Computer Simulation of Potato Processing

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The ERRC food process simulator computer program is described. With the potato flake process as a prototype, we show that the simulation computer program predicts composition and texture. It is written in a user friendly Fortran, requiring no Fortran knowledge by the user and can be used with an IBM* compatible PC. The program can be expanded, with appropriate models, to other food processes.

Introduction

For years the petroleum and petrochemical industries have had computer simulators such as FLOWTRAN [*1*], CHEMSHARE [2], and PROCESS [3] for their processes. These simulators are applicable to hydrocarbon systems rather than the water systems found in the food industry. More recently, ASPEN PLUS [*4*] was developed to handle water and electrolyte processes but its cost and complexity are drawbacks. We set out to develop a simulator program that applies specifically to food processes; is simple to use; can be used on a personal computer; can be expanded to include models specific to the user's process; and, since it is developed by the ARS, is equally available to all at no cost.

To start from scratch to develop a simulator perfectly general for food processing, including models for all unit operations in the food process industry, is essentially an impossibility. Instead we developed the simulator in two stages. The first was the executive program. The second was the initiation of model development for the subroutines. The executive program is general and can be used for any food process by adding the appropriate subroutines. (Unfortunately, a major difficulty with food systems is the lack of mathematical models to describe mass and energy balances in the unit operations). To perfect the executive program and begin model and subroutine development we used a specific food process as a prototype — the potato flake process. It was necessary to develop the mathematical models for many unit operations e.g. precooking and cooling [5, 6], cooking [7], and drum drying [8]. To make the simulator more versatile, we opted to develop theoretically based models. Although emperical models are acceptable, theoretical models of the unit operations would permit application and extrapolation of the models to other food process plants. Obviously many more models must be developed and added to the subroutine package. Cooperation between industry and researchers will be needed for the model development.

The purpose of this study was to test the accuracy of the computer simulation program by comparing simulation results against pilot plant potato flake process data.

Experimental

Hardware

We compared the simulator to a pilot plant potato flake process, Figure 1. Five varieties of potatoes were used in the study: Russet Burbank, Red Pontiac, Russette, and Superior from Maine and Atlantic from Florida. Except for Atlantic, potatoes were stored at 3-4°C until removed for processing.

Potatoes were peeled in a pilot model high pressure steam peeler, DSA 45 Kunz 45 L unit with steam pressure at 1.3×10^6 Pa for 18 sec. Loosened peels were removed in a rod/reel washer. The potatoes were cut into French fries or cubes with a nominal minimum dimension of 1-cm with an Urschel slicer model G-A. A Robins Vibro-Flo washer removed the starch liberated in the cutter.

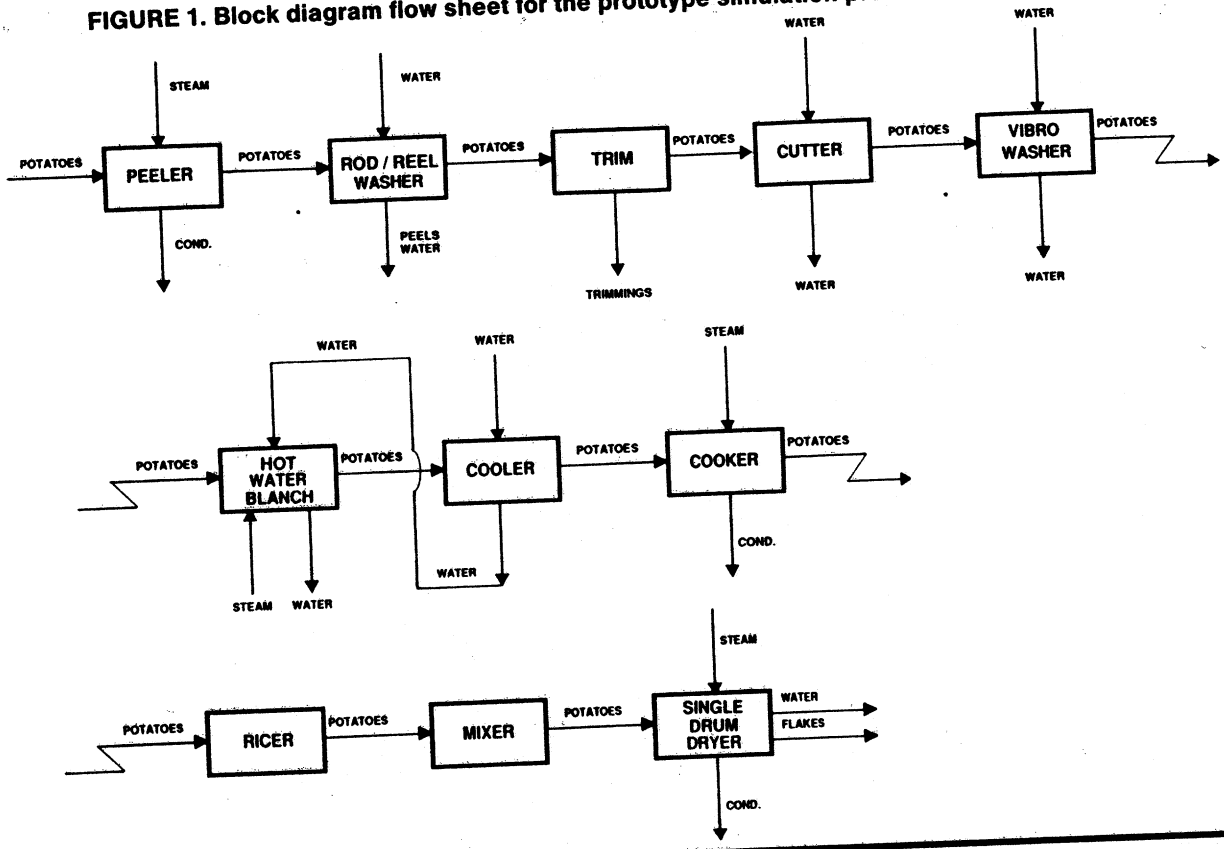
The potatoes were given the "Philadelphia Cook", that is, they were precooked in a Rietz water blancher, model TL-36K2210, for 18 min and cooled in an Abbott screw conveyor for 8 min [*9, 10, 11*]. The temperature was controlled in the precooker at various temperature settings between 76 and 84°C for the various experiments. The cooler was similar in construction to the precooker except for temperature which was in the range of 33 to 39°C. To test the trial and error subroutines for simulating the pilot plant process, we recycled the exit water from the cooler to the inlet of the hot water blancher or precooker.

Water samples from the precooker and cooler were filtered through 2V folded filter paper to remove insoluble solids. Potassium concentration was determined directly on the samples acidified with HNO_3, in an atomic absorption spectrophotometer, Perkin Elmer 306.

The precooked and cooled potato pieces were sent

*The mention of firm names or trade products does not imply endorsement or recommendation by the U.S. Department of Agriculture over other firms or similar products not mentioned.

FIGURE 1. Block diagram flow sheet for the prototype simulation process—Potato flakes.



through a continuous atmospheric steam blancher or cooker, Robins model 20283. To test the cooker model, the residence time in the cooker was varied.

Texture tests were performed with a Food Texture Corp. testing machine, Model TP2 (Food Texture Corp., Rockville, MD) with a model FTA-300 force transducer. The test cell was 53.2 mm diameter and 76.2 mm deep. The piston was 45.2 mm diameter resulting in an annular clearance of 4 mm. The stroke depth was 65.1 mm (11.1 mm bottom clearance) and the stroke rate was 6.8 mm/sec. Potatoes for testing were placed in a 27°C water bath for 3 min to standardize the texture test temperature. Six to eight tests were made on each sample of potatoes and the average peak force recorded as the texture.

Software

The computer simulator, called ERRC, is written in Fortran and is user friendly. No knowledge of Fortran is required. It is IBM compatible and fits on one 360K floppy disk for a PC although a second is required for some small auxiliary programs and data files. The program consists of an executive program and a package of subroutines. The executive program is the interface between the process engineer and the computer.

Simulation begins, not with the computer, but with a process flow sheet. All streams are numbered on the flow sheet and all required information for the input data streams and unit operations is assembled. Then the computer is accessed.

The computer needs information on the process and the input data streams. The input data streams are streams entering the process, trial streams in trial and error calculations, and streams used to establish product specifications. It must know which unit operations are in the process, and in which order, model parameters for the unit operations, how many streams are in the process, which streams are input data streams, and the corresponding data. The computer prompts for all needed information.

The information is stored in two data files to which the computer reads and writes. The user must name these files when asked by the computer. One data file contains stream data. This data file is filled first by executing an auxiliary program called "BGIN". This program prompts for the total number of streams in the process, the number of input data streams in the process, the number assigned to each input data stream, and the data for these streams. Table 1 lists a sample of computer prompts for "BGIN". Other components can be substituted for glucose, potassium, etc. by supplying the appropriate diffusivities.

The other data file is filled by the executive program "ERRC". This data file contains a numeric code of the unit operations in the process in the proper sequence and

TABLE 1. SAMPLE COMPUTER PROMPTS FOR BGIN

Total number streams in process including trial streams
Number streams specified or guessed
List stream numbers specified or guessed
What is stream temperature for stream 1
What is stream pressure for stream 1
What is stream flow rate for stream 1
What is stream solids concentration for stream 1
What is stream starch concentration for stream 1
What is stream glucose concentration for stream 1
What is stream sugars concentration for stream 1
What is stream potassium concentration for stream 1

all required information for the models. The executive program prompts for the information. The program also prompts for cost and coefficient data but default values are included. These files are stored so data need not be entered for each simulation. Table 2 lists computer prompts for a sample single unit operation process — steam cooking.

The executive program calls the appropriate subroutines as they appear in the process and calculates the mass and energy balances. There is a subroutine for each unit operation in the potato flake process; however, some are trivial and require no theoretical development e.g. Trim Table, Sizing, Ricing. Table 3 gives a listing of subroutines in the simulator.

Extensive theoretical development was required for hot water blanching or precooking, water cooling, cooking, and single drum drying. Models were developed from bench and pilot plant data. The accuracy of the models was checked at the pilot plant level and to a limited extent at the commercial level. Although the models were developed for the potato flake process, the individual models apply to other potato processing, e.g. French fries.

The hot water blanching or precooking model predicts

TABLE 2. SAMPLE COMPUTER PROMPTS FOR ERRC USING A STEAM COOKER

Do you want to specify unit operations yes or no
What is process unit #1
Do you want to specify process parameters yes or no
What is potato input stream #
What is steam input stream #
What is exit potato stream #
What is exit condensate stream #
What is potato bulk density
What is the horse power needed for the unit
What is the dwell time in the cooker
What is the piece size, minimum dimension
What is the belt loading or depth
What is the belt width
What is the belt length in the steaming chamber
What are the labor requirements

TABLE 3. SUBROUTINES INCLUDED IN THE SIMULATOR

PEELER—high pressure steam peeler
BOILER—steam boiler
WASHER—rod/reel washer for removing peels following the peeler
SO_3—sulfite rinse or soak
TRIM—trimming operation
CUTTER—mechanical cutter such as an Urschel cutter
SPWASH—vibro washer for removing surface starch and slivers
SIZE—sizing operation to remove slivers
IBLANCH—hot water blancher with complete back mixing
BLANCH—hot water blancher with non-ideal flow
COOLER—cold water chiller assuming complete back mixing
STCOOK—atmospheric steam cooker
RICER—machine for ricing or mashing foods
DRUM—single drum dryer with steam internal and food on the surface
WEGST—accelerated trial and error, trial stream adjusted
TANDE—accelerated trial and error, stream other than trial stream adjusted
LOS—miscellaneous losses, e.g., conveyor losses
SUM—utility subroutine for merging two stream
STSUM—utility subroutine for injecting steam into a water stream
DIV—utility subroutine for dividing a stream into two usually for recycle

the amount of leaching of water soluble material from the potato in this unit. Using diffusion as the rate controlling step we developed a model to describe the leaching due to hot water blanching [*5, 6, 12*]. This model also applies to a limited extent to the water cooler.

We also developed a model to predict the kinetics of cooking and gelatinization in the precooker and cooker [*7*] and a model to predict the moisture profile during drum drying [*8*].

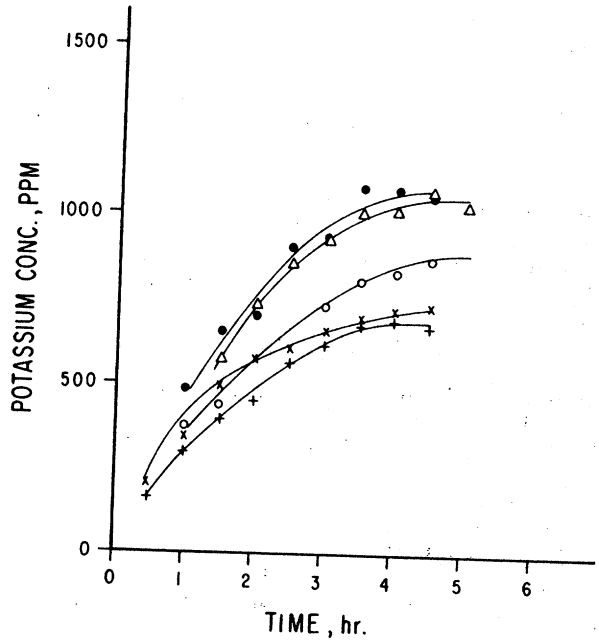
The subroutine package also contains two trial and error routines. Each uses the Wegstein iteration procedure [*13*]. These subroutines are needed to solve for recycle stream loops or adjust an input stream to reach a specified value in an exit stream. It was necessary to use the trial and error subroutine in the pilot plant simulation since we set up a recycle water stream loop from the cooler to the precooker.

Results and Discussion

There is little compositional change in the potato streams in the early process steps. Most changes are due to losses which can be accurately accounted for from experience e.g. peeling losses, trim losses. To test the accuracy of the Simulator we measured the concentration of potassium at the inlet and outlet of the precooker and cooler.

Potassium is a good component to study since it is not

FIGURE 2. Determination of steady state in the precooker-cooler—a plot of the potassium concentration leaving the precooker *vs.* time. The different curves represent different levels of potato and water flow rates.



prone to biological degradation as sugars and starches are and is easy to analyze using atomic absorption. Although potassium is of little or no direct practical concern to potato processors, it can be used as a key component. Potato processors, such as frozen French fry processors, are concerned with keeping surface sugars low to minimize nonenzymatic browning and darkened product. Hot water blanching is used to leach sugars (and potassium) yielding an acceptable product. When raw material or process changes occur the hot water blancher must be adjusted to compensate. Until a fast, reliable method of in-line sampling and analysis is available for sugars, the potassium simulation can be used as a tracer for sugars.

Good simulation requires accurate, steady state data. To assure that the data are collected at steady state, samples of water leaving the precooker were taken every half hour and the potassium concentration determined until the concentration appeared to level off, indicating steady state (Figure 2). Since the cooler water was recycled to the blancher, we assumed steady state at the precooker indicated steady state in the cooler. Due to a delay of about 20 min for receiving analytical feedback, data were taken about 20 min after steady state was reached.

Experimental results and simulation predicted values are listed in Tables 4 and 5 for one processing season. A typical process season is Autum to Spring. The difference in predicted versus experimental data for the precooker averaged 9% or 225 ppm for the precooker potato stream and 9% or 75 ppm for the water stream (Table 4). An estimated error in the experimental data was calculated by

TABLE 4. STEADY STATE CONCENTRATIONS IN PRECOOKER

Simulation	Experimental	% Diference*
Potato		
2170	2150	0.9
2560	2760	7.2
2320	2770	16.2
2090	1830	14.2
2430	2240	8.5
2370	2230	6.3
2310	2150	7.4
2160	2520	14.3
2120	2350	9.8
Water		
995	900	10.6
850	740	14.9
800	690	15.9
810	830	2.4
1100	1170	6.0
960	830	15.7
1060	1050	1.0
880	790	11.4
980	1000	2.0

$$*\frac{|SIM-EXP|}{EXP}100$$

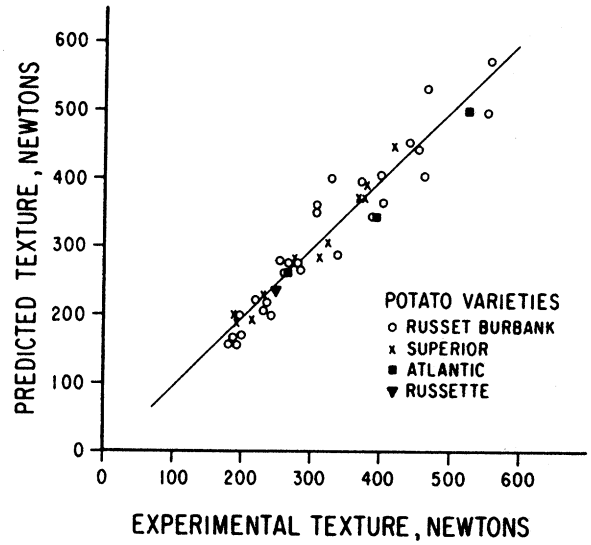
TABLE 5. STEADY STATE CONCENTRATIONS IN COOLER

Potassium Concentration, ppm

Simulation	Experimental	% Difference*
Potato		
1760	1800	2.2
2070	2530	18.2
1900	2390	20.5
1720	1200	43.3
1920	1890	1.6
1860	1840	1.1
1730	1860	7.0
1630	1910	14.7
Water		
330	325	1.5
305	300	1.7
280	260	7.7
220	270	18.5
330	500	34.0
250	230	8.7
250	290	13.8
190	185	2.7
260	250	4.0

$$*\frac{|SIM-EXP|}{EXP}100$$

FIGURE 3. Comparison of predicted and experimental values of potato texture leaving the cooker, Force (Newtons).



computing, from the concentration data, the difference in the mass balance for the input streams (potatoes and water) versus the exit streams. The error in the experimental data was 7% and is present in the predicted data error.

Table 5 lists the concentration data for potassium in the Cooler. The error in the potato stream averaged 14% or 245 ppm and in the water stream 10% or 35 ppm. The error in the experimental data was 5%. Given the difficulty of obtaining good data on a commercial type plant, even at the pilot plant level, we consider a 20% difference between simulated and experimental data acceptable.

Included in the precooker and cooker subroutines is the model for the kinetics of precooking and cooking. Hence the simulator should be able to predict the texture of the potatoes leaving the cooker. The ratio of the texture to the texture of the raw potato is a measure of cooking. It is important to optimize the degree of cooking since overcooking wastes energy while undercooking presents a less desirable or unacceptable product to the consumer.

We used the simulator to predict the change in texture or softening of the potatoes in the pilot plant process. This involved simulating the precooker and cooker. Figure 3 compares the results of predicting the texture of potatoes after various cooking times with the experimentally determined values. As can be seen, the simulator predicted the results quite accurately. The relative error (|(EXP-SIM)/EXP|) was calculated for each point. The average relative error was 8.2%.

Unfortunately, simulating drum drying with the rest of the process is not possible at this time. Various compositional factors associated with the potato greatly affect the feed rate or capacity of the unit. Although some of the factors are known, they can not be measured accurately enough to develop a correlation. The parameters of the drum dryer which control the capacity or potato feed rate are known [*13*]; but, variety and lot specific variables are undetermined.

Summary

The simulator is a useful program for simulating potato processing. It gives good simulation for a process through the steam cooker. Error in predictions for the precooker average 9%, for the cooler, 10-14%, and for the cooker, 8%. The program is expandable. Any number of unit operations can be modelled and added to the subroutine package. With the addition of more models to the subroutine package, it is possible to simulate, not only other potato processes, but other food processes as well. It is usable on an IBM compatible personal computer. Copies of the program are availabble from the authors at no charge. The program package includes two 360K floppy disks, a manual and a tutorial. The source code, microsoft Fortran, is also available for those who wish to write additional models.

Literature Cited

1. Seader, J.D., W.D. Seider, and A.C. Pauls, *Flowtran Simulation—An Introduction,* (Manual) CACHE, Cambridge, MA (1987).
2. *Guide to Solving Process Engineering Problems by Simulation,* (Manual) The ChemShare Corp., Houston, TX.
3. *Process Simulation Program—Application Briefs,* (Manual) Simulation Sciences, Inc., Fullerton, CA (1979).
4. *Aspen Plus—An Introductory Manual,* Aspen Technology, Inc., Cambridge, MA
5. Kozempel, M.F., J.F. Sullivan, and J.C. Craig, Jr., *Lebensm.-u.-Technol.* **14,** 331–335 (1981).
6. Kozempel, M.F., J.F. Sullivan, and J.C. Craig, Jr., *Lebensm.-u.-Technol.,* **16,** 338–342 (1983).
7. Kozempel, M.F., *Journal of Food Science,* In press. (1988).
8. Kozempel, M.F., J.F. Sullivan, J.C. Craig, Jr., and W.K. Heiland, *Lebensm.-u.-Technol.,* **19,** 193–197 (1986).
9. Anon., *Food Tech.,* **31,** 37 (1977).
10. Cording, Jr., J., M.J. Willard, Jr., R.K. Eskew, and J.F. Sullivan, *Food Tech.,* **9,** 236 (1951).
11. Cording, Jr., J., J.F. Sullivan, and R.K. Eskew, U.S. Dept. of Agriculture, Agricultural Res. Service, 73–75 (1959).
12. Kozempel, M.F., J.F. Sullivan, and J.C. Craig, Jr., *Am. Potato J.,* **62,** 69-82 (1985).
13. Wegstein, J.H., Comm. Assoc., *Computing Machinery,* **1,** No. 6, 9 (1958).