4 C for eight months served as feedstock. These were steam-peeled, washed in a rod/reel washer, cut into 1 × 1 cm french fry pieces, spray washed, and then blanched in a steam-injected hot water blancher at 81 C. The pilot-plant equipment has already been described (10). In individual experiments, potatoes were blanched at residence times, τ, of 6, 9 and 18 minutes and processed further by cooling for 7.5 minutes at 34 C in an Abbott screw-conveyor. The effects of holding time period before frying on color development during frying, defined by Califano and Calvelo (4), have not been studied here. The freshwater flow rate to the cooler was 150 kg/hr. Seven potato strips were then par-fried for 1 or 2 minutes at 201 C in corn oil in a Dazey Products Co., Inc., Model DCP-6 home fryer and drained of excess oil for 30 seconds. After frying, some samples were stored at -30 C for two months. These samples were refried for 1 min to determine if storage affected color of potatoes upon frying.

If experimental conditions resulted in potatoes that fried dark, the process control loop for glucose control described by Tomasula *et al.* (10) was activated. Concentration of glucose in the blancher and therefore in the potato was adjusted through manipulation of the value controlling the flow rate of fresh water to the blancher. The blanch water was sampled every minute, T_s =1 minute, by the glucose analyzer. The schematic drawing of the glucose analyzing and color control system is shown in Figure 1.

An HPLC was used to determine glucose, sucrose and fructose concentrations in the potatoes. Samples were lyophilized, ground to a powder,

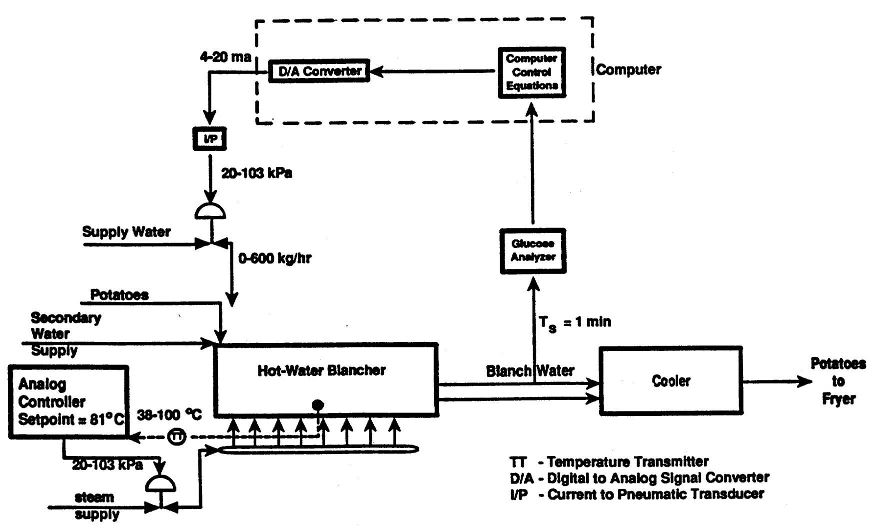

FIG. 1. Schematic drawing of the Glucose Analyzing and Control System.

packed into micro-columns, weighed and the columns extracted with 80% methanol:water, v/v. The column effluents were taken to dryness under a stream of nitrogen at room temperature and redissolved in 5 ml of deionized water. The samples were run on an HPLC (Spectra-Physics, San Jose, CA) using an Aminex HPX-87H ion exchange column (Bio-Rad Labs, Richmond, CA). A mobile phase of 0.013 N HNO_3 was pumped at 0.5 ml/min. A four level calibration was performed using solutions containing sugars at 0.2, 0.4, 0.8 and 1.0 mg/ml. Unknown sugar samples were injected and the concentration of the unknown (mg/ml) was calculated. (The reducing sugar contents of the potatoes, blanch water and cooler water, measured but not reported in this study, were roughly twice the glucose concentration.)

Color appearance upon frying was evaluated by visual comparison with the USDA Color Standards for frozen french fried potatoes (2). These color scores range from 000 (lightest) to 4 (very dark). Fries corresponding to a 1 color (light) were considered acceptable. Color readings were taken for potato samples par-fried for 2 minutes directly after exiting the cooler and in some cases, directly from the blancher.

Results and Discussion

Table 1 gives the initial glucose concentration in the potato, the concentration after blanching or cooling, the glucose concentrations in the exit waters of the blancher and cooler, respectively, and the USDA Color Score for potatoes that were blanched, cooled and then par-fried. Prior data for glucose concentration in potatoes after blanching only or after blanching and cooling showed these concentrations to be approximately the same indicating that very little or no diffusion of glucose occurred in the cooler. Consequently, these are considered as similar treatments in Table 1 for the "Final-In-Potato" column. The samples that were frozen at -30 C and refried two months later showed no change in color upon frying.

Potatoes blanched and then fried immediately without cooling (results not tabulated) exhibit unacceptable color readings of 3 or 4 for all potato and blancher water glucose concentrations. For potatoes that were blanched for 6 minutes, cooled and then fried, the color scores increased to 2 as the glucose concentration in the blanched and cooled potatoes increased (See Runs 1-11). Blanching these potatoes for longer periods of time resulted in potatoes of the desired color. This can be seen by comparing runs 8, 10, and 11 with runs 17 and 18 and by comparing run 9 with 19. Once the potatoes passed through the cooler, desired color scores of 1 were obtained upon frying; also demonstrating that the cooler rinses off the surface sugars carried from the blancher water. Run 15 is the exception where the glucose concentration in the cooler water is greater than that seen in the other runs. Blanching potatoes for as long as 18 minutes with subsequent cooling always resulted in potatoes that fried light because most of the reducing sugars are

TABLE 1.—*Color after 2 minute par-fry time as a function of blancher residence time, τ, for blanched or blanched then cooled potatoes.*

		Glucose Concentrations, ppm				
		In Potato		In Exit Water		USDA Color
Run	τ	Initial	Final*	Blancher	Cooler	Score
1	6	1890	100	1050	400	1
2	6	750	120	1740	0	1
3	6	1680	150	2670	310	1
4	6	1680	170	1470	280	-
6	6	4040	349	2380	490	2
7	6	1680	400	320	44	1
8	6	1790	950	360	570	2
9	6	4040	996	1300	230	2
10	6	1790	1040	490	110	2
11	6	1790	1720	1660	500	2
12	9	500	50	3000	350	1
13	9	1890	75	1220	400	1
14	9	1890	120	600	410	-
15	9	1600	150	4300	790	2
16	9	750	205	2490	0	1
17	9	1790	210	1310	530	1
18	9	1790	367	930	520	1
19	9	4040	550	2560	550	1
20	18	500	60	600	30	0
21	18	1890	140	420	400	1
22	18	750	240	3830	0	1
23	18	4200	270	3100	300	1
24	18	5100	700	1100	130	0
25	18	4500	750	1200	170	00
26	18	5750	900	700	300	1
27	18	1700	1200	200	90	00
28	18	2771	2000	200	120	1
29[1]	6	750	120	1370	-	2
30[2]	6	750	120	1740	-	3

τ-Blancher residence time, minutes.
*Concentration in potatoes leaving blancher or cooler.
-No data taken.
[1]Quickly rinsed.
[2]Cooled in air, 6 minutes.

leached from the surface of the strips (See Runs 20-28). However, blanching for this period of time often results in a soggy product.

To make sure that it was the rinsing effects of the cooler water and not the lower temperature encountered in the cooling step that was responsible for the lighter fries, potatoes were blanched, subjected to a quick water rinse, and then fried. The potatoes showed a reduction in color from 3 to 2 indicating that some surface sugars were washed away. Potatoes were also hot water blanched and cooled in air for 6 minutes. These potatoes showed no decrease in color. Typical results are shown in Table 1 (Runs 29-30). A comparison of runs 29-30 with run 2 shows the effects of the cooling step on color.

The results of Table 1 show the importance of glucose concentration control in potatoes to achieve desired color. Proper selection of residence time and water flow rate assures a good product. For the conditions of this study, desirable color upon frying was achieved for potatoes of initial glucose concentrations less than 750 ppm, in most cases. At this concentration, once a processor sets the residence times of the blancher and cooler and water flow rates to both units, processing conditions would not have to be modified for a good product. However, if the feed potatoes are high in glucose, product of desirable color will not result without processor intervention. Potato cultivars used in french fry production, such as Russet Burbank and Shepody, accumulate glucose upon storage.

For the two control runs described below, the process line configuration shown in Figure 1 was used to change the water flow rate to the blancher automatically to alter the glucose concentration in the potatoes if the potatoes fried dark. The objective of these runs was to produce fries with a color score of 1 (light) from potatoes with an average glucose concentration of 1790 ppm and total reducing sugar content of 3400 ppm. An anticipatory-feedback proportional control strategy previously described by Tomasula *et al.* (10) was used. The time when the setpoint was reached was anticipated using a simulation model for blanching so that process disturbances were acted on before they affected the processed end product. The process disturbance in this case is the glucose that leaches from the potato. The effect of residence time on the control of leaching was not examined.

In the first run, the residence time of the blancher was set to 6 minutes to mimic industry conditions. Blanching must be done for at least 6 minutes at temperatures greater than 71 C to prevent enzymatic browning. Following industry practice, the glucose concentration of the blanch water was allowed to build up; *i.e.*, no fresh water was admitted to the blancher. The setpoint for glucose in the blanch water was set to an arbitrarily high value for 2.5 hr so that the control system would not be activated. From Figure 2a, it can be seen that up to this time, the color score of potatoes fried after leaving the cooler was 2. The corresponding average concentrations of glucose in the potatoes, the blancher exit water and cooler exit water are shown in Figure 2b and show an increase of glucose in the exit blanch and cooler water. The control system was activated after 2.5 hr by choosing an arbitrarily low setpoint so that fresh water was admitted to the blancher to lower the reducing sugar content of the blanch water. Although the control valve was open to admit water at the rate necessary

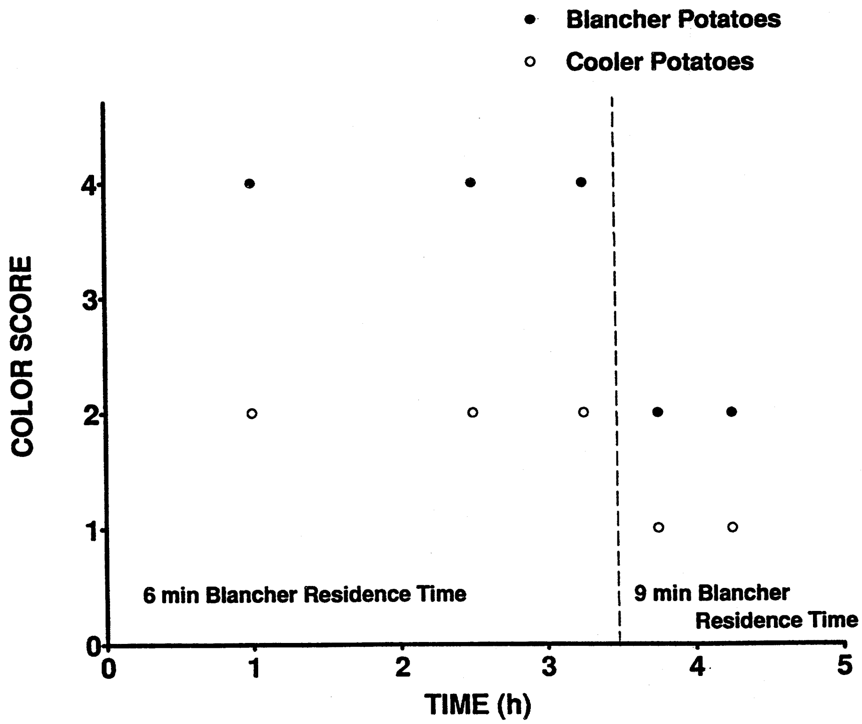

FIG. 2a. USDA color scores for potato samples exiting the blancher and cooler at two blancher residence times.

to maintain the setpoint concentration, this rate was not sufficient for leaching potatoes down to the sugar concentration required for adequate color. This is shown at a time of 3.25 hr, when the corresponding color score was still 2. Because the color score could not be lowered by controlling fresh water flow rate only, the only variable to adjust in order to increase leaching was blancher residence time.

The residence time of the blancher, therefore, was manually increased to 9 minutes at a time of 3.5 hr and the desired color score of 1 was realized in less than 30 minutes. The setpoint was also increased to decrease the flow of water to the blancher.

This control run shows the difficulty in developing control strategies for the food process industries that rely on simulation models and why human intervention is used to control food quality. The strategy described above requires an average value of the initial glucose concentration in potatoes to effect control through the simulation model. However, processors typically process potatoes around the clock. The potatoes may be of different

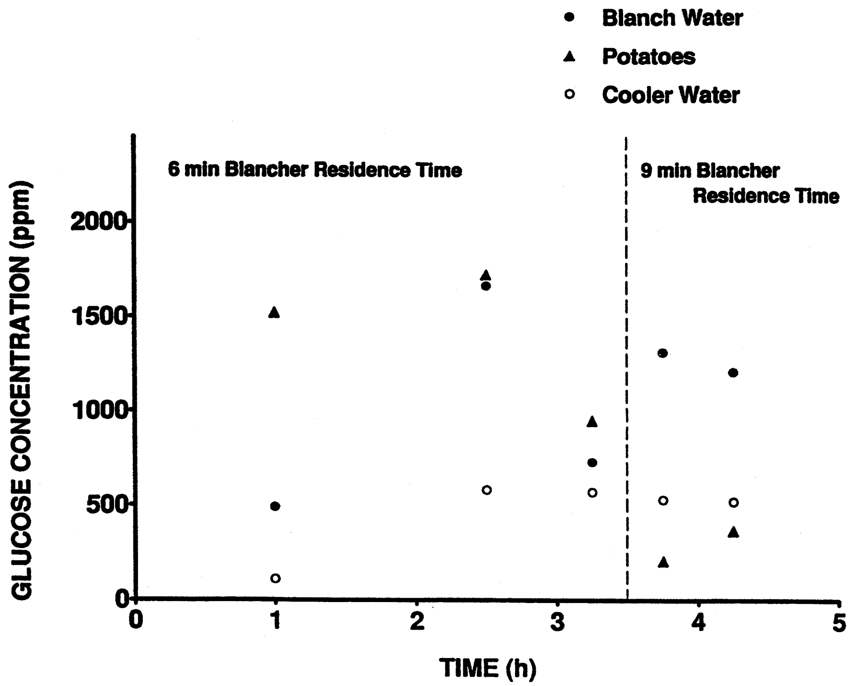

FIG. 2b. Glucose concentration of water and potato samples exiting the blancher and cooler at two blancher residence times.

cultivars or have different harvest and storage histories. An average concentration of glucose cannot be determined.

Because of this problem, the control program was modified to include subjective rules which are consulted every τ minutes. These rules guide the control program in deciding if the residence time of the blancher should be adjusted to increase leaching to improve color or minimize the flow rate of water adjusted to increase energy savings. These rules are shown in Figure 3. The input variables to the program were discussed in a previous paper (10) and include the potato and initial water flow rates to the blancher, the residence time and an estimate of the glucose concentration in the potatoes entering the process.

Every 5 minutes, the color readings were manually entered. A colorimeter may be used to automatically and more freqently, if desired, submit color values to the control program. If measured color is greater than or equal to 1 and the control valve is fully open, the control system will increase the residence time in the blancher. If the water flow rate is not a maximum, the setpoint glucose concentration of the blanch water is decreased in this case by 100 ppm to increase the flow of water. If meas-

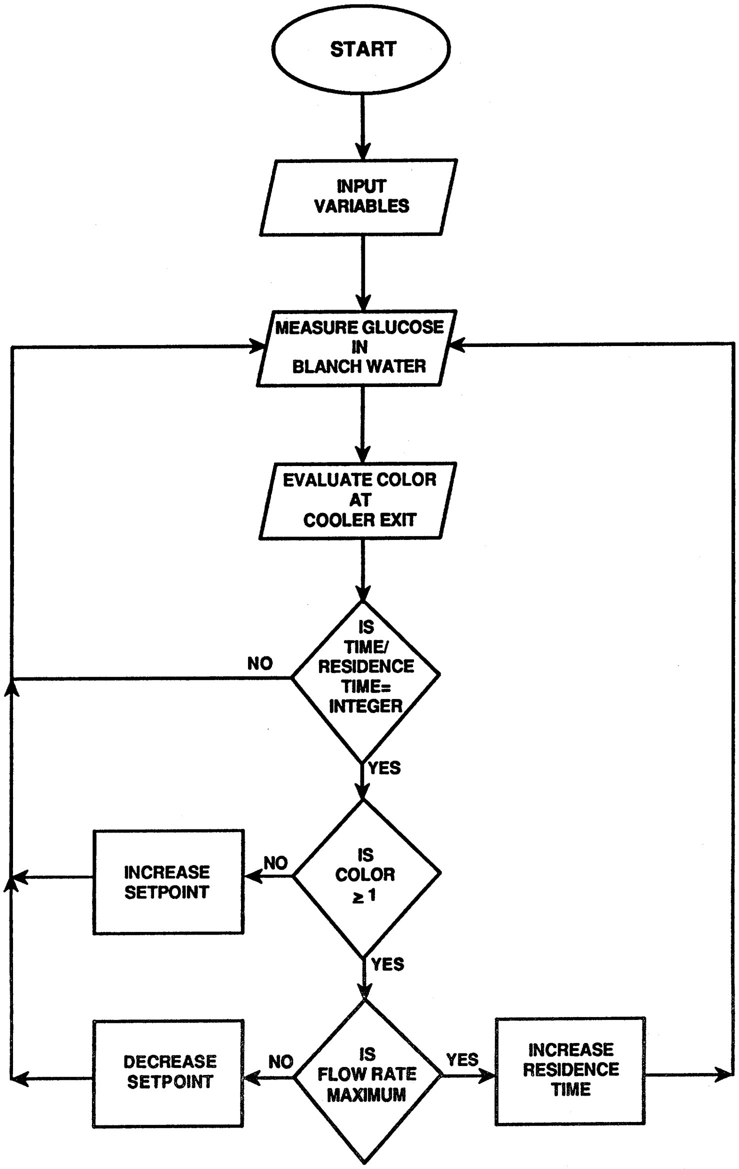

FIG. 3. Flow chart of subjective rules for control of the hot-water blancher.

ured color is less than 1 the setpoint is increased, in this case by 100 ppm, so that the flow rate of water to the blancher is minimized.

The data of Table 2 show the basis for the development of the rules and the effects of increasing water flow rate on the steady-state glucose con-

TABLE 2.—*Simulated glucose concentrations in water and potatoes leaving a hot-water blancher at two residence times, τ, and as a function of water flow rate.*

	Glucose Concentration, ppm			
Water flow rate kg/hr	τ = 6 min		τ = 9 min	
	Water	Potato	Water	Potato
0.0	1740	1620	1770	1560
150	590	1260	650	1150
306	340	1210	380	1085
460	240	1190	270	1060
610	180	1180	210	1040
760	150	1170	170	1035
920	130	1170	140	1030
1070	110	1160	120	1020
1220	96	1160	110	1020
1380	86	1160	98	1020
1530	77	1160	88	1020

centrations in the blanch water and potato at residence times of 6 and 9 minutes. These values were calculated using the model described by Kozempel *et al.* (6) and the diffusion coefficients of Tomasula *et al.* (9). The table shows that increasing water flow rate from 0 to 460 kg/hr will greatly decrease the amount of glucose both in the potato and in the blanch water. However, increasing the water flow rate from 460 to 1530 kg/hr will have practically no impact on the leaching of glucose. Only increasing the residence time will result in more leaching.

Figures 4a and 4b show the results for the second run using the modified control program with rules. The glucose concentration of the blanch water was allowed to build up for 1 hr using an arbitrarily high setpoint. As Figure 4a shows, the color score of potatoes leaving the cooler after 1 hr was 2. The control program was then activated by choosing a setpoint of about 400 ppm. The control program succeeded in decreasing the amount of glucose in the potatoes and color as shown in Figures 4a and 4b at a time of 2 hrs. It also suggested a change in residence time of the blancher from 6 to 9 minutes at 3 hr because the control valve was fully open. However, increased production may be preferable and this change does not have to be made. Because the setpoint was still at its previous value, the setpoint concentration of glucose in the blanch water was automatically increased to maintain the color score of fried potatoes at 1 and to decrease the flow of water to the blancher.

Conclusions

A system for the control of color in french fried potatoes has been presented. The system combined an anticipatory-feedback system with a

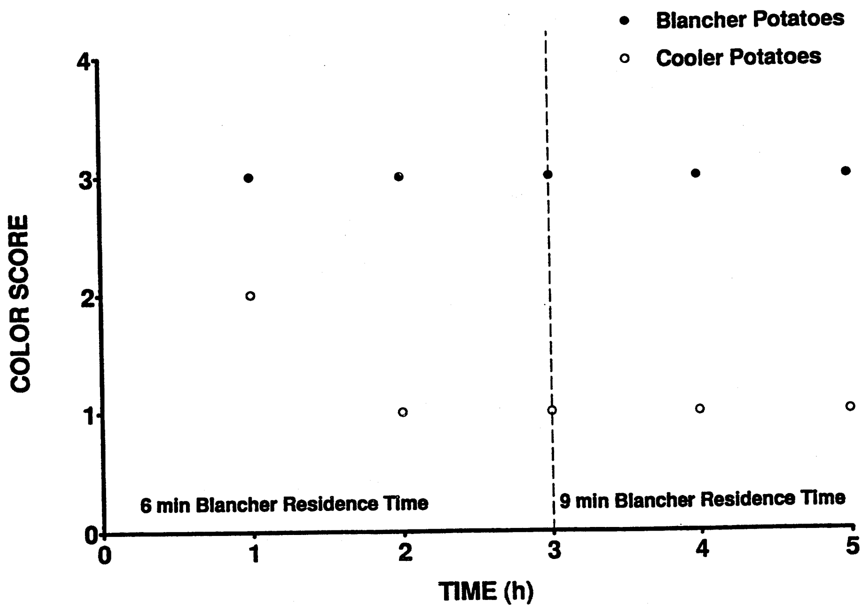

FIG. 4a. USDA color scores for potato samples exiting the blancher and cooler at two blancher residence times.

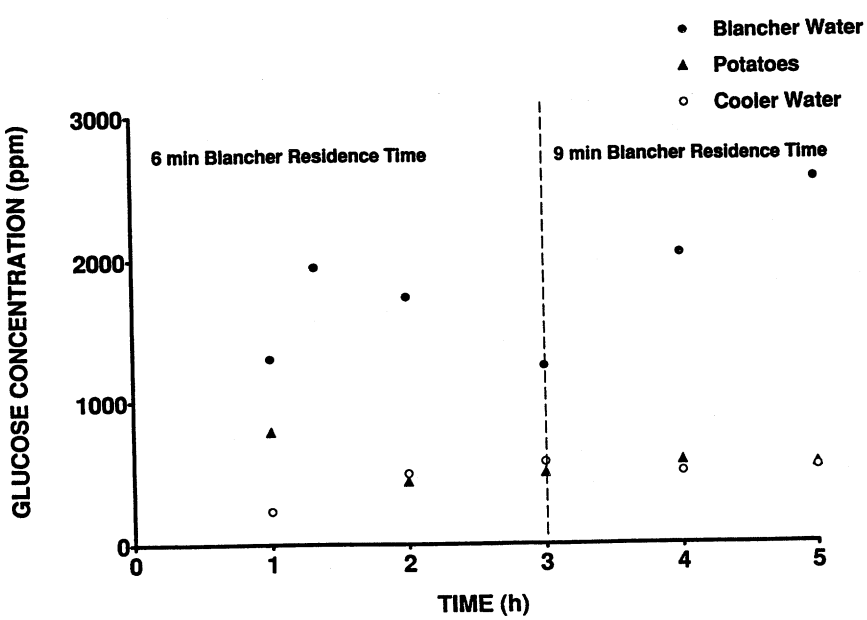

FIG. 4b. Glucose concentration of water and potato samples exiting the blancher and cooler at two blancher residence times.

series of subjective rules to guide the system in determining setpoint changes or process changes. The system eliminates the need for operator intervention in controlling the glucose concentration of potatoes during blanching and their color upon frying.

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