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**Journal of
FOOD PROCESS
ENGINEERING**

**Edited by
D. R. HELDMAN**

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JOURNAL OF FOOD PROCESS ENGINEERING

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All articles for publication and inquiries regarding publication should be sent to Prof. D. R. Heldman, Michigan State University, Department of Food Science and Human Nutrition, East Lansing, Michigan 48824 USA.

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LETTER TO THE EDITOR

I would like to comment on the paper by Jao *et al.* 'Response Surface Analysis of Egg White Gelling Properties in a Meat Loaf Analog' published in Vol. 4, pp 227–239, 1980. Although it seems to be based on solid technical ground with respect to the studied variables and data analysis, I have noted some serious flaws in relation to texture testing methods used to quantify the effect of cooking time and formulation.

First, the interpretation of the force/distance curve in Fig. 3 and the definition of the parameters are totally at odds (except in the case of 'toughness') with the accepted nomenclature and proven engineering meanings. I find this very disappointing because it increases the confusion in this rapidly growing field of texture measurements in which a number of dedicated researchers are striving diligently for unified definitions and methods. The accepted definition for the strength of a material is the force required to break it, *not* total deformation. The accepted units are, thus, force/area and *not* length. Hardness is defined as the force needed to achieve a given deformation (or the slope of the force/deformation plot), and not as maximum resistance (which is strength). Apparent elasticity (using the popular, rather than the rheological, meaning of the term) is measured as the degree of springback after removal of the deforming force, and not as deformation before fracture.

Second, the phrase "a specially designed apparatus was used" (p. 228, line 10 from bottom) is a misrepresentation since only a special test probe was designed. In addition, the authors should have acknowledged the fact that this type of a probe has been described in the literature before. One of its recent mentions is by Bruns and Bourne (*J. of Texture Studies* 6, 445–458, 1975), who also reviewed the past literature on the subject and reported on the effect of support spacing on the values of apparent sample strength.

Finally, in the discussion of the results, Jao *et al.* use the terms 'hardness' and 'gel strength' interchangeably (e.g., p. 237, lines 6–7). This is an unfortunate legacy from the old literature on gel characteristics. With today's prevalent use of recording instruments and a better appreciation of rheology by food scientists, these two parameters can and should be quantified and treated separately.

Alina S. Szczesniak, Sc.D
Principal Scientist, Central Research
General Foods Corp., Tarrytown, NY

MEETINGS

September 1984

- 9/10-9/12 BioTech 84—Second World Congress on the Commercial Applications and Implications of Biotechnology. Washington, D.C. Contact: BioTech 84, London Online, Inc. Suite 1190, Tupan Plaza, New York, NY 10121.
- 9/10-9/13 3rd International Conference of Catering Equipment and Systems Design. Harrogate, England. Contact: G. Glew, The Hotel and Catering Research Center, The Polytechnic, Huddersfield HD1 3DH, Great Britain.
- 9/14-9/18 Tokyo Pack 84. Harumi, Tokyo, Japan. Contact: Y. Kusuda, Secretary General, Japan Packaging Institute, Honshu Bldg., 5-12-8 Ginza, Chuo-Ku, Tokyo, 104, Japan.
- 9/17-9/21 68th Annual Meeting of the International Dairy Federation. Brog, Czechoslovakia. Contact: H. Wainess, Secretary, U.S. National Committee of the IDF, 464 Central Ave., Northfield, IL 60093.

October 1984

- 10/2-10/3 The Third Annual Midwest Food Processing Conference. Sponsored by the Iowa, Minnesota and Wisconsin sections of IFT. Radisson Hotel, LaCrosse, WI. Contact: M.K. Schmidl, Doyle Pharmaceutical Company, 5321 West 23rd St., Minneapolis, MN 55416.
- 10/9-10/10 Dairy Industry Conference. Hyatt/Long Beach, Long Beach, CA. Contact: J.C. Bruhn, Dept. of Food Science and Technology, University of California, Davis, CA 95616.
- 10/9-10/11 Fall 84 Symposium of the Research and Development Associates for the Military Food and Packaging Systems, Inc. US Army Natick R/D Center. Natick, MA. Contact: M. Singer, Executive Director, Research and Development Associates for Military Food and Packaging Systems, Inc., 103 Biltmore Dr., Suite 106, San Antonio, TX 78213.
- 10/17-10/19 Annual Meeting of the National Single Service Food Association. Hyatt Hotel, Hilton Head, S. Carolina. Contact: Robert H. Caline Company, 5775 Peachtree, Dunwoody Rd., Suite 500D, Atlanta, GA 30342.
- 10/28-11/2 First PanAmerican Congress on Agricultural Engineering. Caracas, Venezuela. Contact: R.L. Green, Apt. 3A, 15310 Beaver Brook Ct., Silver Spring, MD 20906.

November 1984

- 11/11-11/14 IFT Workshop on Research Needs. Harrison Conference Center, Glencove, NY. Contact: Dr. William W. Marion, Iowa State University, Ames, IA 50011.
- 11/25-11/30 Annual Meeting of the American Institute of Chemical Engineers. San Francisco Hilton and St. Francis Hotels, San Francisco, CA.

Contact: Henry G. Schwartzberg, Dept. of Food Engineering, University of Massachusetts, Amherst, MA.

December 1984

12/11-12/14

Winter Meeting of the American Society of Agricultural Engineers. Hyatt Regency Hotel, New Orleans, LA. Contact: M.A. Purschwitz, American Society of Agricultural Engineers, 2950 Niles Rd., POB 410, St. Joseph, MI 49085.

ENERGY CONSUMPTION IN A CONCENTRATED ORANGE JUICE PLANT

**J. GASPARINO FILHO, ALFREDO A. VITALI
and FLAVIO C. P. VIEGAS**

*Instituto de Tecnologia de Alimentos (ITAL)
Caixa Postal 139
Campinas, S.P., Brazil*

and

M. A. RAO

*New York State Agricultural Experiment Station
Cornell University
Geneva, NY 14456*

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ABSTRACT

The consumption of electricity and thermal energy for frozen concentrated orange juice (FCOJ) and citrus pulp pellets (CPP) was determined in a plant. Thermal energy accounted for 90% of the total energy consumption in the plant and its consumption for CPP exceeded that for FCOJ. The kilocalories of thermal energy per kg of water evaporated (KKWE) in the evaporators increased as the feed rate of single strength juice was decreased. At the design evaporation capacity, the steam efficiency of two tubular evaporators and two plate evaporators was found to be 0.85N and 0.82N, respectively; N being the number of effects of the evaporator. Fouling of the waste heat evaporator was a major reason for the high energy consumption in the CPP unit.

INTRODUCTION

Frozen concentrated orange juice (FCOJ) is consumed widely in the U.S.A., European common market countries, Japan, Venezuela and other countries. The State of São Paulo, Brazil and Florida, U.S.A., are the two leading areas in the production of FCOJ (Strohl 1981/82).

Most of the FCOJ (65° Brix) produced in Brazil is exported. Exports of FCOJ from Brazil have increased from about 210,000 tons in 1976 to

639,000 tons in 1981. The revenue in 1981 due to FCOJ exported was estimated at \$650 million. In addition to FCOJ, citrus pulp pellets (CPP), made from orange residues; peel, pulp, seeds, citrus molasses, etc., are sold as cattle feed. Other by-products of the FCOJ industry are D-limonene and essence oils.

In spite of the impressive growth and exports, the Brazilian FCOJ industry faces an uncertain future. The impressive export figures are tempered by the realization that they were the result of freeze damage to Florida oranges in 1979, 1981 and 1982. In addition, the rising fuel costs have put increased pressure on the industry to seek steps to reduce energy consumption.

The present study was undertaken to examine the energy consumption in a FCOJ plant located in the northwest of the State of São Paulo. The specific objectives of the study were to identify the leading energy source in the plant, to identify the energy intensive operations as well as to determine the energy consumption in the orange juice evaporators and to recommend methods to reduce the consumption of petroleum derived fuels in the plant.

Previous studies on energy consumption were conducted in plants processing tomatoes (Singh *et al.* 1980), clingstone peaches (Carroad *et al.* 1980), spinach (Chhinnan *et al.* 1980), spray dried coffee (Okada *et al.* 1980) and concentrated and powdered milk (Goel *et al.* 1979).

TASTE (temperature accelerated short-time evaporator) evaporators are used extensively for concentrating orange juice (Chen 1982). These evaporators were developed to accomplish pasteurization to inactivate pectin esterase as well as to concentrate the orange juice (Veldhuis 1971). The word "effect" indicates vapor flow in the evaporator, while the word "stage" indicates the flow of orange juice in the evaporator (Rebeck 1976). Because of the reduction in the quantity of orange juice as it is concentrated, two to four stages are incorporated in the last effect.

Chen *et al.* (1979) determined the energy consumption in a four-effect, seven-stage TASTE evaporator with a capacity of evaporation of 18,140 kg of water/hour, to be between 200 and 240 kcal per kg of water evaporated (KKWE). By introducing one effect and one stage after the fourth stage, the magnitude of KKWE was reduced to the range 136–153.

In most orange juice evaporators, the flow of orange juice and the steam pressure are controlled manually to obtain concentrated juice of the desired °Brix. By means of automatic control, the energy consumption in a six-effect, eight-stage evaporator with a capacity to evaporate 9,070 kg of water/h was reduced by 6.7% (Chen *et al.* 1983). Steam pressure was controlled by means of proportional, integral and differential control, while juice flow was controlled by means of proportional and integral control.

Peel, pulp and seeds left after extraction of orange juice are converted to CPP, a by-product used as cattle feed. First, lime is added to the orange residues to hydrolyze the pectins and increase their solubility. By means of mechanical presses, solids content of the residues is increased from about 20% to about 35%. Liquid from the presses is concentrated in waste heat evaporators (WHE) and the molasses are added to the residues before and after the pressing operation. The solids enriched in carbohydrates with the added molasses are dried in rotary driers to about 8% moisture content. The driers are operated with minimum excess air and the humid exhaust gases provide the thermal energy for evaporation in WHE (Bryan 1977; Cook 1971).

Bryan (1977) studied energy consumption in three citrus by-products plants in Florida. Based on water evaporated from pulp and peel only, a system consisting of two presses, a rotary drier, a flash evaporator and a double-effect WHE consumed 486 KKWE. In contrast, on the basis of total water evaporated (including a large amount of plant waste water), the system of one press, a rotary drier and a triple-effect WHE consumed 328 KKWE. A plant with only a rotary drier was found to be the least efficient requiring 911 KKWE.

MATERIALS AND METHODS

The present study was conducted in a FCOJ plant with a capacity to produce 70,000 tons of 65° Brix FCOJ and 85,000 tons of CPP per season. The plant also produced small quantities of essence oils and D-limonene. The plant was constructed in 1972 employing technology developed by the Florida FCOJ industry. It had on-site storage facilities for 17,600 tons of FCOJ at -8°C in tanks having a capacity of 1,100 tons and 900 tons of CPP in silos. At a separate location away from the plant, 13,650 tons of FCOJ were stored in 55-gallon drums at -25°C along with 625 tons of essence oil at 0°C . Data on energy sources were collected during three processing seasons: '78-'79, '79-'80 and '80-'81, while data on the performance of evaporators were obtained during the '80-'81 season.

FCOJ Unit

The unit operations for the production of FCOJ were: reception of oranges and their cleaning, selection and grading; extraction of orange juice, finishing, clarification, concentration, homogenization, cooling, refrigerated or frozen storage and shipping. One unique characteristic of

the Brazilian FCOJ is its relatively low pulp content (1–6% by volume of single strength juice). In the clarification operation, centrifuges remove pulp to the desired level.

CPP Unit

The orange residues from the FCOJ unit were used to produce CPP. In the CPP unit, lime was added to the residues followed by size reduction and mechanical pressing to remove water from the residues. The liquor from the hydraulic presses was concentrated in a double-effect WHE whose source of thermal energy was the hot humid gas discharged from the rotary drier. In the drier, the residues were dried to about 8% moisture content. Part of the concentrated liquor (citrus molasses) was added back to the residues before the presses and the rest after the presses. The dried residues exiting the rotary drier were pelletized after the addition of a small amount of steam.

Energy Sources

Fuel oil #6 was the source of thermal energy. The oil stored in two separate tank systems was used in boilers to generate steam for evaporation of orange juice and in the drier furnaces of the CPP unit. The tanks were equipped with level indicators so that the consumption of the oil each month or for a desired length of time could be determined. Consumption of electricity for various sections of the plant, to be identified later, was determined by means of watt meters. The quantities of fuel oil and electricity consumed were converted to kcal by means of the factors: 9,525 kcal/kg of oil and 860 kcal/kwh of electricity.

Performance of Evaporators

The performance of two tubular (TASTE) evaporators (T1 and T2) and two plate evaporators (P1 and P2) was studied. T1 and T2 were five-effect, seven-stage evaporators (shown schematically in Fig. 1) with nominal evaporation capacities: 27,211 kg (60,000 lb) and 45,352 kg (100,000 lb) of water/h (KGWH), respectively. P1 and P2 were four-effect, five-stage evaporators (shown schematically in Fig. 2) both having the capacity of 13,605 (30,000 lb) KGWH. The plant also had a tubular triple-effect, five-stage evaporator with a capacity of 4,536 (10,000 lb)

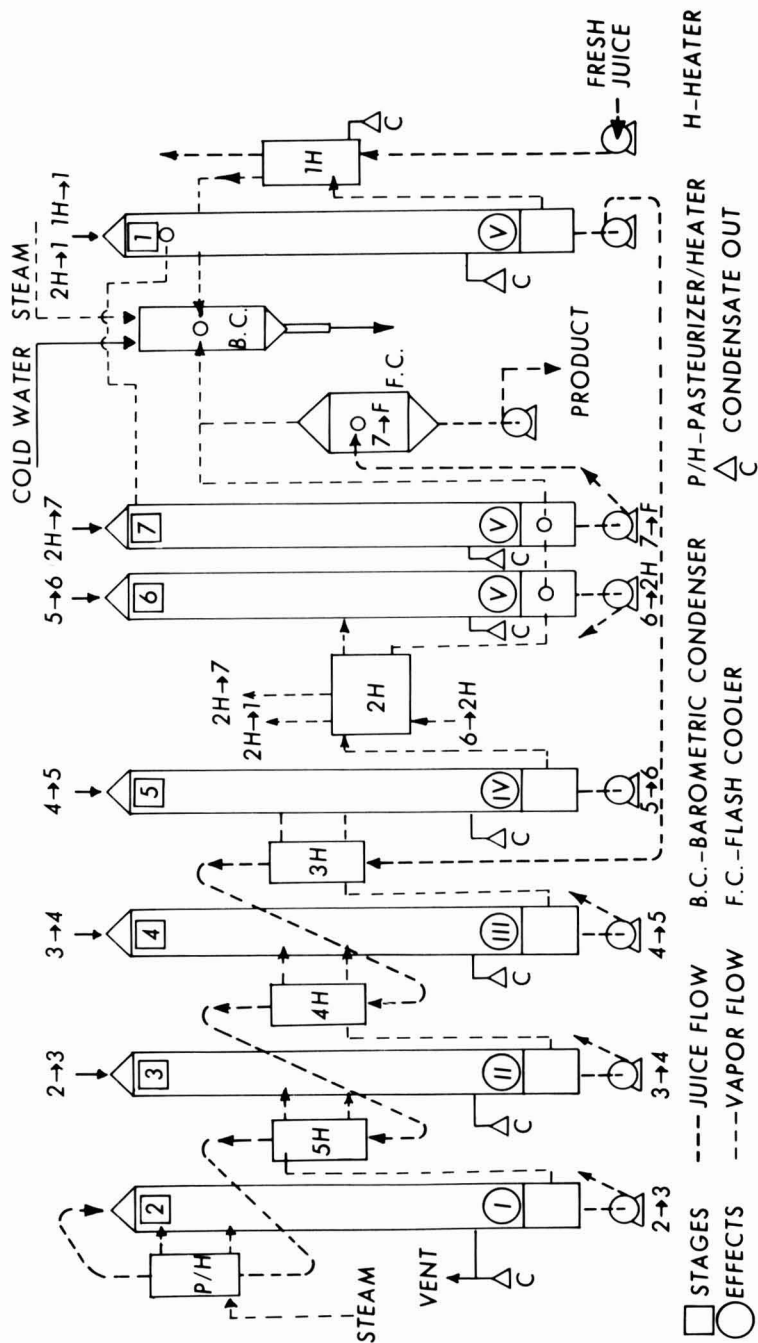


FIG. 1. SCHEMATIC OF A FIVE-EFFECT, 7-STAGE TASTE EVAPORATOR

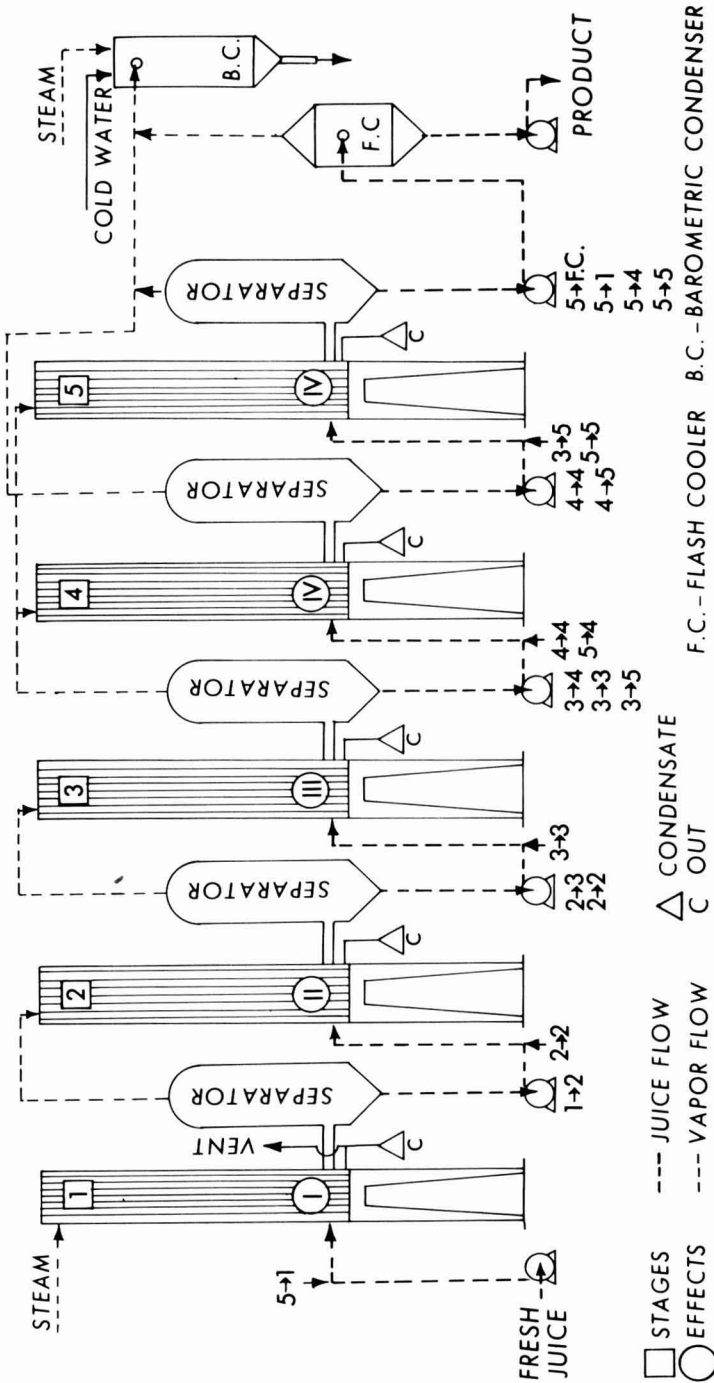


FIG. 2. SCHEMATIC OF A 4-EFFECT, 5-STAGE PLATE EVAPORATOR

KGWH and two plate evaporators similar to P1 and P2. However, these were not used as extensively as the studied evaporators and hence performance data were not obtained on these evaporators.

The elapsed times to fill a 208 liter (55-gallon) drum with steam condensate from the first effect, with water evaporated in the first through the penultimate effects, and with concentrated orange juice were recorded with a stop watch. The concentrations ($^{\circ}$ Brix) of the feed and product streams were measured with a refractometer and corrected for the acidity of the juices. These data were obtained after steady state operating conditions were established at different rates of production of concentrated orange juice.

In the case of the tubular evaporators, T1 and T2, the time elapsed to fill the drum with water evaporated was very short (19–32 s) so that a small error in recording the time could result in a large error in the calculation of the rate of evaporation of water. For this reason, the amount of water evaporated in T1 and T2 was calculated by means of mass balance employing the rate of flow of concentrate and the concentrations of the initial and concentrated juice streams.

In the case of the plate evaporators P1 and P2, the elapsed times were more than 70 s, and these were considered to be accurate values. The water evaporated in the four-effects was calculated by multiplying the quantity for the three effects by the factor (4/3).

RESULTS AND DISCUSSION

Overall Energy Consumption

The overall consumption of thermal energy and electricity and production of FCOJ and CPP are in Table 1. For the plant as a whole, electricity accounted for only 10% of the total energy consumed in the plant. Motors in the FCOJ and CPP units accounted for 30% and 35% of the installed capacity in the plant, respectively, while those on various pumps and refrigeration compressors accounted for 19.8% and 7.5% of the total capacity, respectively. The rest of the installed capacity in the plant was for motors in the waste water treatment unit and the boiler house. We note here that the auxiliary storage facilities for 13,650 tons of FCOJ and 625 tons of essence oil consumed 3.60, 4.29 and 3.97 billion kcal during 1978, 1979 and 1980, respectively. For this reason, electricity consumption by the motors of the refrigeration unit in the plant (7.5%) is low and one must add the consumption in the auxiliary storage facilities to obtain the energy requirements for refrigeration of FCOJ.

Table 1. Annual production of FCOJ and CPP, and consumption of electricity and thermal energy.

	<u>1978</u>	<u>1979</u>	<u>1980</u>
Production of FCOJ in million kg	58.21	52.13	62.39
Production of CPP in million kg	57.97	59.98	74.99
Electricity (total) in billion kcal ^a	20.53	19.76	21.43
Thermal Energy for FCOJ in billion kcal	86.55	80.32	73.35
Thermal Energy for CPP in billion kcal	90.69	91.03	117.58

^aReflects electricity consumed in plant. Auxiliary storage facilities for FCOJ in 55-gallon drums at -25°C and essence oil at 0°C required 3.60, 4.29, and 3.97 billion kcal during 1978, 1979, and 1980, respectively.

Because thermal energy accounted for 90% of the total energy consumed in the plant, its consumption and the potential for conservation in the FCOJ unit were studied in detail. Most of the steam generated was used to concentrate orange juice in evaporators; a small portion (16%) was used in the pelletizing operation of the CPP unit. This was considered in apportioning energy consumption for FCOJ and CPP.

Vergara *et al.* (1978) and Cleland *et al.* (1981) showed that regression analysis can be used to determine the energy consumption for food products. Using this technique, the consumption of thermal energy per ton of FCOJ and CPP was estimated (Table 2). It is readily seen that each year

Table 2. Consumption of thermal energy per ton of FCOJ and CPP per month by linear regression analysis

	<u>1978</u>	<u>FCOJ</u> <u>1979</u>	<u>1980</u>	<u>1978</u>	<u>CPP</u> <u>1979</u>	<u>1980</u>
Thermal energy, million kcal per ton per month	1.02	1.04	1.28	1.28	1.35	1.50
Average non-production related consumption per month million kcal	2,737.4	1,000.1	1,077.0	1,682.3	1,025.6	542.3
correlation coefficient (r)	0.96	0.99	0.97	0.97	0.98	0.99

the thermal energy consumption per ton of CPP was either equal to or higher than for FCOJ.

Performance of Tubular Evaporators

The tubular evaporators T1 and T2 were utilized extensively due to their higher evaporation capacities and the more number of effects (5) in comparison with the other evaporators. The performance of the evaporators in kcal per kg of water evaporated (KKWE) as a function of rate of water evaporated is shown in Fig. 3. Because of the few data points, the least square method was not employed and the curves in the figure were drawn to pass through as many points as possible. The energy consumption (KKWE) decreased rapidly as the rate of water evaporated increased and it reached a minimum value near the nominal design capacity. Due to insufficient supply of feed juice, it was not always possible to operate the evaporators at the design capacity and this resulted in lower than optimum evaporator performance.

The magnitudes of KKWE ranged between 125 and 158 for T1 and between 120 and 175 for T2. The high value of 175 KKWE for T2 was obtained when it was operated at about 71% of the design evaporation capacity, a rare and isolated phenomenon. The above magnitudes of KKWE are in the range of values (136–153) reported by Chen *et al.* (1979) for a five-effect, eight-stage evaporator with a capacity of 18,140 kg/h. The steam economy (kg of water evaporated/kg of steam) target of TASTE evaporators was estimated to be 0.85N, where N is the number of effects of the evaporator (Rebeck 1976; Chen *et al.* 1981). For a five-effect evaporator, this translates to 127 KKWE; a value achieved for T1 and T2 at their design evaporation capacities.

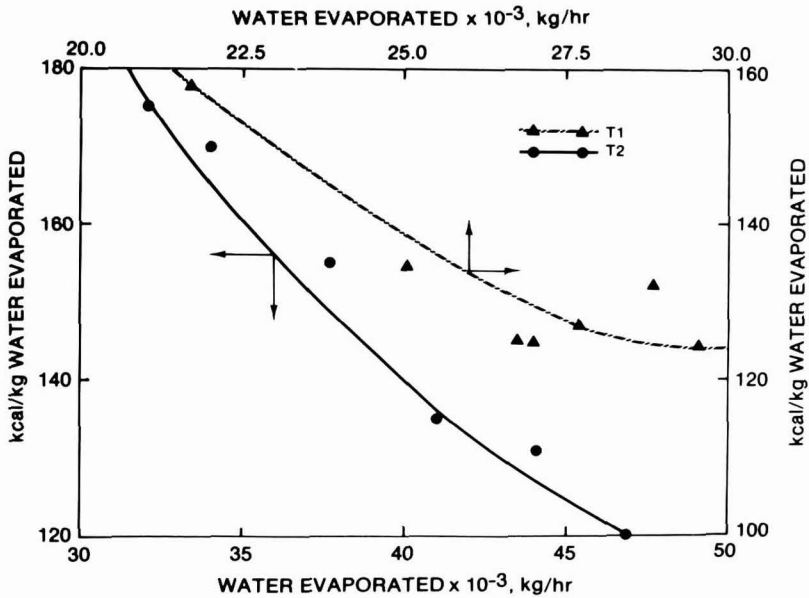


FIG. 3. PERFORMANCE OF TASTE EVAPORATORS T1 AND T2

Performance of Plate Evaporators

The energy consumption (KKWE) as a function of rate of water evaporated for P1 and P2 is shown in Fig. 4. Because of the few data points, statistical methods were not employed to draw the best line. Even though the two evaporators were of the same design and were operated in an identical manner, their performances were different. One can only conjecture that the difference in the performances was due to differences in the fabrication of the two evaporators.

As in the case of T1 and T2, the magnitude of KKWE for P1 and P2 decreased with increase in the evaporate rate. The magnitudes of KKWE were between 165 and 228. These values are higher than those for T1 and T2 due to having four effects instead of five effects. The low value of 165 KKWE achieved in the case of P2 corresponds to the steam economy of 0.82N and this was attained when P2 was operated near the design capacity. There do not appear to be published data on the performance of plate evaporators for comparison with the results of the present study.

An average value of KKWE for the entire plant and for each processing season was calculated assuming an average concentration of 10.2°Brix for the feed juice, 65°Brix for the concentrated juice, and assuming that all the thermal energy consumed in the FCOJ unit was used in the evaporators. The assumed concentrations of the feed and concentrated juices

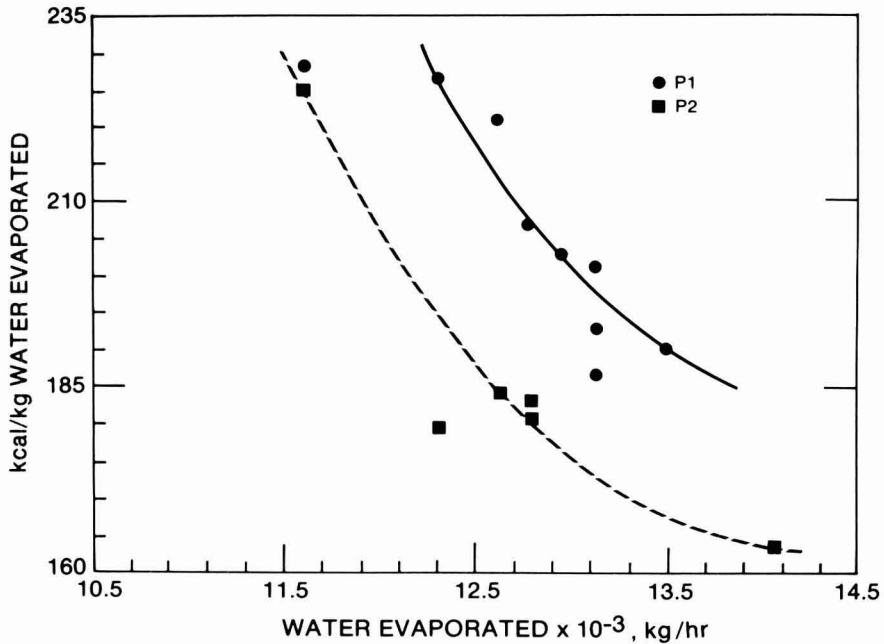


FIG. 4. PERFORMANCE OF PLATE EVAPORATORS P1 AND P2

were selected after examination of daily records of the plant. The average value of KKWE for each season reflects the operation of the evaporators at less than their design evaporation capacities as well as the cleaning of the heat transfer surfaces to prevent excessive fouling. The average values of KKWE for '78, '79 and '80 seasons were 277, 287, and 223, respectively.

Energy Conservation Options

The FCOJ Unit. In the concentration of orange juice, the major options for energy conservation are: (1) increasing the number of effects of the evaporators (Chen *et al.* 1979, 1981), (2) microprocessor based control of evaporators (Chen *et al.* 1981) and (3) mechanical vapor recompression (MVR). Increasing the number of effects of evaporators will reduce energy consumption and the gains to be obtained can be calculated readily assuming the performance of the TASTE evaporators to be given by 0.85N. As an example, Chen *et al.* (1979) found that increasing the number of effects of an evaporator from 4 to 5 resulted in an increase in the steam economy from 2.2–2.7 to 3.5–4.0 kg of water/kg of steam.

Chen *et al.* (1981) indicated that a 6.7% reduction in energy consumption was achieved by means of a microprocessor based control of an evaporator. The use of this relatively new technology may not be desirable in Brazil due to the paucity of the necessary support services. The addition of a MVR unit requires investment equal to that of a multiple effect evaporator system (Beesley and Rhinesmith 1980). It, thus, appears that increasing the number of effects of the TASTE evaporators is the desirable option.

The CPP Unit. The operating efficiency of the WHE must be improved by minimizing fouling of the heat transfer surfaces. The fouling of the external surfaces was due to the particulates in the drier exhaust air, while the internal surface fouling was due to the excess lime and organic matter in the liquor from the hydraulic presses. Studies are needed on treating the liquor from the presses such that the internal heat transfer surfaces of the WHE are not fouled within short periods of time.

Increasing the number of mechanical presses will reduce the water content of the pulp being fed to the drier. It will also result in more water being evaporated in the WHE. Because multiple effect evaporators are efficient in the removal of water, this measure could be a viable option.

Sugarcane Bagasse As An Energy Source

Sugarcane bagasse is a potential energy source due to the proximity of the FCOJ plant to the sugarcane growing areas of the State of São Paulo and several fuel alcohol plants. The fuel alcohol plants have an excess of 89 kg of bagasse per ton of sugarcane consumed in the plant after meeting the thermal energy requirements in the plants. Assuming that 2.42 kg of steam can be produced per kg of bagasse in the steam boilers and an efficiency of combustion of 63% in the furnaces of the CPP drier units, Gasparino Filho (1982) estimated that about 103,000 tons of bagasse is needed per year to replace fuel oil as the energy source. However, a well-planned and executed program for the excess bagasse from the alcohol plants would be necessary in order to supply without disruptions the large quantity of bagasse needed in the plant.

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REFERENCES

- BEESELEY, A. H. and RHINESMITH, R. D. 1980. Energy conservation by vapor compression evaporation. *Chem. Eng. Progress* 76(8), 37-41.
- BRYAN, W. L. 1977. Recovery of waste heat from drying citrus by-products. *Am. Inst. Chem. Engrs. Symp. Series* 73(163), 25-32.
- CARROAD, P. A., SINGH, R. P., CHHINNAN, M. S., JACOB, N. L. and ROSE, W. W. 1980. Energy use quantification in the canning of clingstone peaches. *J. Food Sci.* 45, 723-725.
- CHEN, C. S. 1982. Citrus evaporator technology. *Trans. ASAE* 25, 1457-1463.
- CHEN, C. S., CARTER, R. D. and BUSLIG, B. S. 1979. Energy requirements for the TASTE citrus juice evaporator. In *Energy Use Features*, Vol. 4, p. 1841, Pergamon Press, New York.
- CHEN, C. S., CARTER, R. D., DEIMLING, C. J. and MOISA, E. S. 1981. Micro-computer control of commercial citrus TASTE evaporators. *Trans. 1981 Citrus Engineering Conference*, p. 58-80.
- CHHINNAN, M. S., SINGH, R. P., PEDERSEN, L. D., CARDOSO, P. A., ROSE, W. W. and JACOB, N. L. 1980. Analysis of energy utilization in spinach processing. *Trans. ASAE* 23, 503-507.
- CLELAND, A. C., EARLE, M. D. and BOAG, I. F. 1981. Application of multiple linear regression to analysis of data from factory energy surveys. *J. Food Technol.* 16, 481-92.
- COOK, R. W. 1971. Evaporation in the Florida citrus industry. *Proc. 3rd International Congress Food Science & Technology*, p. 452, Institute of Food Technologists, Chicago.
- GASPARINO FILHO, J. 1982. Estudo do consumo e conservação de energia em uma unidade industrial de suco de laranja concentrado congelado, (A study of energy consumption and conservation in a frozen concentrated orange juice plant), M. S. Thesis, Escola Politécnica, Univ. of São Paulo, Brazil.
- GOEL, V. K., JORDAN, W. K. and RAO, M. A. 1979. Energy use profile in concentrated and powdered milk manufacture. *J. Dairy Sci.* 62, 876-881.
- OKADA, M., RAO, M. A., LIMA, J. E. and TORLONI, M. Energy consumption and the potential for conservation in a spray-dried coffee plant. *J. Food Sci.* 45, 685-688.
- REBECK, H. 1976. Economics in evaporation. *Proc. 16th Annual Short Course for the Food Industry*, University of Florida, Gainesville, p. 43.
- SINGH, R. P., CARROAD, P. A., CHHINNAN, M. S., ROSE, W. W. and JACOB, N. L. 1980. Energy accounting in canning tomato products. *J. Food Sci.* 45, 735-739.
- STROHL, R. J. 1981/82. The explosive growth of the Brazilian FCOJ industry. *Agribusiness Worldwide* 3(1), 8-17.
- VELDHUIS, M. K. 1971. Orange and tangerine juices. In *Fruit and Vegetable Juice Processing Technology*, 2nd ed., p. 31, AVI Publishing Company, Westport, CT.

MULTIPLE SIEVE SIFTER PERFORMANCE USING VARIOUS COMBINATIONS OF FEED RATES, CIRCLES AND SPEEDS¹

John Wingfield and Alonso Ferrer

Department of Grain Science and Industry
Kansas State University
Manhattan, Kansas

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ABSTRACT

Wheat was ground on a rollermill then sifted into several size classifications to determine how certain sifting characteristics changed when the material was subjected to changes in feed rate, sifter circle or throw and sifter speed.

The travel speed of the stocks over the sieves decreased with a decrease in average particle size. Changes in the rate of feed to the sieves had no effect on the stock travel time. Travel speed was increased for all stocks when the linear cloth speed of the sieve was increased.

Sifter efficiency, as defined by the percent of undersize material removed by each sieve in a series of sieves having the same cloth aperture, compared to the amount of undersize material going to the first sieve of the series was influenced by changes in feed rates and in sifter dynamics.

Particle size analysis of individual sieve throughs showed that when the stocks were sifted on a series of sieves having the same aperture opening size, the finest material was sifted out on the first sieve with subsequent sieve throughs becoming progressively coarser.

INTRODUCTION

Most cereal grain milling processes involve sifting of the dry materials into several size ranges from coarse scalps to fine flours. These separations are most often carried out by using rotary motion sifters that utilize a stack of square or rectangular sieves. The sieves in these stacks

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are arranged in sets, each set having a specific cloth aperture opening and making a specific size separation (Fig. 1). The cloth may be either perforated or woven and may be made from metals, silk or synthetic fibers. Commercial grain millers are interested in obtaining maximum sifter capacity while at the same time maintaining uniformity of the size separations.

Previous studies in dry sifting have been restricted to tests using single

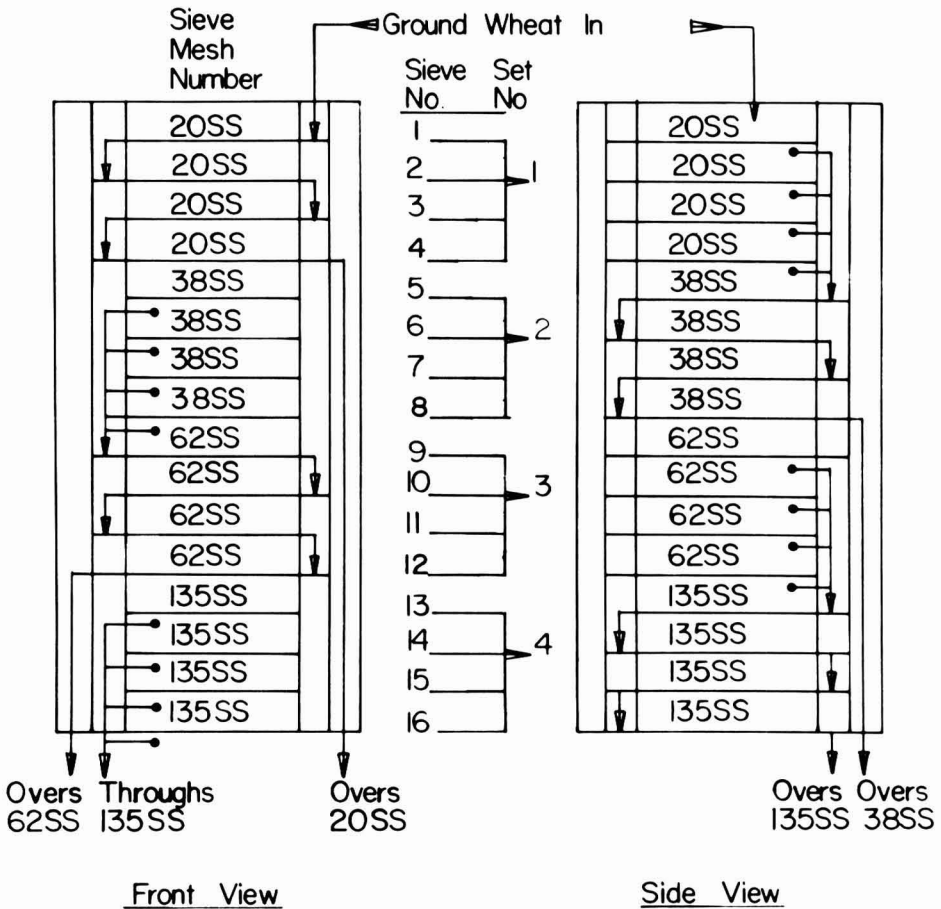


FIG. 1. COMMERCIAL FLOW DIAGRAM SHOWING HOW SEPARATE SIEVES ARE STACKED TO FORM A MULTIPLE SEPARATION FLOW.

Sieve sets are groups of two or more sieves having the same aperture opening as indicated by the sieve mesh number. The above flow has 16 sieves arranged in 4 sets producing 5 separations.

sieve, batch feed methods and do not necessarily reflect what will happen in multiple sieve, continuous feed conditions. Commercial observations, while of value, do not attempt to scientifically document the results. This study has used commercial sized equipment, using the same flow techniques normally found in a mill, so there is no scale-up error involved. The data reported here should be of direct use by both the sifter designer and the mill operator.

LITERATURE REVIEW

The factors affecting sifter capacity have been enumerated by several authors based on experience and observation. They include:

1. Physical nature of the feed stocks
2. Feed rate to sieves
3. Stock thickness on the sieves
4. Types of sifting media used
5. Types of sifter motions
6. Design of the sieves and sifters

(Lockwood 1949, Kuprits 1967).

Stock stratification has also been discussed as a factor affecting sifter capacity (Povey 1959; Scott 1961; Jones 1964; Stucheli 1967). Stratification allows the finer material to sink through the coarser, often lighter, material and thereby facilitates its early removal through the sieve mesh. High loading rates will promote the thick beds of stock needed to obtain this stratification phenomena.

Bed thickness, in turn, must be known by the sifter designer so that sufficient clearance in all the stock channels is provided; otherwise, the restricted flow will result in lowered efficiencies and eventual back-up or stoppage of flow (Sugden 1958; Aizlewood 1967; Hopf 1970; Penndorf 1951). Stratification also accounts for the fact that the finest of the material to be removed will be removed in the first seconds of a timed static sieve test (Whitby 1954). Whitby also found that fines removal efficiencies will vary with the amount of fines available. Thus, sieve efficiency drops along the length of sieve due to a lack of fines to be removed.

The effect of sieve motion or sieve dynamics has been a subject of discussion as this will affect the gravitational forces on this sifted stock. It has been suggested that these forces also affect the speed of stock travel (Lockwood 1960; Speight 1960; Lagarde 1979). It has long been observed that different mill stocks respond differently to changes in sifter circle and speed (Jurkow 1947; Rowan 1949; Hebebrand 1957; Sanderson 1957; Zerull 1966).

MATERIALS AND METHODS

A floor mounted sifter was used for testing (Fig. 2). This sifter is of the full circle, gyratory, reed mount type using sieve-on-sieve stacked flow. The sifter circle (sometimes referred to in the literature as “throw”) was adjustable and required resetting of the counter weights to maintain sifter equilibrium. Sifter speed was adjustable by means of an adjustable pitch motor sheave. Commercial size sieves were used, (Fig. 3). The overall

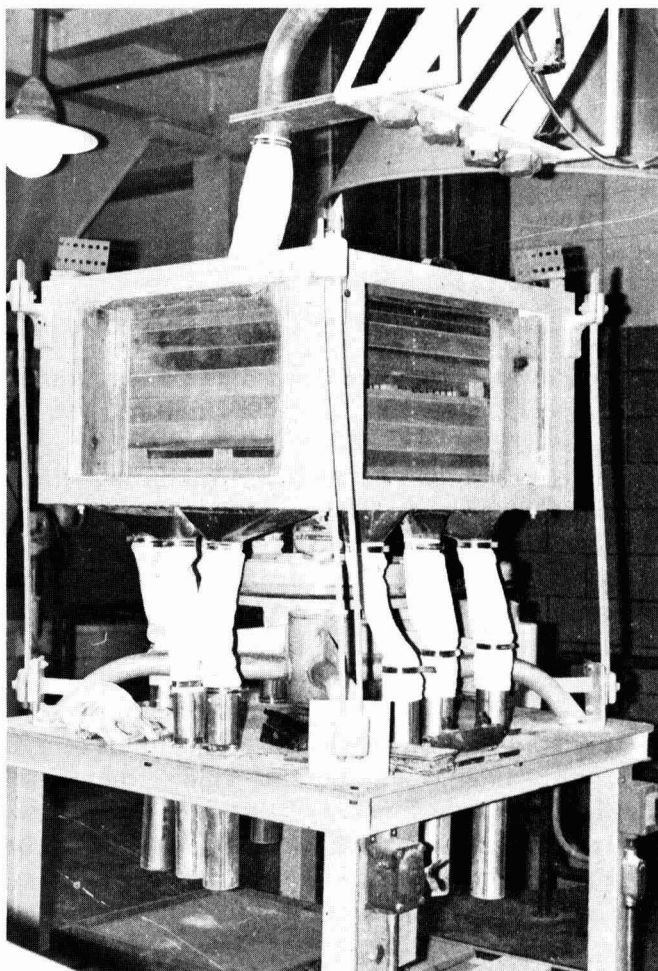


FIG. 2. FLOOR MOUNTED SIFTER USED FOR TESTS. This sifter is of the full circle, gyratory, reed mounted type. The speed of rotation and diameter of circle are adjustable.

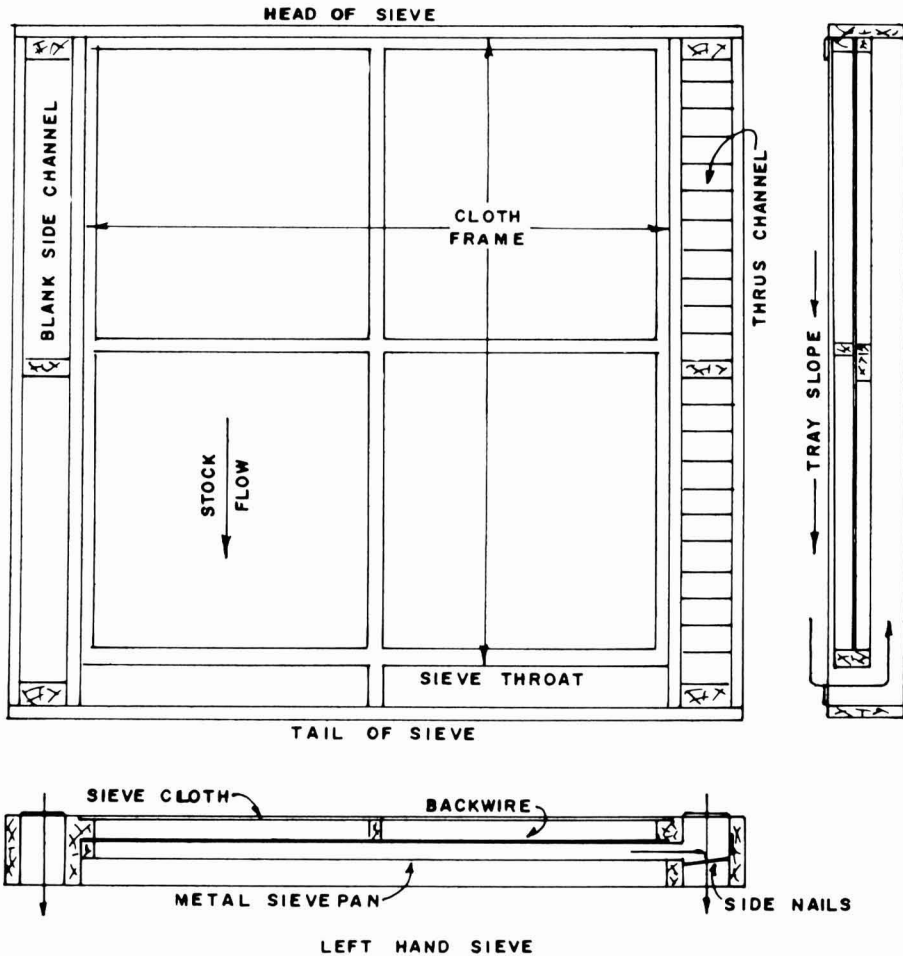


FIG. 3. SIEVE CONSTRUCTION DETAIL.

Stock enters at head of sieve. Overs discharge through the sieve throat to next sieve. Fines leave sifter through side channels. Sieve cloth covers area denoted as cloth frame. Backwire retains the rubber ball cleaners. Sieve pan carries fine material to side discharge. Side nails prevent loss of sieve pan cleaners. Hand of sieve denotes which side of the sieve is left open for throughs discharge—can be left side, right side or both sides (no hand).

size was $24 \frac{11}{16}$ in. square with an unobstructed sifting cloth area of 2.48 sq ft.

A 9 in. wide, belt type, gravimetric feeder was used to regulate the feed rates of stock to the sifter (Fig. 4).

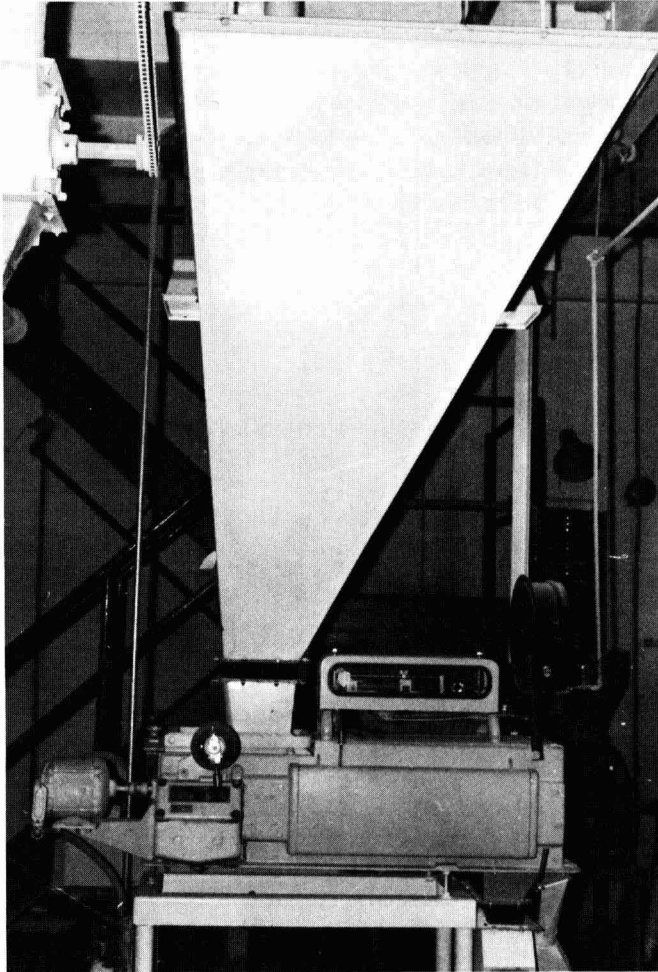


FIG. 4. GRAVIMETRIC BELT FEEDER WITH STOCK HOPPER USED TO REGULATE FEED RATES TO SIFTER.

The material used as the primary feed stock was Kansas Hard Red Winter wheat, cleaning and tempered for 24 h to 16.0% moisture. The wheat was ground on a rollermill having 9 in. diameter rolls, with 12 corrugations per inch, running at a $2\frac{1}{2}$:1 differential. Roll gap was set to obtain a 36% extraction (throughs) on a table top test sifter using 20 mesh metal clothing. This setup was chosen to simulate the conditions of the first breaking operation in a wheat flour mill. It is expected, however, that other grains would react in a similar manner since their milling processes are quite similar.

The testing sifter used was similar to commercial sifters in most aspects but did not have sufficient height to accommodate all of the 16 sieves needed for a complete, one pass flow as shown in Fig. 1. A simulation of this flow was therefore necessary using four sieves, comprising one set, at a time (Fig. 5). The throughs of each sieve set were weighed then remixed to serve as the feed stock to the next sieve set of four sieves.

To maintain the full flow simulation, the feed rate to each sieve set was maintained at the rate that set would have received had the flow been continuous from set to set. The feed rate schedules for the ten tests made are shown in Table 1. The cloth mesh number and aperture size in micrometers (10^{-6} meters) of each sieve set is shown in Table 2.

Rubber ball cleaners were used to prevent blinding of the cloth apertures by lodged particles of stock. The number of balls used varied with the aperture size of the cloth and is indicated in Table 2.

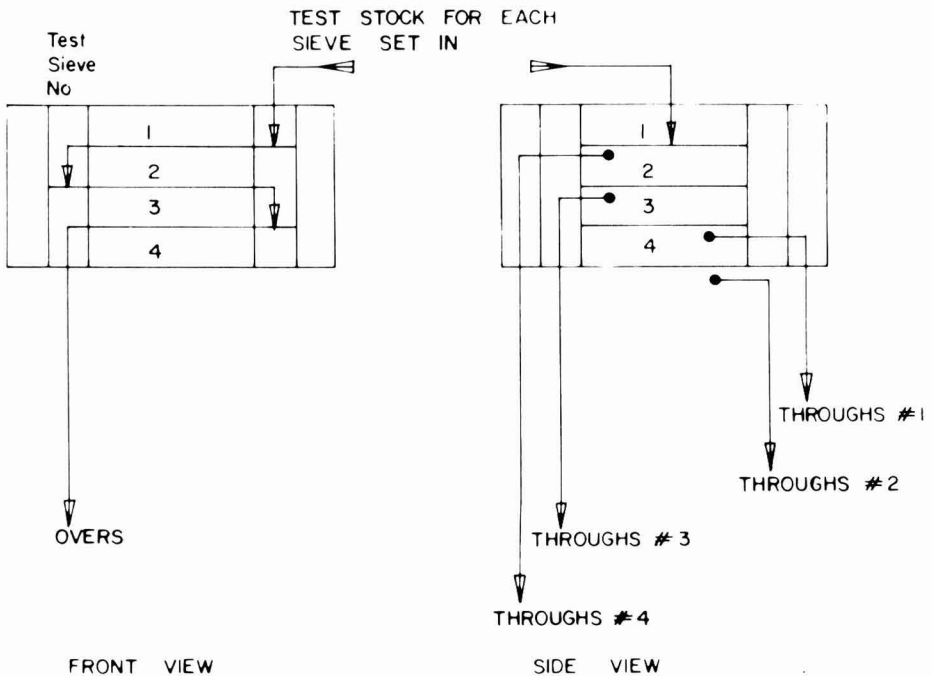


FIG. 5. TEST SIFTER FLOW DIAGRAM.

The flow shown in Fig. 1 was simulated by testing each sieve set of 4 sieves separately. The throughs of each sieve were collected separately for testing. In commercial practice, the throughs of each set would normally be combined inside the sifter and discharged as one product.

Table 1. Conditions used in each trial

Trial No.	Circle Dia. (in.)	RPM ¹	L.C.S. ² (In./sec.)	Feed Rate (lb/min.)			
				20 SS	38 SS	62 SS	135 SS
1	4	185	38.7	19.9	11.4	7.6	4.1
2	4	185	38.7	28.2	16.6	11.3	6.2
3	4	185	38.7	38.0	23.9	15.6	7.8
4	4	185	38.7	46.9	31.2	20.0	9.3
5	3	185	29.1	47.1	25.0	15.6	7.8
6	3.5	210	38.5	47.0	25.0	16.6	7.8
7	3	210	33.0	47.1	24.7	15.6	7.8
8	2.5	210	27.5	46.7	24.9	15.5	7.8
9	3	235	36.9	46.1	24.5	16.3	8.2
10	2.5	260	34.0	46.8	23.8	15.5	7.8

¹Rotations per minute

²Linear cloth speed = $\text{Pi} \times \text{Circle Diameter} \times \frac{\text{RPM}}{60}$

Table 2. Sieve data: sieve clothing—tyler woven stainless steel

Sieve set number	Number sieves per set	Meshes per inch	Aperture opening (microns)	Open area (%)	Number of Ball cleaners used per sieve
1	4	20	1041	67.2	20
2	4	38	503	56.7	32
3	4	62	308	56.6	40
4	4	135	130	47.4	48

The throughs of each sieve were collected separately so they could be individually examined. In normal commercial practice, all of the throughs from one sieve set (and there might be more sieves than four in a set) are collected together in one, or perhaps two, outlets from the sifter. This testing procedure does not detract from its simulation of commercial experience.

The method for determining the "travel speed of stock" was to measure the elapsed time from when the feed stock hit the first sieve in an empty sifter to the time a scalp discharge from the fourth sieve was first observed. The total length of all four sieves divided by the elapsed time resulted in the stock travel speed in inches/second.

"Sieving efficiency" was established by comparing the amount of fine material removed in a test to the amount of fine material available in the feed stock. The percent of fines removed divided by the percent of fines available $\times 100$ equals the "sieving efficiency" in percent. This method of reporting was chosen because it shows the contribution of each sieve in a series to the total efficiency of that series or set. The mill designer must use the number of sieves that will result in optimum use of sifter volume. Even though an individual sieve may be removing nearly all of the fines from the feed going to that sieve, it is the efficiency of that sieve as related to the material going to the sieve series that decides whether that sieve should remain or whether additional sieves are necessary.

Particle size distribution curves were developed by sifting 300 gr of each material on a testing sifter for two min. The sifter clothing used is indicated on the various graphs presented under Results. The method used is described by Farrell *et al.* (1965).

A complete review of the statistical analyses used in these tests is available in Ferrar (1982).

RESULTS AND DISCUSSION

Stock Travel Speed

The finer materials tested had slower rates of travel over their respective sieves than did the coarser materials over their sieves (Fig. 6).

Increasing feed rates to the sieves did not materially affect stock travel time for any of the four products tested (Fig. 6). This explains the beneficial effect of high feed rates in building up stock depths on the sieves and thus improving stratification. By knowing these stock travel times, in addition to stock densities and sieve widths, the sifter designer can make the necessary calculations for determining the proper channel depth between sieves, between sieve cover and pan and in the throats and side channels to allow free movement of given stock quantities.

Lineal Cloth Speed describes the amount of circular movement a point on the sieve will transcribe when in motion. It is calculated by the formula $\text{Pi} \times \text{sifter circle diameter (in.)} \times \text{revolutions per minute} \div 60 = \text{L.C.S. (in./s)}$. Increasing the L.C.S. by either increasing the circle diameter (Fig. 7), increasing the sifter speed (Fig. 8), or increasing the circle while

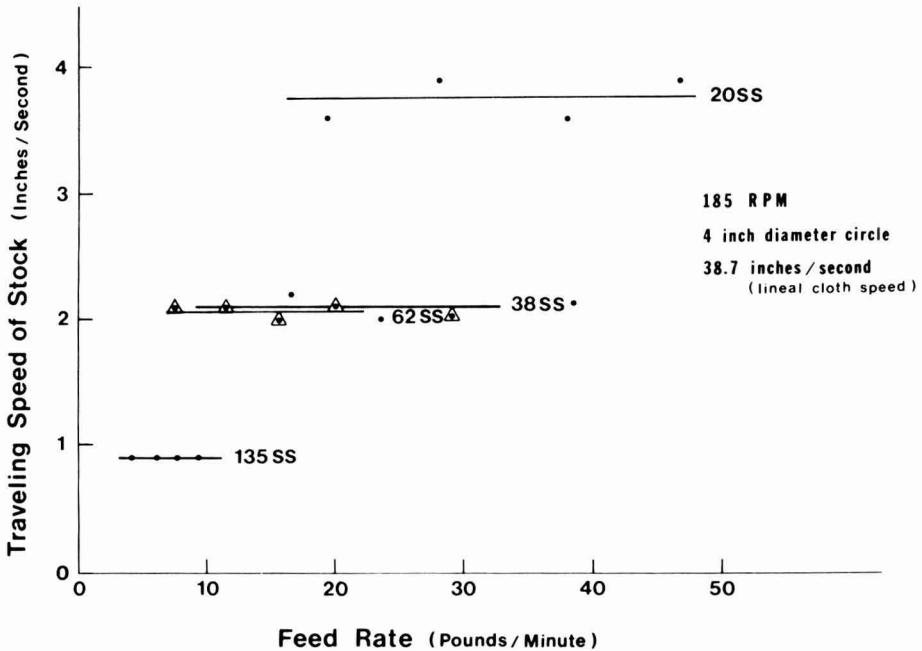


FIG. 6. TRAVELING SPEED OF STOCK ON SIEVES.
 Feed rates varies. Sifter speed and sifter circle held constant. Lineal cloth speed equals sifter circle circumference in inches times sifter speed in RPM.

decreasing sifter speed (Fig. 9), resulted in lineal increases in stock travel time. Results indicated that equivalent changes in L.C.S. caused by increasing the circle brought about greater increases in stock travel time than did increased rpm. The stock travel times of the finer stocks increased more rapidly than the stock travel time of the coarser stocks when L.C.S. was increased by any of the methods tried.

Sieving Efficiency

The effect on fines removal when feed rates were increased is shown in Fig. 10. The first sieve in all of the tests removed from 60% to 90% of the available fines. In many cases, a reduction in fines removal efficiency on the first sieve caused by increased loading resulted in more than compensating increased fines removal efficiency on the second sieve. Clearly, sieving efficiency improves with loading to a point then decreases after

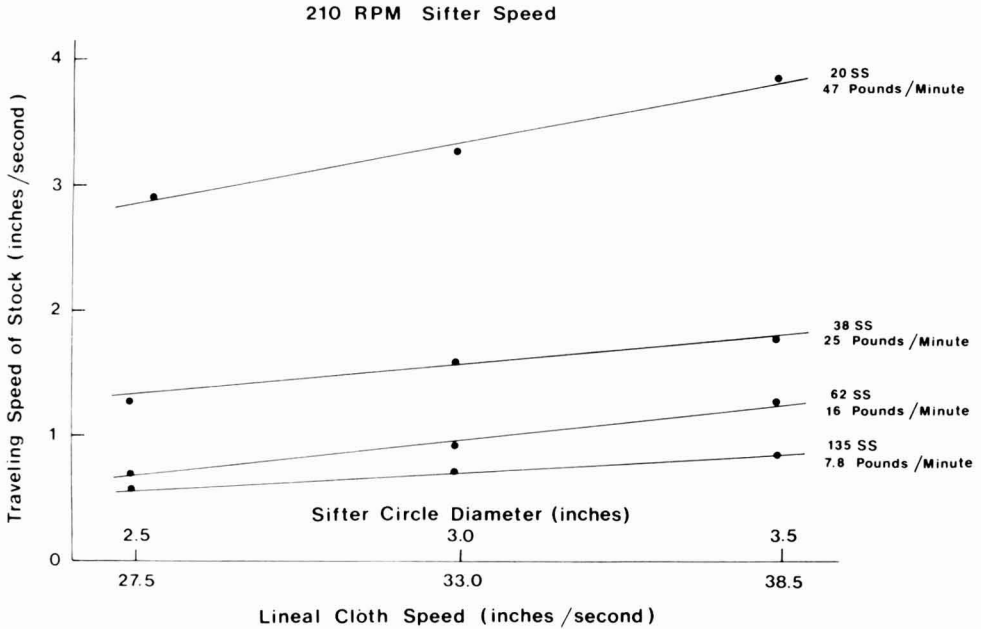


FIG. 7. TRAVELING SPEED OF STOCK ON SIEVES.

Sifter circle diameter was varied with sifter speed held constant. Feed rates for each material tested was also held constant at rates expected had flow been continuous as in Fig. 1.

this optimum loading has been reached. Optimum loads were not obtained in all cases, but the optimum load rate decreases as the material size and cloth aperture opening becomes smaller. In the commercial applications of the principle, the feed rate of the material to the top sieve in the sieve stack as well as the amount of fines removed by each sieve set will dictate the loading of all subsequent sieves and sieve sets. This means that optimum load conditions will probably not exist throughout the sifter. These results also point out the rapidly diminishing fines removal percentages obtained by the latter sieves. The degree of accuracy of separation desired is the determining factor in selecting the number of sieves to use for a given separation.

Using the maximum feed rates and a 3 in. circle, the effects of increased sifter speeds are shown in Fig. 11. 210 rpm produced optimum results on the 20 S.S. and 38 S.S. sieve material. Increasing speeds decreased the sieve efficiency for the 62 S.S. material and increased the efficiency on the finer 135 S.S. material.

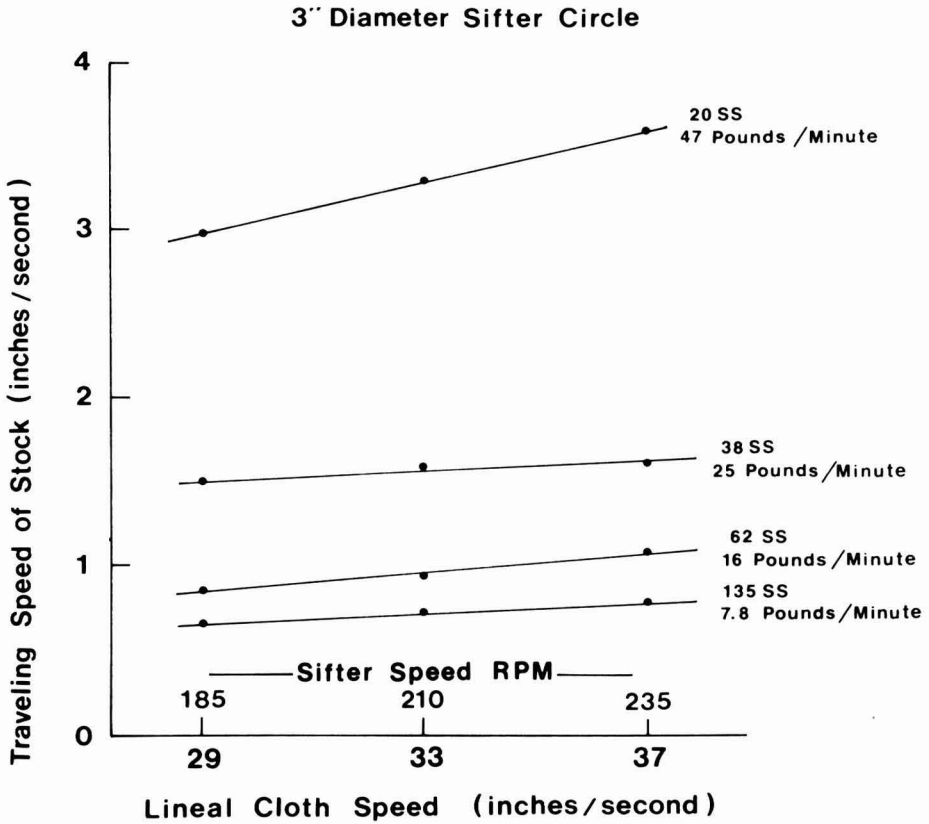


FIG. 8. TRAVELING SPEED OF STOCK ON SIEVES.
Sifter speed was varied with sifter circle and feed rates held constant.

At the same maximum feed rates as above and using a sifter speed of 210 rpm, the effects of increasing sifter circle diameter are shown in Fig. 12. An optimum efficiency was obtained on the 38 S.S. material with a 3 in. circle. Increasing the circle beyond 2½ in. had a negative effect on the 20 S.S. and 62 S.S. material. The increased circle diameters improved first sieve efficiencies on the 135 S.S. material, but the net effect of the four sieve set remained unchanged. Fig. 13 gives the sieving efficiencies when lineal cloth speed was increased by increasing the circle while decreasing the speed.

The sieve efficiency tests point out the complexities of sifter dynamics. The results suggest that high speed, small circle sifters may prove to be more efficient for the type of material tested than the more conventional low speed sifters, and that, when possible, fine materials should be

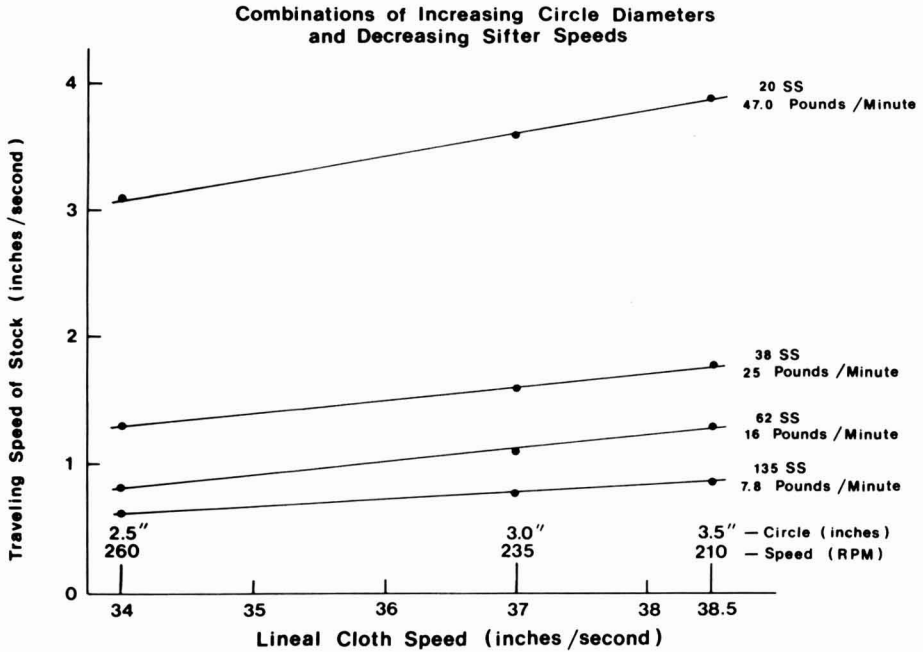


FIG. 9. TRAVELING SPEED OF STOCK ON SIEVES.
Lineal cloth speed was varied by increasing sifter circle while decreasing sifter speed. Feed rates were held constant.

4 inch Circle and 185 RPM Constant = 38.7 inches per second L.C.S.

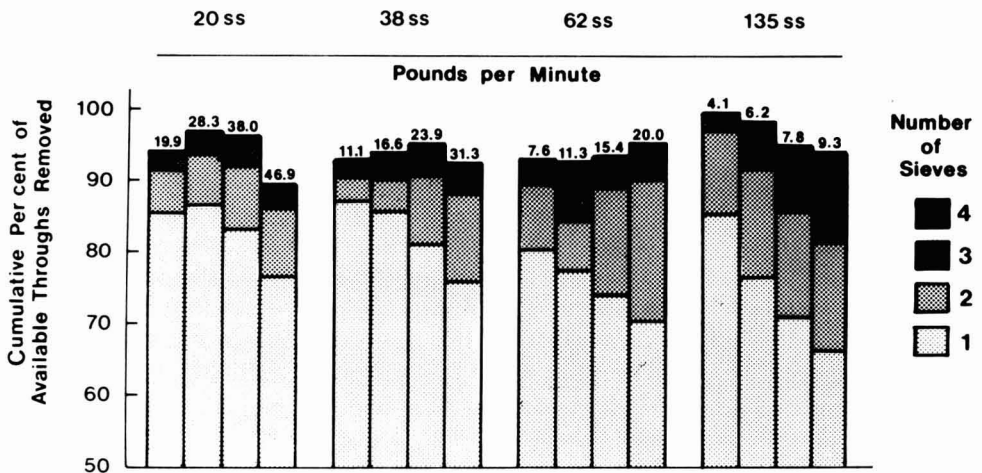


FIG. 10. SIEVING EFFICIENCY.
Feed rate varied. Sifter circle and speed held constant.

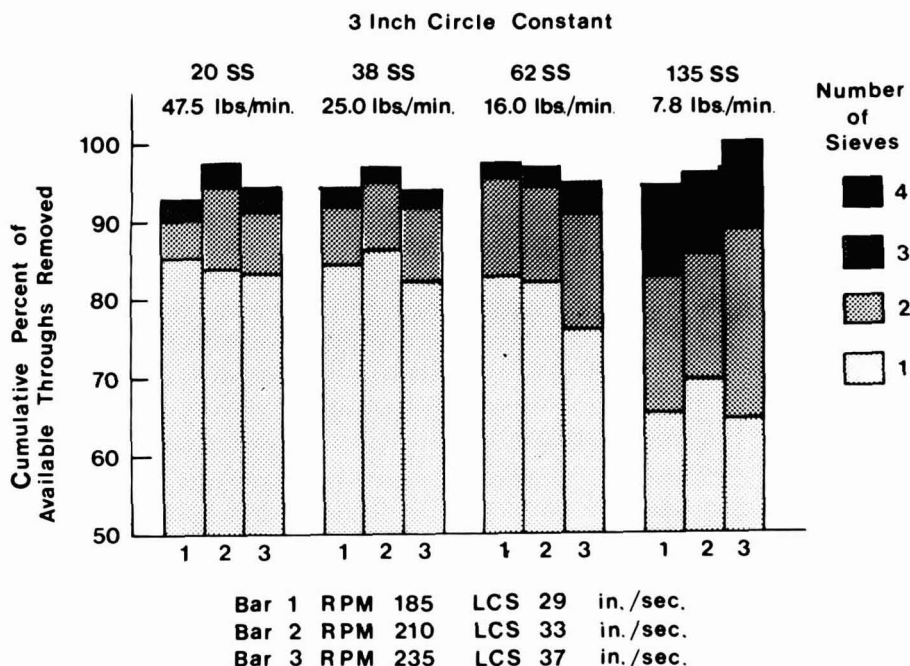


FIG. 11. SIEVING EFFICIENCY.

Sifter speed varied. Feed rate for each product held constant to simulate continuous flow as shown in Fig. 1. Sifter circle held constant.

handled on separate sifters so that optimum dynamics can be used on both the coarse and fine stocks.

Particle Size Distribution

Figures 14, 15, 16 and 17 show the changes in particle size of the throughs from sieve to sieve for each of the stocks tested. The removal of finer material on the first sieve with progressive increases in particle size for subsequent sieves is self-evident. These results show graphically what has long been observed and practiced in the milling industry. Separation of the fine and coarse flours is often advantageous in soft wheat milling.

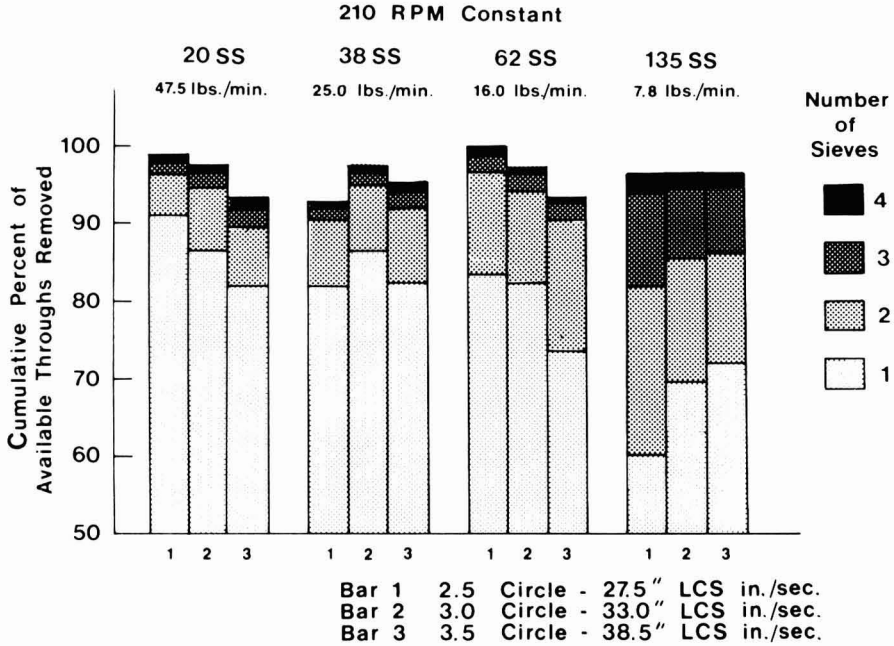


FIG. 12. SIEVING EFFICIENCY.
Sifter cycle varied. Feed rates and sifter speed held constant.

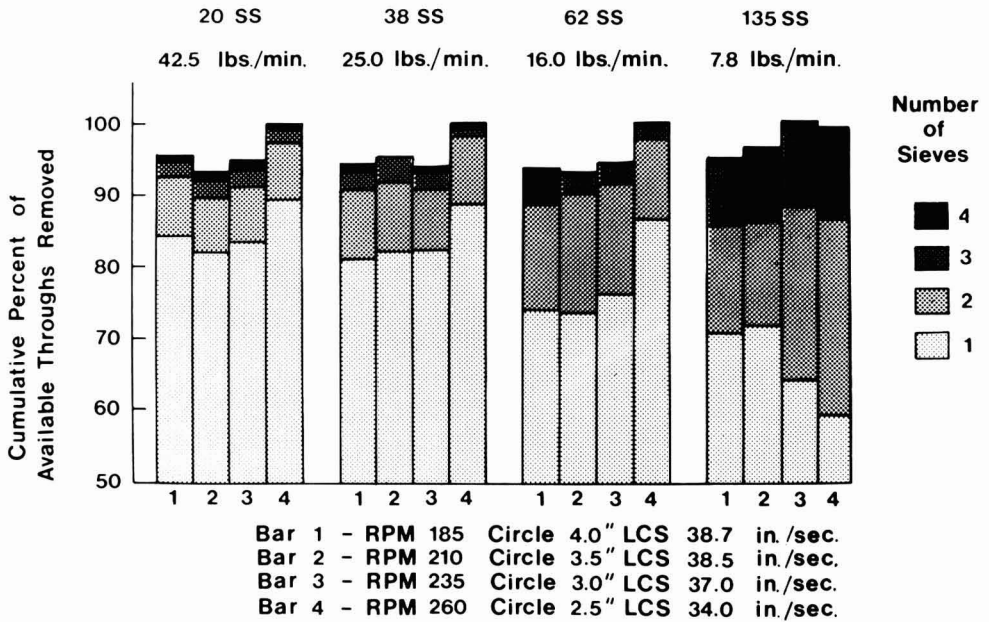


FIG. 13. SIEVING EFFICIENCY.
Sifter linear cloth speed varied by increasing sifter circle while decreasing sifter speed. Feed rates were held constant.

PARTICLE SIZE DISTRIBUTION
(20 SS sieve covering)

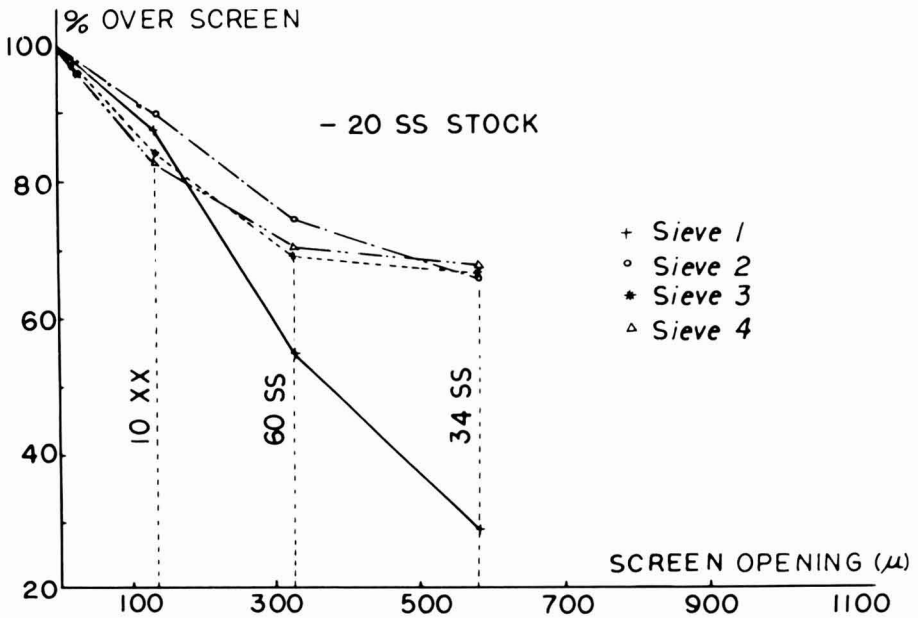
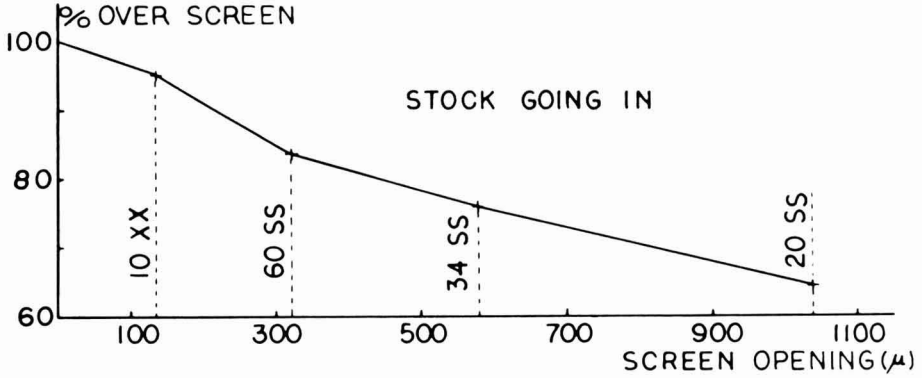


FIG. 14. PARTICLE SIZE DISTRIBUTION.
20 mesh/inch stainless steel cloth set. Upper graph—distribution of incoming stock. Lower graph—distribution of fines removed by each sieve. Dotted vertical lines indicate sifter cloth mesh sizes and corresponding aperture sizes used in table top test sifter.

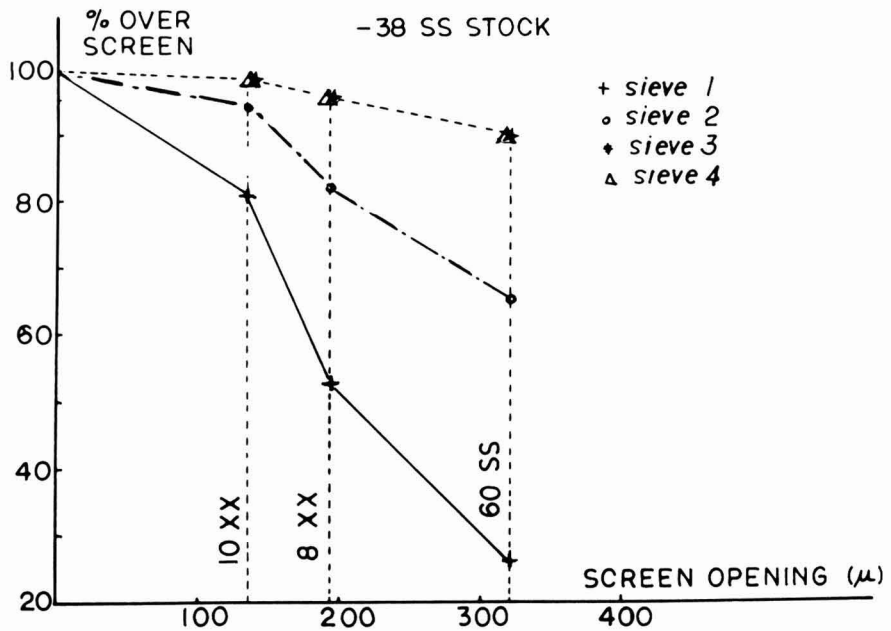
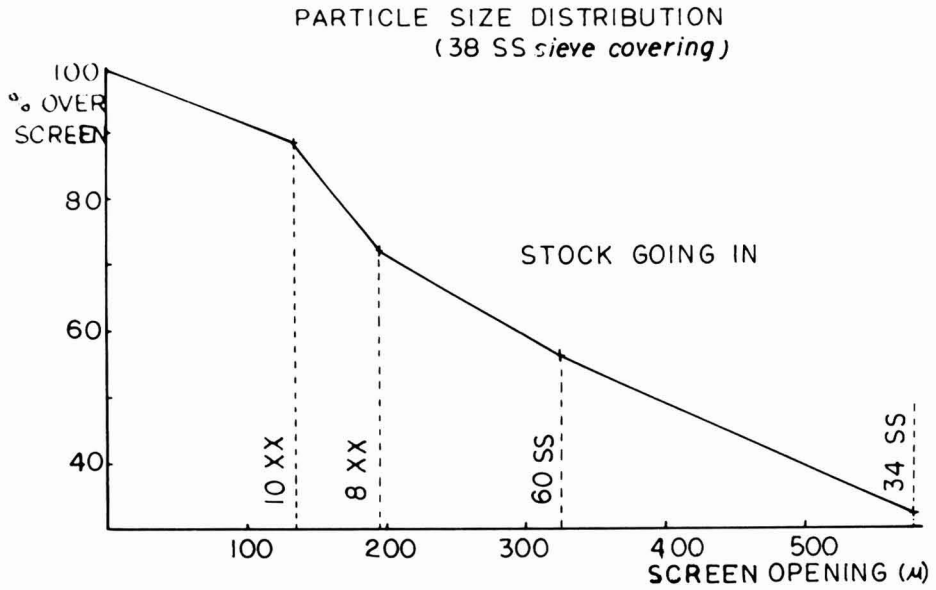


FIG. 15. PARTICLE SIZE DISTRIBUTION.
38 Mesh/inch stainless steel cloth set.

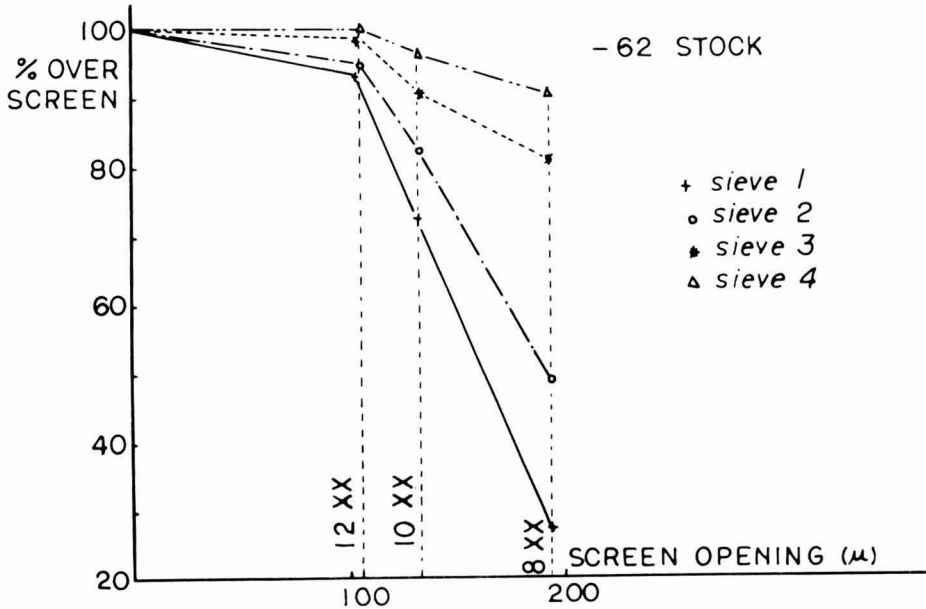
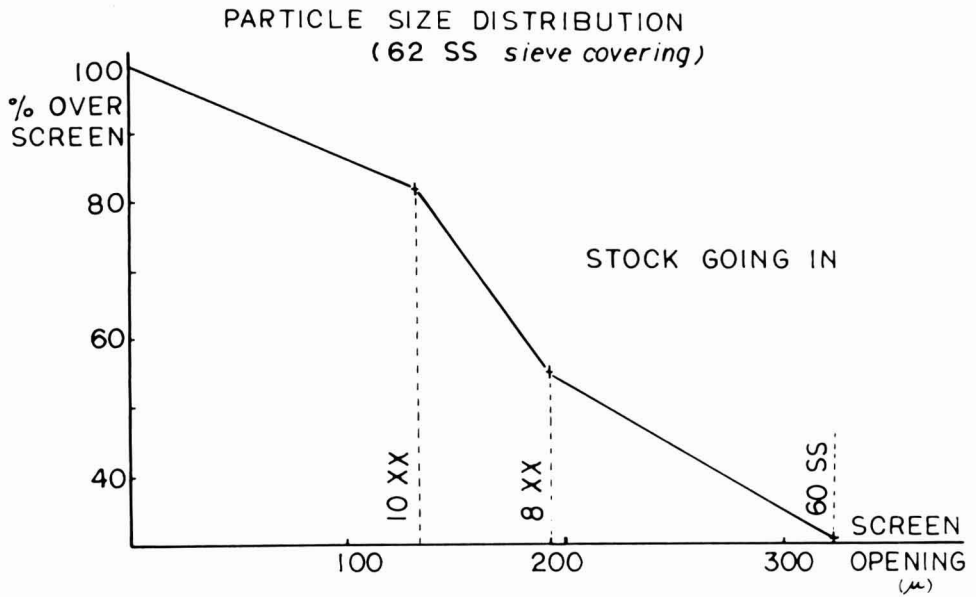


FIG. 16. PARTICLE SIZE DISTRIBUTION.
62 Mesh/inch stainless steel cloth set.

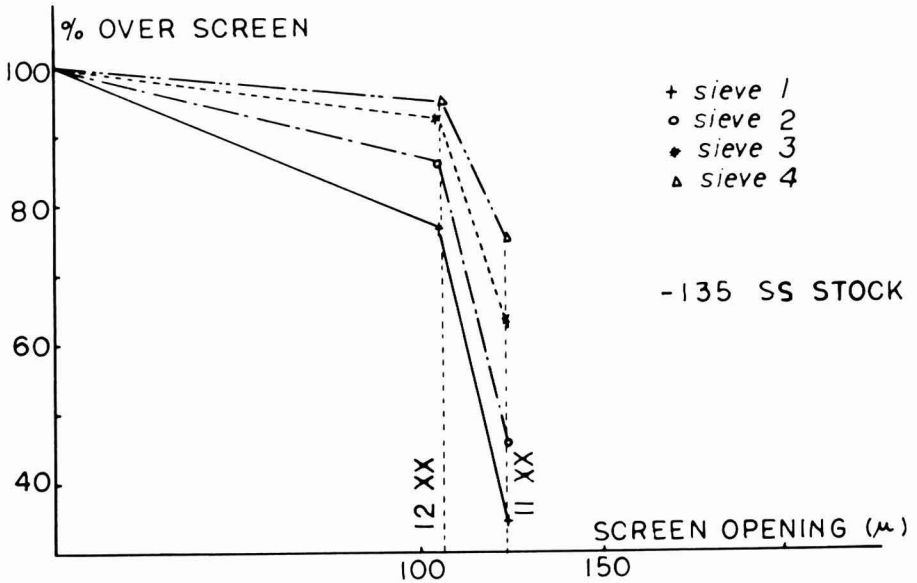
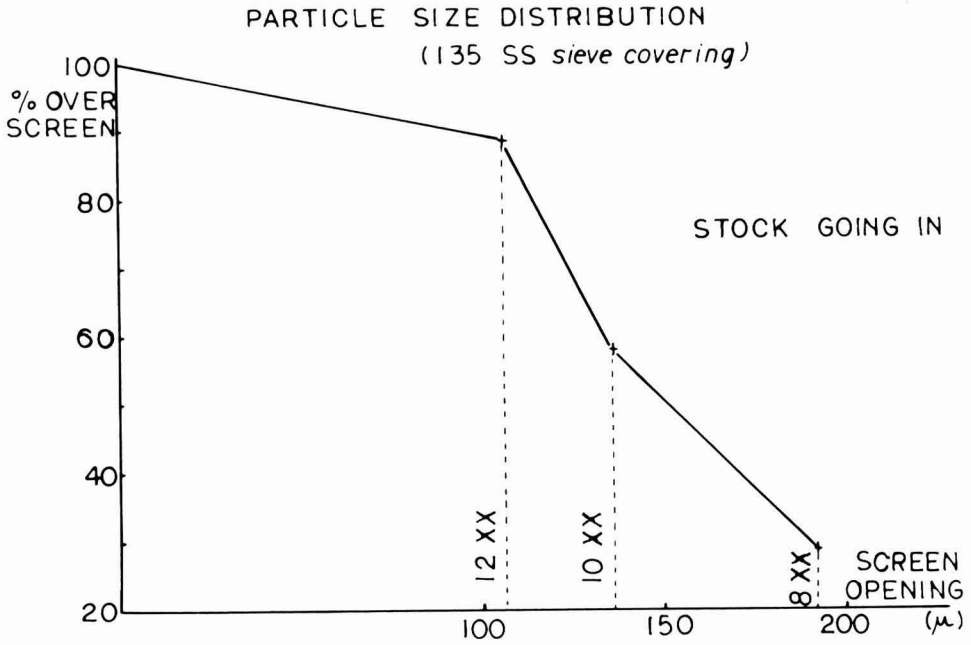


FIG. 17. PARTICLE SIZE DISTRIBUTION.
135 Mesh/inch stainless steel cloth set.

REFERENCES

- AIZLEWOOD, P. G. 1967. Technical Trends and Developments in Flour Milling. *Milling. CXLVIII*, (6), 92-93.
- HEBEBRAND, H. 1957. Sifter Drives. *American Miller Proc.* 85, (8), 28-30.
- HOPF, L. 1970. Comparison of Sieve Surface on Normal and Square Sifters. *Mullerei.* 23, (3), 58-65.
- JONES, C. R. 1964. Recent European Developments in Flour Milling Technology. *Milling. CXXXII*, (13), 324-327.
- JURKOW, J. 1947. Practical Experience with High Speed Sifters. *A.O.M. Tech. Bull.* 1601-1603.
- KUPPITS, YA. N. 1967. Technology of Grain Processing and Provender Milling. pp. 27-72. S. Monsen Binding: Jerusalem, Israel. (Available from U.S. Department of Commerce, Springfield, VA)
- LAGARDE, A. 1979. The Evolution of Sifting Technology. *Bull. de l'Ecole de Meunerie.* 290, 72-82.
- LOCKWOOD, J. F. 1949. *Flour Milling*, 4th Ed., 288-309. Henry Simon Limited. Stockport, England.
- PENNDORF, F. 1961. New Methods of Plansifter Construction. *Die Mühle.* 41, 537-540.
- POVEY, D. W. 1959. Latest Machinery Design. *Milling. CXXXIII*, (16), 332-337.
- ROWAN, W. D. 1950. High Speed versus Low Speed Sifters. *A.O.M. Tech. Bull.* 1800.
- SANDERSON, H. 1957. Bolting Efficiency. *Amer. Miller Proc.* 85, (8), 27-28.
- SCOTT, J. H. 1961. Flour Milling Trends. *Milling CXXXVI*, (21), 62-65.
- SPEIGHT, J. 1960. Rotary or Reciprocating Motion? *Milling CXXXV*, (21), 564-567.
- STUCHELLI, A. 1967. Some sifting Problems and Solutions. *Amer. Miller Proc.* 95, (7), 8-10, 31.
- SUGDEN, G. H. 1958. Purifiers and Sifters. *Milling CXXXI*, (12), 70-72.
- WHITBY, K. T. 1954. The Mechanics of Fine Sieving. Doctoral Dissertation. University of Minnesota.

ENERGY USE IN TOMATO PASTE EVAPORATION

T. R. RUMSEY¹, T. T. CONANT², T. FORTIS¹,
E.P. SCOTT³, L. D. PEDERSEN⁴, and W. W. ROSE⁴

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ABSTRACT

The energy consumption of several tomato paste evaporators was monitored to provide baseline data for equipment selection or modification. Daily average performance data are given for single, double and triple effect evaporators. Average daily steam economies for the single effect evaporator ranged from 0.74 to 1.02 and averaged 0.84 compared to a theoretical average of 0.95. Two similar double effect evaporators had average daily steam economies which ranged from 0.79 to 2.03. The average daily steam economy measured was 1.45 while the theoretical average was 1.91. The average daily steam economies for the three triple effect evaporators ranged from 1.66 to 3.06.

INTRODUCTION

Evaporation is an energy intensive unit operation in the production of tomato paste. Schwartzberg (1977) estimated that the production of tomato paste used 1.99×10^{12} kJ/year; nearly 3.2% of the total energy used for liquid food concentration. One study (Singh *et al.* 1980) showed that evaporation accounted for over 70% of the total energy consumed in a particular tomato paste processing operation.

A typical double effect evaporator can process 25 tons of tomatoes per hour using 12,100 kg/h of steam. A typical cost for steam in 1983 is \$15/1000 kg (Pedersen 1983). If the processing season is 2000 h in length, then the total steam cost in this case is \$363,000 per season.

The benefits of equipment modifications to increase steam economy

¹Department of Agricultural Engineering, University of California, Davis

²MCR Geothermal Corp., Lakeport, California

³Department of Agricultural Engineering, Michigan State University

⁴National Food Processors Association, Berkeley, California

have been recognized by evaporator manufacturers and process plant owners. Attiyate (1978) describes one evaporator manufacturer's conversion of a double effect tomato paste evaporator to a triple effect evaporator. This modification reportedly increased the output by 40% without changing steam consumption.

Continuous measurements of steam flow, feed flow, and product temperatures were made to monitor the performance of six tomato paste evaporators. The evaporators were located in three different plants in the central valley of California, and included single, double and triple effect models.

Steady state mathematical models of all of the evaporators were developed. These were used to calculate theoretical steam economies for comparison with the measured ones. They were also used to check the validity of the data as they gave a good estimate of what the measurements should be at other than rated conditions.

This work was part of a Department of Energy project on energy conservation in the food industry. A complete set of the data is given in the final report (Rumsey *et al.* 1980).

MATERIALS AND METHODS

Evaporator Descriptions

Table 1 contains manufacturer's and estimated rated performance data for each evaporator tested. One single effect forced recirculation evaporator, denoted S1, was monitored. There were very few single effect evaporators in use in the plants visited. Most were being phased out in favor of the more energy efficient multiple effect evaporators.

Two double effect recirculation evaporators were monitored, D1 and D2. Both are the same model and manufactured by the same company. Their first effect uses forced circulation with a steam turbine powered pump while the second effect utilized natural circulation. A schematic of D1 is given in Fig. 1.

A total of three triple effect recirculation evaporators were monitored. The smallest one, T1, is one of three triple effect evaporators used to pre-concentrate feed for S1. All of its effects utilized forced circulation with pumps powered by electric motors and a forward feed flow system is used.

A third effect was added to an evaporator similar to D1 and D2 to make the triple effect evaporator T2. This is a standard modification offered by the manufacturer (Attiyate 1978). The first and second effects

Table 1. Rated performance of evaporators

Evaporator	Plant	Number Effects	Feed	Tomatoes ^b Processed (kg/hr)	Steam (kg/hr)	Economy (kg/kg)
S1	A	1	Forward	15000 ^a	6800 ^a	0.9
D1	A	2	Backward	28000	12100	1.8
D2	B	2	Backward	28000	12100	1.8
T1	A	3	Forward	15000 ^a	3400 ^a	2.4
T2	A	3	Mixed	39100	11800	2.6
T3	C	3	Mixed	35000	16000	2.8

^aEstimated from performance measurements; manufacturers data not available

^bApproximate solids of product in at 5% except S1 for which the input solids were approximately 17%

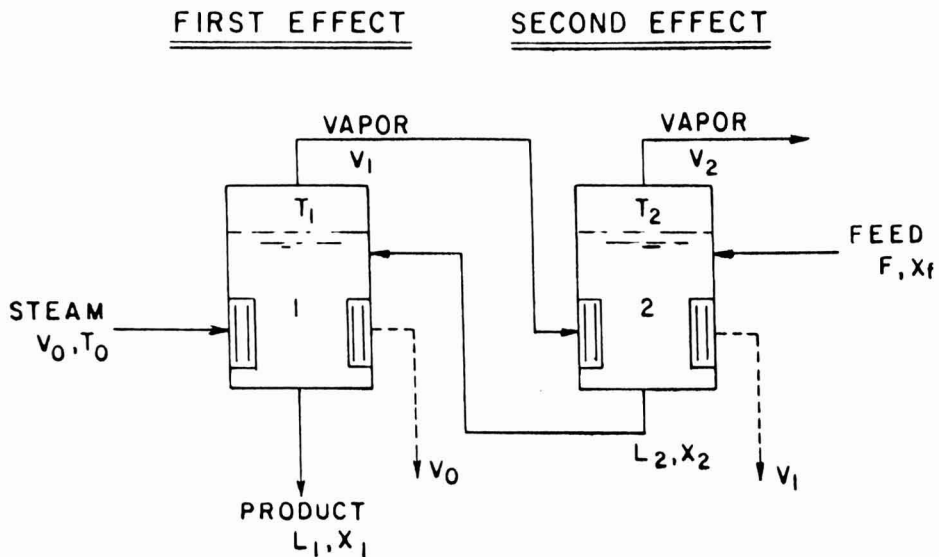


FIG. 1. DOUBLE EFFECT EVAPORATOR SCHEMATIC.

of the evaporator use forced circulation with steam turbine powered pumps. Natural circulation is used in the third effect. Feed flow is mixed, going from the third to first and then second effects.

Evaporator T3 was the largest one monitored both in terms of its capac-

ity and physical size. Each of its three effects use a steam powered turbine to run their circulation pump. As with T2, the feed flow is mixed, but in this case flow is from the first to the third and finally the second effect.

The method of automatic control of feed rate in and product rate out was similar in all of the evaporators monitored. In-line instrumentation to sense total solids in the final product effect is used to control the rate of product out in each case. Level controllers are used to control the flow rate of paste between effects and flow rate of raw juice feed into the evaporator. Maximum feed flow rate could also be controlled manually.

Steam turbines are used to power pumps in forced circulation effects for all the evaporators except T1, which used electric motors. High pressure steam is fed into the turbine. On exit, it is routed to an accumulator where it is mixed with high pressure make up steam. From the accumulator, the steam flows to the first effect heat exchanger. The steam side temperature is automatically controlled by a valve in the make up steam line. A relief valve on the accumulator vents excess steam in the event product flow into or out of the evaporator is shut down. Steam is still needed to run the circulation pump in this case.

Instrumentation

All steam flows were measured with Accutube differential pressure flow meters (Merriam Instrument Co.). The differential pressures were converted to a 4 to 20 ma signal with electronic differential pressure transmitters (Westinghouse Electric Corp., Model 75DP1). Steam flow sensors were usually placed in high pressure steam lines from the boiler to the first effect heater. In some cases, because of the physical layout, it was necessary to use two sensors to obtain total stream flow to an evaporator. During the second season of tests, two independent measurements of the total steam flow were taken for most of the tests.

Tomato juice flows into each evaporator were measured with a portable clamp on ultrasonic flow meter (Polysonics, Inc., Model LCDT/LCDM). The meter uses the doppler effect to measure average velocity in the pipe. Output was in the form of a 4 to 20 ma signal proportional to average fluid velocity.

Temperatures were measured with copper constantan thermocouples attached to evaporator surfaces with tape and covered with two layers of insulation.

A portable digital data logger (Campbell Scientific Co., Model CR 5) was used to record the signals from the flow meters and thermocouples.

Data were recorded both on magnetic and paper tape at 10 min intervals. All flows were averaged over the interval, while temperature data were instantaneous values. The data were transferred to disk files for reduction and analysis with a microcomputer. Time averaged data for each test day are presented in this paper.

Theoretical Models

Steady state mathematical models were developed for each evaporator following the technique outlined by Holland (1975). The equations for the double effect evaporator, D1, are given below. Boiling point elevation was assumed to be negligible, and heat losses were assumed negligible. Mass and energy balances are combined (Rumsey and Scott 1982) to give

$$L_2X_2 - L_1X_1 = 0 \quad (1)$$

$$V_0\lambda(T_0) - U_1A_1(T_0 - T_1) = 0 \quad (2)$$

$$L_2h(T_2, X_2) + V_0\lambda(T_0) - (L_2 - L_1)H(T_1) - L_1h(T_1, X_1) = 0 \quad (3)$$

$$F_{X_f} - L_2X_2 = 0 \quad (4)$$

$$(L_2 - L_1)\lambda(T_1) - U_2A_2(T_1 - T_2) = 0 \quad (5)$$

$$Fh(T_f, X_f) + (L_2 - L_1)\lambda(T_1) - (F - L_2)H(T_2) - L_2h(T_2, X_2) = 0 \quad (6)$$

The juice enthalpies were estimated using an approximation for specific heat from Heldman and Singh (1981). Curve fits of saturated steam tables were used to calculate steam vapor and condensate enthalpies. Instead of solving the traditional design problem, the unknowns were L_1 , L_2 , U_1 , U_2 , V_0 and X_2 . The known (measured) quantities were A_1 , A_2 , F , T_f , T_0 , T_1 , T_2 , X_f and X_1 . A similar analysis has been described by Shewchuk *et al.* (1980) to monitor fouling in multiple effect evaporators. Theoretical steam economies calculated using the steady state models were made for each of the day long tests.

RESULTS

Single Effect Evaporator

The single effect evaporator was successfully monitored for five days during the first season. A summary of daily average performance data

are given in Table 2. There are two general reasons that the test lengths were not 24 h long. The first, and most common reason, was instrumentation malfunction. The second was that the evaporator was shut down for a period of time due either to equipment problems or shut downs in the processing lines on either side of the evaporator.

Total steam to the evaporator was found by adding the steam flow to the turbine powering the circulation pump and make up steam flow to the accumulator. Over the five test days, the steam flow to the turbine averaged 3600 kg/h and averaged 48% of the total steam to the evaporator. Because of physical limitations, it was not possible to measure steam vented from the first effect and steam flow through the relief valve on the accumulator.

Measured and theoretical steam economies averaged 0.84 and 0.95, respectively. The theoretical steam economies averaged 11.6% greater than the measured ones.

Double Effect Evaporators

Evaporators D1 and D2 were monitored for a period of several days during each season. A summary of the test results are given in Table 3. The amount of juice processed per hour was lower than the rated 28000 kg/h for all tests except test D2/2 which averaged 35400 kg/h.

The steam flow sensors were positioned differently each season at each evaporator. During the first season, steam flow to the turbine supplying power to the circulation pump averaged 8850 kg/h for D1 and 6550 kg/h for D2. Steam flow to the turbine was 63% of the total steam to D1 and 43% of the total steam to D2. Multiplying these flow rates times the

Table 2. Average measured performance data for single effect evaporator

Day	Test Length (hrs)	Ave. Solids In (%)	Solids Out (%)	Measured			Theoretical Economy (kg/kg)
				Feed (kg/hr)	Steam (kg/hr)	Economy (kg/kg)	
1	22	16.9	30.8	14150	8200	0.76	0.94
7	22	17.6	31.4	14450	7000	0.94	0.95
8	24	16.4	31.4	11850	5450	1.02	0.96
9	12	16.6	31.2	15550	9550	0.74	0.92
10	16	17.4	31.3	12850	8100	0.74	0.96

Table 3. Average measured performance data for double effect evaporators

Test	Day/Season	Test Length (hrs)	Ave. Solids		Measured			Theoretical Economy (kg/kg)
			In (%)	Out (%)	Feed (kg/hr)	Steam (kg/hr)	Economy (kg/kg)	
D1/1	1/1	24.	5. ^a	30. ^a	24450	14550	1.42	1.92
D1/2	2/1	24.	5. ^a	30. ^a	20500	14650	1.22	1.92
D1/3	3/1	20.	5. ^a	30. ^a	13150	12800	0.79	1.92
D1/4	1/2	6.	5.7	28.2	21350	11250	1.52	1.92
D1/5	5/2	18.	5.9	28.1	20900	11000	1.38	1.91
D1/6	7/2	24.	5.4	28.1	22800	12400	1.50	1.93
D2/1	1/1	20.	5. ^a	34. ^a	22450	11750	1.58	1.92
D2/2	6/1	24.	5.6	34.8	35400	13950	2.03	1.92
D2/3	12/1	22.	5. ^a	34. ^a	23750	10750	1.72	1.94
D2/4	1/2	24.	5. ^a	40.5 ^a	18000	11400	1.25	1.89
D2/5	2/2	24.	5. ^a	40.5 ^a	20950	12150	1.55	1.87

^aTotal solids estimated from plant data

changes in steam enthalpy yielded average powers delivered to the turbine of 155 and 140 kw for D1 and D2, respectively.

During the second season, total steam flow to D2 was measured on the main steam line from the boiler and on the low pressure line from the accumulator to the first effect heat exchanger. There was no difference between these two average flows for test D2/5 and 6% differences in test D2/4. This indicates that if there was a steam loss, it was due to the venting from the first effect heat exchanger.

Theoretical steam economies were greater than measured values for all but one test. Theoretical values averaged 24.1% higher, with an average value of 1.91 compared to 1.45 for the measured steam economies.

Triple Effect Evaporators

Evaporator T1 was monitored several times during the first season. The results of these tests are given in Table 4. Measured steam economies averaged 15.7% higher than theoretical values. The average economies were 2.82 and 2.44 for measured and theoretical data.

Table 4. Average measured performance data for triple effect evaporators

Test	Day/Season	Test Length (hrs)	Ave. Solids		Measured			Theoretical Economy (kg/kg)
			In (%)	Out (%)	Feed (kg/hr)	Steam (kg/hr)	Economy (kg/kg)	
T1/1	1/1	12.	4.9	16.8	13750	3400	2.85	2.45
T1/2	10/1	17.	6.2	17.3	12600	2700	2.99	2.44
T1/3	11/1	23.	5.7	17.6	11900	2850	2.75	2.42
T1/4	12/1	3.	6.6	16.4	12700	2900	2.69	2.44
T2/1	1/1	21.	5.	41.	22000	11700	1.76	2.61
T2/2	3/1	20.	5.7	40.7	18350	11200	1.66	2.61
T2/3	3/2	24.	5. ^a	30. ^a	32950	10600	2.60	2.67
T2/4	4/2	9.	5. ^a	30. ^a	32200	9250	2.91	2.67
T2/5	6/2	23.	5. ^a	30. ^a	28250	9700	2.46	2.69
T2/6	7/2	14.	5. ^a	30. ^a	32750	8800	3.06	2.69
T3/1	1/2	15.	5.0	35.3	43000	14450	2.56	2.63
T3/2	2/2	24.	5.0	35.4	38150	14250	2.30	2.69
T3/3	3/2	24.	5.0	35.4	34500	13400	2.21	2.69
T3/4	4/2	24.	5.1	35.1	28500	10750	2.29	2.69
T3/5	8/2	24.	5.2	44.6	42250	15450	2.42	2.51
T3/6	9/2	10.	5.1	44.8	43250	16600	2.31	2.50

^aTotal solids estimated from plant data

Evaporator T2 became operational during the first season of tests. Plant personnel had trouble operating the evaporator, frequently fouling the heat exchangers by burning on product. The result was a nearly 50% reduction in evaporator capacity as evidenced by the low measured feed rates. Results for the tests conducted over the two seasons are given in Table 4. The steam flows listed were measured on a line to the first effect heater. Steam flows to the first and second effect turbines averaged 2500 and 8100 kg/h. This meant that there was little or no make up steam required. For the last three tests, the sum of steam flows into the turbines plus make up steam was within 3.5% of the measured steam flow into the first effect heater, thus helping to confirm the values reported in Table 4. The average measured steam during the second season was 2.76; slightly above the 2.68 theoretical value.

Evaporator T3 was monitored during the second season. Performance results are given in Table 4. Measured feed flows were always less than the rated capacity of 55,000 kg/h. Steam flows were measured on the main steam line from the boiler and on the line from the accumulator to the first effect. The percent difference between these two readings averaged 2.8% on all tests except T3/3 and T3/4. The differences in steam flow for those two days were 3650 and 7150 kg/h, respectively. This steam was being vented out the relief valve on the accumulator since more steam was needed to run the turbines than to evaporate product. The evaporator was being slowly shut down over these two days prior to a total shut down and clean out. Measured steam economy for this evaporator averaged 2.35 while the theoretical average was 2.62.

DISCUSSION

With few exceptions, measured steam economies were less than theoretical economies. The theoretical calculations did not include heat losses due to venting or convection and radiation to the ambient air. Neglecting these losses accounts for some of the theoretical economies being higher than measured ones. Miller *et al.* (1980) found heat losses to be significant in a laboratory scale triple effect evaporator for citrus. They measured a steam economy of 2.07 and calculated theoretical economies of 2.26 and 2.57 with and without heat losses. Chen *et al.* (1979) measured steam economies of 2.2 to 2.7 for a four effect commercial citrus evaporator and economies of 2.5 to 4.0 when a fifth effect was added. The low economies were attributed to heat losses, and the size of the heat transfer surface areas for the first two effects. One publication (ERDA 1977) estimates typical energy savings of 5% by adjusting venting and using thermal insulation.

Steam was usually vented from the heat exchangers to get rid of non-condensibles which enter the evaporators by leaks or with the feed. Venting was usually through hand regulated gate valves directly to the surroundings, and was thus difficult to measure or quantify. There was another type of steam loss that could occur with the evaporators with steam turbine powered circulation pumps.

When the feed rate was maintained at low values, more steam was required to run steam turbine powered circulation pumps than was required for evaporation. The excess steam was lost through a relief valve. Problems with instrumentation and the physical layout of evaporator piping made the measurement of this loss extremely difficult. We were able to obtain some limited data on the triple effect evaporator, T3.

During two consecutive days prior to a shut down, steam flow out the relief valve averaged 3650 and 7150 kg/h.

Measured feed flow rates were usually smaller than rated capacities. In some cases, there was not enough demand for product downstream, so the evaporators were run at less than rated capacity.

As expected, the triple effect evaporators showed the best steam economies; ranging from 2.2 to 3.1. The most recent evaporators to be installed in tomato processing plants have four effects. At least two of these have come into operation in the last two years.

NOMENCLATURE

- A_j = total heat transfer surface for evaporator effect j , [m²]
 F = feed rate to evaporator, [kg/h]
 $h(T_j)$ = enthalpy of pure solvent in liquid state at temperature T_j , [kJ/kg]
 $H(T_j)$ = enthalpy of pure solvent in vapor state at temperature T_j , [kJ/kg]
 $h(T_j, X_j)$ = enthalpy of liquid at temperature T_j and composition X_j , [kJ/kg]
 L_j = mass flow rate from evaporator effect j , [kg/h]
 T_f = temperature of feed to evaporator, [°C]
 T_o = temperature of steam to evaporator, [°C]
 T_j = temperature of liquid and vapor in j th effect, [°C]
 U_j = overall heat transfer coefficient effect j , [W/m² - °C]
 X_j = mass fraction of solute in the liquid leaving effect j , [kg/kg]
 $\lambda(T_j)$ = latent heat of vaporization at temperature T_j , [kJ/kg]

REFERENCES

- ATIYATE, Y. 1978. Modified evaporator boosts tomato processing output. *Food Engineering*. 50(11), 98-100
 CHEN, C. S., CARTER, R. D. and BUSLIG, B. S. 1979. Energy requirements for the TASTE citrus juice evaporator. In *Changing Energy Use Futures*, Vol. 4, R. A. Fazzolare and C. B. Smith (eds) pp. 1841-48, Pergamon Press, Elmsford, New York.
 CHEN, C. S., CARTER, R. D., MILLER, W. M. and WHEATON, T. A. 1981. Energy performance of a HTST citrus evaporator under digital computer control. *Trans. ASAE*. 24(6), 1678-1682.
 ERDA. 1977. Upgrading existing evaporators to reduce energy consumption. Report C00/2870-2. National Technical Information Service, Springfield, VA.
 HOLLAND, C. D. 1975. *Fundamental of Modeling of Separation Processes*. Prentice Hall, Inc. New Jersey.
 MILLER, W. M., WHEATON, T. A., CARTER, R. D. and GRANDALE, P. G. 1980. Data acquisition for engineering analysis of citrus evaporators. *Trans. ASAE*. 23(2), 508-514.

- PEDERSON, L. D. 1983. Unpublished data from National Food Processors Association.
- RUMSEY, T. R., CONANT, T. T., PEDERSON, L. D. and ROSE, W. W. 1980. Energy conservation in the food processing industry: Measurement of energy used in evaporation of tomato products. Final Report. NFPA-DOE Contract No. DE-AC07-78C540191.
- RUMSEY, T. R. and SCOTT, E. P. 1982. Measurement of heat transfer coefficients in multiple effect evaporators. American Society of Agricultural Engineering Paper No. 82-6029. Presented at ASAE Summer Meeting, Madison, WI.
- SCHWARTZBERG, H. G. 1977. Energy requirements for liquid food concentration. *Food Technol.* 31(3), 67-76.
- SHEWCHUK, C. F., WAITE, S. J. and HINTON, R. A. 1980. A practical user oriented computer program for evaporator analysis. *AIChE Symposium Series.* 76(200), 143-158.
- SINGH, R. P., CARROAD, P. A., CHHINNAN, M. S., ROSE, W. W. and JACOB, N. L. 1980. Energy accounting in canning tomato products. *J. Food Sci.* 45(3), 735-739.

CLEANING KINETICS MODELING OF HOLDING TUBES FOULED DURING MILK PASTEURIZATION¹

THIERRY GALLOT-LAVALLEE, MARC LALANDE and
GEORGES CORRIEU

INRA—Laboratoire de Genie Industriel Alimentaire
Villeneuve D'Ascq, France

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ABSTRACT

In the present study, 25 cm tubes fouled during pilot plant scale pasteurization of raw whole milk were cleaned with sodium hydroxide. The pasteurization conditions resembled those of the dairy industry. An optical sensor sensitive to the turbidity of suspended deposits removed by the cleaning solution was placed successively at the outlet of each fouled tube. Use of this sensor combined with a nonrecycled cleaning solution process enabled us to measure the cleaning rate on line. In these conditions it was observed that, at zero time, the cleaning rate was null. Based on the above observations a kinetic model of cleaning was established. It consists of two steps in series. The adhesive deposit passes through an intermediate state before being washed away by the cleaning solution. Each step is a first order reaction related to the mass of the adhesive deposit and the mass of the intermediate compound, respectively.

Among the many physico-chemical parameters affecting the cleaning process, three major ones were studied; temperature, concentration and circulation rate of the soda solution. An empirical model of the rate constant was set up which takes into account those three parameters and the initial weight of deposit to be cleaned. A 1% increase in the amount of NaOH caused the same increase in the constant rate as 8°C or 0.5 m/s.

INTRODUCTION

Milk pasteurization in heat exchangers causes formation of solid deposits on hot surfaces which requires at least a daily cleaning of the dairy

¹Translated into English by K. RERAT

equipment. The cleaning process is expensive; on the one hand, it means that the line and, accordingly, the production must be stopped and, on the other hand, the cost of thermal energy, mechanical energy, chemical reagents and water is very high. Whether the line cleaning is done by hand or automatically (cleaning in place system [CIP]), the operating conditions (temperature, nature and concentration of the detergent solution, flow rate, etc.) are chosen in a more or less empirical way mainly depending on industrial habits.

Few studies have been made on cleaning kinetics. Most of the works propose cleaning methods (detergent choice, working conditions, etc.) based on practical observations, but they do not really contribute to improving our knowledge of that problem. Only studies taking into account the fundamental aspects of cleaning and their practical applications may lead to the understanding of the mechanisms involved and the modeling of the phenomena. Two approaches are possible. (1) If the aim of the study is to apply practical results, the cleaning kinetics is described by an empirical model which represents the phenomena and which takes into account the influence of the main parameters. (2) If the aim is to improve the fundamental knowledge concerning the different mechanisms involved during cleaning, the kinetics is described by an explanatory model. This last approach may join the first one as far as the means used allow not only to suggest a mechanism, but also to measure the influence of the different parameters.

The most representative studies are those carried out by Jennings (Jennings *et al.* 1957; Jennings 1959 a, b, 1960, 1961, 1963 a, b, 1965; Bourne and Jennings 1961, 1963 a, b, c) and Schlusser (1970, 1976). When cleaning complex heterogeneous protein rich soils, these authors chose an empirical modeling of the phenomena because they wanted to show a practical application, but also because of the complex mechanism involved (Jennings *et al.* 1957; Jennings 1959 a, b, 1960; Schlusser 1970). In order to know the mechanisms playing a part during cleaning, they thereafter worked on homogeneous soils of simpler composition, tristearin deposit for Bourne and Jennings (1961, 1963 a, b, c) and triolein deposit for Schlusser (1976). However, their results on that type of model soils are extremely limited and cannot in any case be applied to the cleaning of heterogeneous soils.

The aim of our study was to examine the cleaning kinetics of deposits obtained during milk pasteurization. Because of the complexity of the mechanisms involved in the cleaning of heterogeneous soils, our purpose was to establish an empirical model of the phenomenon which takes into account the influence of the main physico-chemical parameters involved.

This study was thus performed in practical conditions in order to make the cleaning of industrial milk pasteurizers optimal.

When examining more in the details the works of Jennings (Jennings *et al.* 1957, Jennings 1959 a, b, 1960) and Schlusser (1970) on the cleaning of heterogeneous soils, we observed that the quantities of cleaned soils may be compared (0.05 to 0.3 Kg/m²), but that differences appear in the way of obtaining this deposit, the conditions of cleaning it and the overall results.

Schlusser (1970) cleaned milk, butter milk and chocolate milk samples deposited on glass strips of 30 cm² and dried them at a low temperature (max. 40°C). The strips were immersed in a stirred vessel containing the cleaning solution. The assessment method was based on a visual observation of the surface wettability by water. This gave a very inaccurate answer (negative or positive) which cannot be considered as satisfactory. Nevertheless, Schlusser experimentally determined the cleaning time necessary to eliminate the soil, whose initial quantity was determined beforehand. Then, he chose an average cleaning rate supposed to remain constant. This process cannot give any cleaning aspect versus time and, being considered as a zero order reaction, the true kinetic study of the phenomena cannot be done. Average cleaning rates were obtained (between 0.16 and 1.3 Kg/s m²) which led to cleaning durations between 30 and 150 s. On this basis, Schlusser studied the influence of a certain number of parameters on the cleaning process rate (temperature, nature and concentration of the detergents, mechanical action, kind of soil, surface state). He proposed an empirical model relating the cleaning time to the temperature and the detergent concentration.

Jennings *et al.* (1957) and Jennings (1959 a, b, 1960) cleaned the obtained deposits by steaming to dryness a few milliliters of ³²P labelled milk. The deposits were placed on 4.5 cm² stainless steel disks. The disks were inserted into a cylindrical pipe parallel to the circulation flow of the cleaning solution. Using a radioactive counting, these authors obtained cleaning aspects versus time by taking one disk after another. Their conclusion was that the elimination rate of the deposit (dm/dt) was proportional to the quantity of deposit (m) present on the surface at each moment and to the concentration of hydroxide ion (C_{OH}). *They proposed the following relation:*

$$- dm/dt = k' \cdot m \cdot C_{OH} \quad (1)$$

However, the model could only be applied to the elimination of about 60% of the initial deposit. In fact, the authors considered that at the end

of the elimination process specific linkage phenomena with the surface occurred and that the subsequent kinetics was no longer represented by Eq. (1). The influence of the soda concentration was studied on a restricted range (0 to 0.6%).

It is therefore impossible to generalize Eq. (1). This is the reason why Eq. (2), corresponding to a first order reaction according to the adhesive deposit on the surface is more commonly admitted today as the basic equation ruling the cleaning phenomenon (Loncin 1976):

$$- dm/dt = k \cdot m \quad (2)$$

Jennings (1959 b) studied the influence of the temperature, soda concentration and mechanical effect on the cleaning rate constant (k) which ranged between 0.01 and 0.2 s⁻¹.

The means used in our study are very different from those cited above. The fouled surface was a tube portion of 125 cm² and the deposit was obtained by pasteurizing milk at 0.6 m/s and 85°C (similar conditions as those of industrial pasteurizers). Besides, to establish the cleaning kinetics, it seemed important to be able to measure the cleaning pattern on line. An optical sensor sensitive to the turbidity created by the flow of the detergent solution on the deposit was therefore developed. Fixed at the outlet of the fouled tube, it gives information in real time on the cleaning and, owing to an appropriate calibration, it is possible to know directly and at any time the elimination rate of the deposit.

MATERIAL AND METHODS

The deposit was obtained by pasteurizing about 2,000 liters of bulk raw whole milk. The holding section of the plate pasteurizer used was widened by adding twelve identical stainless steel tubes linked to each other (see Fig. 1). Each tube (length 25 cm, inner diameter, 1.6 cm) has a surface of about 126 cm². From run to run, the deposit mass adhering to the tube wall after water rinsing (time 15 min, rate 0.6 m/s) varied from 0.05 to 1.2 kg/m² of dried matter according to the quantity and the quality of the treated milk (Lalande and Corrieu 1981). The variation coefficient of the deposit mass in the twelve tubes ranged from 5 to 25%, according to runs. For each tube, the deposit was uniformly spread on the inner surface. Analyses showed that, for one run, the deposit composition was the same in the twelve tubes (approximately 60% protein, 30% fat and 10% minerals). From run to run, the variation coefficients were

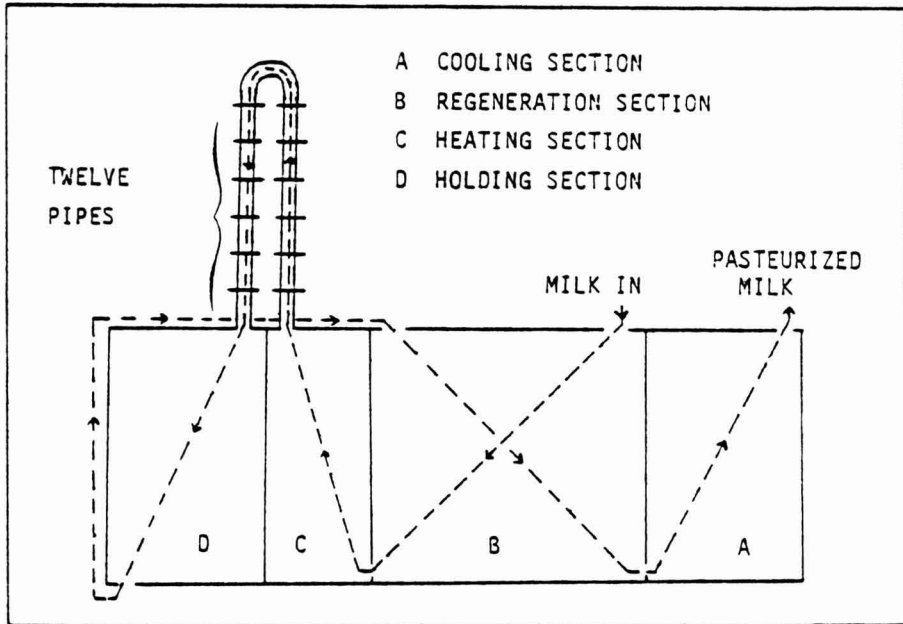


FIG. 1. SETTling PATTERN OF THE TUBES ON THE PASTEURIZER DURING THE FOULING PERIOD.

10% for protein, 15% for fat and 20% for minerals. Each pasteurization enabled us to perform twelve cleaning tests (one for each fouled tube).

In a previous work, we showed that cleaning with soda after water rinsing of the deposit mainly consisted of suspending the deposit in the detergent solution (Gallot-Lavallee *et al.* 1982). From this observation, an optical sensor was developed (Corrieu *et al.* 1980) whose principle is based on the overall decrease in the light beam by the suspended matters placed on the optical way. This sensor only permits a general observation of the concentration of soil removed and does not enable us to measure the different deposit compounds (protein, fat, minerals). This sensor and the calibration method have already been described (Gallot-Lavallee *et al.* 1982). The calibration allowed us to convert the output voltage of the optical sensor created by the flow of the solution into the deposit concentration of this solution. During cleaning, the sensor was fitted just behind the fouled tube. The equations established during the calibration enabled us to perform an on line and in real time measurement of deposit concentration of the cleaning solution at the outlet of the tube with an accuracy of 4%.

The device used to perform the cleaning of each tube is shown in Fig. 2. The soda solution flows in a closed circuit in a heat exchanger until its temperature becomes stabilized at a given value. Its flow rate, measured with an accuracy of approximately 1%, is fixed by a pump whose speed is automatically controlled. After commuting a three-way pneumatic valve, the soda solution flows through the fouled tube and the optical sensor before being eliminated (sewer). A microcomputer is used to automatically control the cleaning process and to collect the data given by the sensors.

The experimental curves obtained show the variation in the cleaning rate which is defined as the amount of deposit washed away per unit of time and of fouled surface. Owing to the uniform spreading of the deposit and the short residence time of the particles (0.1 to 0.9 s) in the fouled tube we considered that the cleaning rate was constant at any point of the tube (case of the differential reactor). At time " t ," this rate (r) equaled the deposit concentration of the cleaning solution (C_d) flowing through the optical sensor at the same time, multiplied by the solution flow rate (\dot{V}) and divided by the fouled surface (A), i.e. Eq. (3):

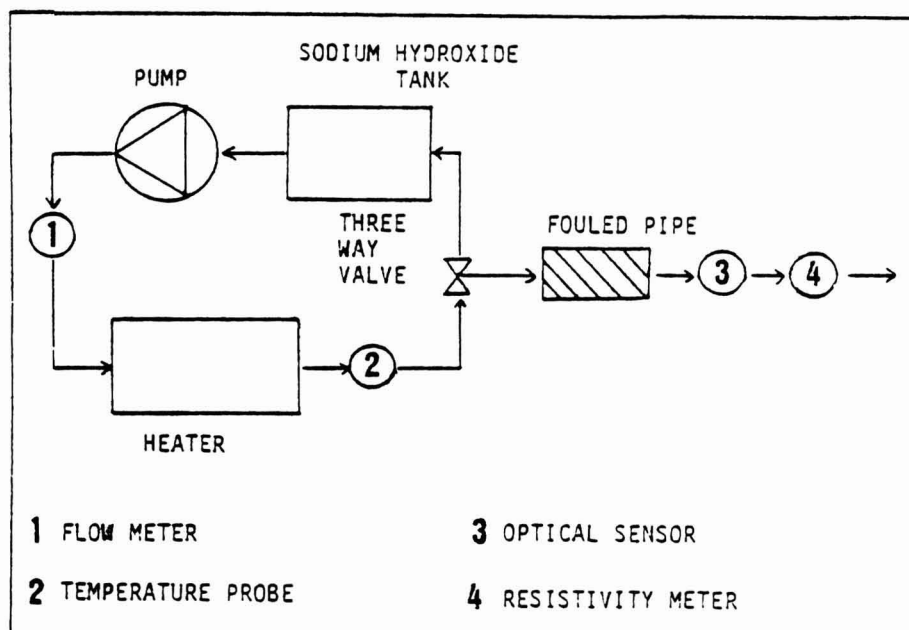


FIG. 2. DIAGRAM OF THE EXPERIMENTAL DEVICE USED TO FOLLOW THE CLEANING OF A TUBE

$$r(t) = C_d(t) \cdot \dot{V}/A \quad (3)$$

The cleaning rates are calculated with an accuracy estimated at 5%.

Once the kinetic model is established, describing the cleaning consists of experimentally modeling the influence of the main parameters responsible for the phenomenon. To study the influence of physico-chemical parameters, we chose the response surface method (Cochran and Cox 1957; Vuataz 1979) which includes two steps, the first one consisting of performing experiments in which the parameters are fixed at different levels and of measuring the corresponding value of the phenomenon response. From collected experimental data, the coefficients of a linear quadratic model are estimated by using the method of generalized least squares. Once the mathematical model is established, the second step consists of studying the behavior of the model in the experimental space, i.e., in determining the respective influence of each parameter on the response.

The experimental design used is a "CCRD" type (Central Composite Rotatable Design). To study the influence of three major physico-chemical parameters (temperature, concentration and circulation rate of the cleaning solution), this design includes twenty experiments. By an appropriate coding of the different parameter values, these experiments form a sphere in the experimental space represented by a system of three orthonormal axes corresponding to each parameter. Each of them represents five values which, after coding, are 0, ± 1 , $\pm \alpha$. For a three parameter study, the value of α is 1.682. The choice of parameter values (Table 1) is derived from our experiment as the deposit is not cleaned at temperatures below 55°C. From our experimental device, as the maximal circulation rate reached by the solution is 3.9 m/s and its temperature 95°C as well as from industrial methods, the cleaning process is always performed in a turbulent flow (in the present case the circulation rate exceeded 0.3 m/s). In addition, we chose an average soda concentration of 2%, commonly used in the industry. Thus, the upper limit for the soda concentration ranged around 4%. In these conditions, the parameter values are derived from the following equations, $x_1 = (\theta - 75)/12$ for temperature, $x_2 = (C_s - 2)/1.15$ for soda concentration and $x_3 = (v - 1.1)/0.5$ for circulation rate.

In the reference conditions (represented by the center of the experimental sphere) cleaning was thus obtained by circulation at a rate of 1.1 m/s in the fouled tube and of a 2% soda solution heated to a temperature of 75°C. In order to obtain a more reliable model, we doubled the number of trials planned in the design.

Table 1. Theoretical values of temperatures (x_1 and θ), soda concentration (x_2 and C_s) and circulation rate of the cleaning solution (x_3 and v) to perform the experimental design.

PARAMETER VALUES						
Number of Tests	Coded Values			Real Values		
	x_1	x_2	x_3	θ ($^{\circ}\text{C}$)	C_s (%)	v (m/s)
6	0	0	0	75	2	1.1
8	1	1	1	87	3.15	1.6
	1	1	-1	87	3.15	0.6
	1	-1	1	87	0.85	1.6
	1	-1	-1	87	0.85	0.6
	-1	1	1	63	3.15	1.6
	-1	1	-1	63	3.15	0.6
	-1	-1	1	63	0.85	1.6
	-1	-1	-1	63	0.85	0.6
6	$+\alpha$	0	0	95	2	1.1
	$-\alpha$	0	0	55	2	1.1
	0	$+\alpha$	0	75	3.9	1.1
	0	$-\alpha$	0	75	0.1	1.1
	0	0	$+\alpha$	75	2	1.9
	0	0	$-\alpha$	75	2	0.3

RESULTS AND DISCUSSION

Description of the Experimental Cleaning Curves

Cleaning of a tube is represented by a curve showing the cleaning rate versus time. Representative examples of all the experimental curves are given in Fig. 3. All these curves show the same cleaning pattern relative to time. The cleaning rate increased rapidly at the beginning then more slowly to reach a maximum from which it decreased toward zero. According to the experimental conditions (temperature, concentration and circulation rate of the soda solution), there was a difference between curves with regard to total cleaning time (30 to 300 s), duration of the increase phase (2 to 60 seconds) and maximal cleaning rate (0.1×10^{-2} to 2.5×10^{-2} Kg/s m²). Obviously, before asserting that the cleaning rate was null at zero time and increased up to a maximum, we made sure that the phase of increase was not an experimental aberration due to the response time of the optical sensor-microcomputer system (0.2 s) or to the dispersion of the removed molecules inside the fouled tube (Gallot-Lavallee 1982).

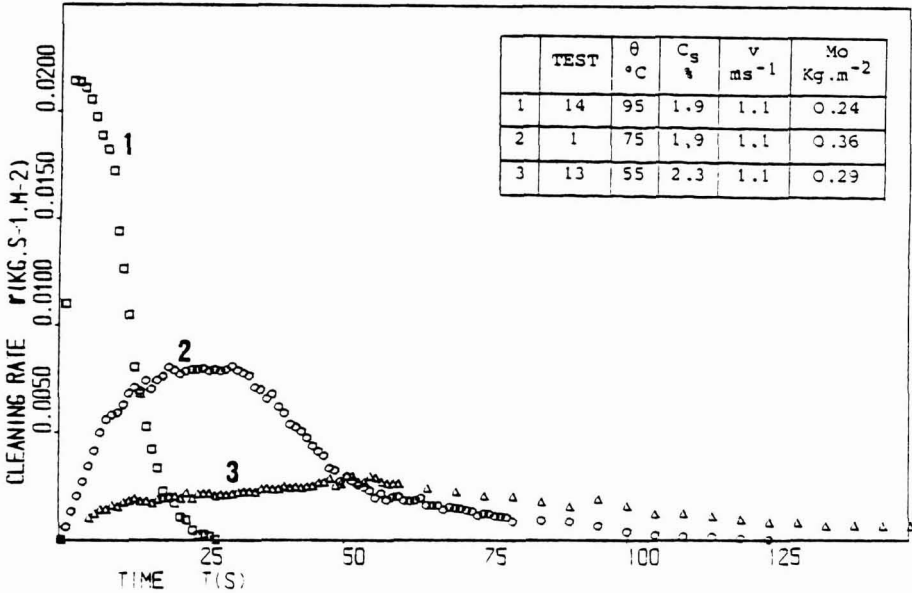
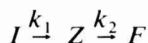


FIG. 3. SOME TYPICAL EXPERIMENTAL CURVES OF THE CLEANING RATE VERSUS TIME.
 For each curve the values of temperature (θ), soda concentration (C_s), circulation rate (v) and initial mass of deposit (M_0) are given.

Research of a Kinetic Model for Cleaning

On the basis of models proposed in the literature to describe the cleaning process, we tried to find a model of the chemical reaction type. Using an optical sensor, it was possible to show that the cleaning rate was null at zero time and we, therefore, eliminated a pattern made of only one reactive step whatever its order. Then, we tested several reactive patterns composed of two steps and finally, for application in practice, we only kept one of them represented by two first order reactions in series according to the deposit mass. In this pattern, the initial compound (I) passes through an intermediate state (Z); this first reaction being a first order one, the disappearance rate of the initial compound ($-r_1$) is proportional to the initial deposit mass still present (M_1). A second first order reaction then provides the intermediate compound with its final form (F) and the optical sensor measures this form (F). The rate of formation of this final compound (r_f) is proportional to the intermediate compound mass present (M_2). The disappearance rate of this intermediate compound ($-r_2$) can be obtained by adding the disappearance

rate of the initial compound to the formation rate of the final compound. By calling k_1 and k_2 the rate constants of each reaction, this reactive pattern can be described as follows in Eq. (4):



$$\left\{ \begin{array}{l} -r_I = k_1 M_I \\ r_F = k_2 M_Z \\ -r_Z = -r_I + r_F = k_2 M_Z - k_1 M_I \end{array} \right. \quad (4)$$

Changes in the formation rate of the final compound are given by Eq. (5):

$$r_F = M_o(e^{-k_2 t} - e^{-k_1 t})k_1 k_2 / (k_1 - k_2) \quad (5)$$

where M_o is the initial mass of deposit to be cleaned.

This expression is symmetrical relative to k_1 and k_2 , but simulations of the cleaning rate pattern in Fig. 4 show that it is always possible to find a single value k which nearly leads to the same theoretical curve as that obtained with different values of k_1 and k_2 . Furthermore, since more than one identification result out of two obtained from Eq. (5) led to identical rate constants ($k_1 = k_2$), we kept the reactive pattern composed of two first order reactions in series, each reaction using the same rate constant. The expression of the formation rate of the final compound is then in Eq. (6):

$$r_F = M_o k t e^{-k t} \quad (6)$$

The constant k is identified by a method of nonlinear regression aiming at fitting the theoretical equation of the formation rate of the final compound to all the experimental points by searching for the value of the rate constant that minimizes the sum of the square deviations between the experimental and the theoretical cleaning rate value. The method chosen is that suggested by Nelder and Mead (1965) already described in a previous study (Gallot-Lavallee 1979). The fitting of Eq. (6) was performed without weighting the experimental points. The results can be read in Table 2. On all experimental curves representing the cleaning rate relative to time, we simulated the theoretical development of the rate value by supplying the initial mass of deposit (M_o) with its experimental value and the rate constant (k) with its value identified by Nelder's method. Some representative examples of all the results are given in Fig. 5. To appreciate the quality of the model proposed it was necessary to evaluate the experimental error of the cleaning rate value. This error was

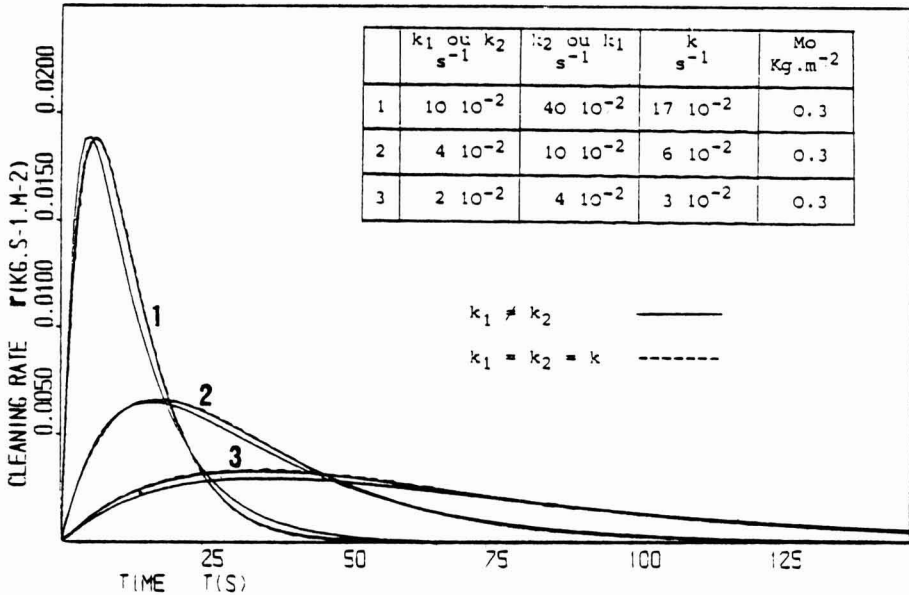


FIG. 4. DETECTION OF THE PRESENCE OF A SINGLE RATE CONSTANT k LEADING ALMOST TO THE SAME THEORETICAL CLEANING RATE CURVE AS THAT OBTAINED WITH DIFFERENT k_1 AND k_2 , AT A GIVEN CONSTANT INITIAL MASS OF DEPOSIT (M_0).

calculated by studying the repeatability of experimental results. Fig. 6 shows six cleaning curves performed in almost identical conditions (reference conditions); the variation coefficients of the different parameters were about 1% for the temperature, 4% for the soda concentration, 2% for the circulation rate and 7% for the initial mass of deposit to be cleaned. The experimental accuracy of the cleaning rate evaluation ranged around 10%, less accurate than the sensor accuracy (5%). From all these curves, we identified a single rate constant from which we simulated the theoretical developmental of the cleaning rate (Fig. 6). The aim of this work being mainly to predict the end of cleaning, we may conclude, although the model is not perfectly specified, it may be used to estimate fouled tube cleaning.

Influence of Temperature, Concentration and Circulation Rate of the Soda Solution on Cleaning

The second step of modeling of cleaning kinetics consists in showing the influence of the physico-chemical parameters (in this case, the

Table 2. Value for each cleaning test of rate constant k of the two first order reactions in series experimentally identified by supplying the initial mass of deposit (M_0) with its experimental value. The experimental values of temperatures (θ), soda concentration (C_s) and circulation rate (v) of the cleaning solution are also given in this table.

TEST	θ °C	C_s %	v m. s ⁻¹	M_0 kg. m ⁻²	$k \times 10^2$ s ⁻¹
1	75	1.9	1.1	0.361	5.3
2	75	1.9	1.1	0.317	7.1
3	75	1.9	1.1	0.327	6.9
4	75	1.9	1.1	0.372	5.6
5	75	1.9	1.1	0.312	6.3
6	75	2.2	1.1	0.263	7.6
7	75	2.2	1.1	0.221	8.5
8	75	2.1	1.1	0.351	6.9
9	75	2.0	1.1	1.089	1.7
10	75	2.0	1.1	0.871	2.8
11	75	2.0	1.1	0.887	1.4
12	55	2.0	1.1	0.274	1.6
13	55	2.3	1.1	0.293	2.4
14	95	1.9	1.1	0.244	20.8
15	95	2.1	1.1	0.282	19.5
16	74	0.2	1.1	0.185	1.6
17	75	0.2	1.1	0.096	1.5
18	75	4.2	1.1	0.452	10.2
19	75	4.1	1.1	0.384	8.4
20	75	1.9	0.3	0.229	2.6
21	74	2.1	0.3	0.217	2.7
22	76	2.1	1.9	0.149	13.9
23	75	2.0	2.0	0.289	12.4
24	64	0.9	0.6	0.158	1.9
25	63	0.8	0.6	0.750	1.1
26	70	0.9	1.6	0.281	4.0
27	64	0.8	1.6	1.163	1.1
28	63	2.9	0.6	0.079	5.4
29	63	2.8	0.6	0.045	6.4
30	63	2.9	1.6	0.090	14.1
31	63	2.8	1.6	0.118	13.9
32	87	0.9	0.6	0.198	7.8
33	85	0.8	0.6	0.704	1.5
34	87	0.9	1.6	0.277	8.4
35	84	0.8	1.6	0.300	8.0
36	87	2.7	0.6	0.126	20.8
37	88	2.7	0.6	0.095	20.3
38	88	2.7	1.6	0.113	35.0
39	87	2.7	1.6	0.169	33.4

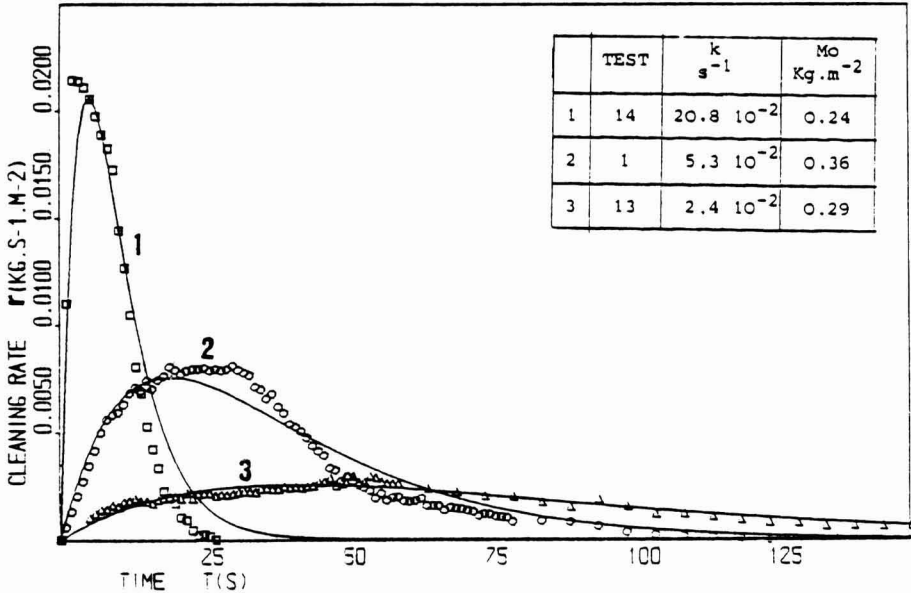


FIG. 5. EXAMPLES OF SIMULATION OF THE CLEANING RATE BY SUPPLYING THE INITIAL MASS OF DEPOSIT (M_0) WITH ITS EXPERIMENTAL VALUE AND THE RATE CONSTANT (k) WITH ITS EXPERIMENTALLY IDENTIFIED VALUE.

temperature, concentration and circulation rate of the soda solution) on the rate constant value defined by the reactive pattern. The response surface method (Cochran and Cox 1957; Vuataz 1979) described above was used. This method consists of two phases.

In the first one, the coefficients of a linear quadratic model are estimated from experimental data. When three variables are to be considered, the mathematical expression of such a model is as in Eq. (7):

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \tag{7}$$

where y =response value (rate constant k), x_1, x_2, x_3 =variables considered (coded values of the studied parameters) and b_i =model coefficients.

This equation represents a Taylor's series second order development of the real unknown function around zero. Taking this equation as a model means that we assume that a limited second order development is sufficient to approximate the unknown function and therefore the response

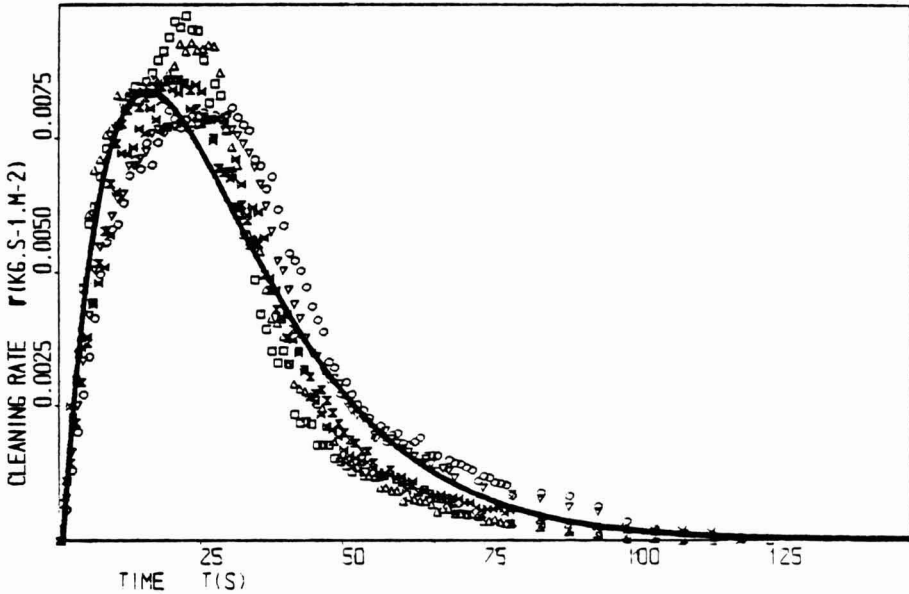


FIG. 6. DETECTION OF THE EXPERIMENTAL ERROR FROM SIX CLEANING RATE CURVES (described by six different symbols) OBTAINED FOR EXPERIMENTAL CONDITIONS ALMOST SIMILAR AND SIMULATION OF THE RATE DEVELOPMENT (described by the solid line) BY SUPPLYING THE INITIAL MASS OF DEPOSIT WITH THE MEAN VALUE OF THE EXPERIMENTAL MASS ($M_0 = 0.34 \text{ g/m}^2$) AND THE RATE CONSTANT WITH THE VALUE EXPERIMENTALLY IDENTIFIED FROM ALL THE EXPERIMENTAL POINTS ($k = 6.7 \cdot 10^{-2} \text{ Kg/s.m}^2$).

variations are small as compared to the experimental conditions. If this is applied to our results, it is necessary for obtaining a well-fitted model on the one hand, to reduce the variation amplitude of the response by taking its decimal logarithm and, on the other hand, to introduce into the quadratic model an extra variable, i.e., the initial mass of deposit to be cleaned. This variable has just to be introduced at the first degree.

The fact that the initial mass of deposit must be taken into account in the equation to get a well-fitted model raises the problem of the meaning of the chosen reactive pattern. Since the rate constant k depends on the initial mass of deposit to be cleaned, this pattern must be considered as arguable from a physical point of view. It is valuable with regard to the aim defined previously since it enables us to represent the experimental

results as a whole and to take into account the three most important physico-chemical parameters.

The second step consists in determining the influence of each parameter, respectively, on the rate constant value. One of the main advantages of this modeling method is in fact to estimate the coefficients of each term of the linear model regardless of each other; therefore, the influence of each parameter or of each parameter combination on the response can be measured by comparing directly the signs and absolute values of the different coefficients (b_i). The higher a coefficient value the larger the corresponding variable is. On the contrary, the lower the coefficient value the smaller the variable is. A statistical hypothesis test based on the "t" distribution allows us to quantify this statement.

The regression coefficient values estimated relative to each term of the quadratic model are shown in Table 3. The study of their absolute value and of their sign leads to the following statements.

1. The value of the coefficient relative to the initial mass of deposit is negative. Therefore, for a constant value of the parameters, an increase in this mass reduces the rate constant value. Besides, the real length of time of cleaning exceeds that expected by two first order reactions in series whose rate constant would not depend on the initial mass of the deposit to be cleaned.
2. All the other coefficients are positive except two whose values are low. An increase in one of the three parameters brings about an increase in the rate constant. Therefore, in experimental conditions any increase in temperature, concentration or circulation rate of the soda solution reduces the length of time of cleaning. However, these three parameters have not the same influence and comparison of the different coefficient values shows that the temperature has a stronger influence than the soda concentration whose influence is higher than the circulation rate. This result is obtained on the basis of the values of the coefficients relative to coded variables and must be analyzed in relation with the variation range of each variable in experimental conditions. Thus, increasing the variables from value 0 to value 1 corresponds to a temperature increase of 12°C (75 to 87°C), a concentration increase of 1.15% (2 to 3.15%) and a circulation rate increase of 0.5 m/s (1.1 to 1.6 m/s). Assuming that the temperature has a larger influence than the soda concentration means that by increasing the coded variables of the same value, the rate constant increase caused by the temperature rise exceeds that caused by the soda concentration increase.
3. The value of the coefficient relative to the soda concentration squared is negative. Therefore, when this concentration increases, its favorable effect on the cleaning decreases more and more.

Table 3. Value and meaning of the regression coefficients (b_1) of the linear quadratic model of the rate constant k and of the regression coefficient (b_M) relative to the initial mass of deposit to be cleaned

Variables	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	M_0
Coefficients	b_0	b_1	b_2	b_1b_2	b_1b_3	b_2b_3	b_{11}	b_{22}	b_{33}	b_M
$\log k$	-1.01	0.27	0.20	0.02	-0.04	0.03	0.04	-0.04	0.03	-0.67
	$\pm 1.4 \cdot 10^{-2}$	***	***	**	N.S.	N.S.	N.S.	N.S.	N.S.	***
	(a) (s^{-1})									

x_1 = coded value of the temperature	*** significant at 0.1%
x_2 = coded value of the soda concentration	** significant at 1%
x_3 = coded value of the circulation rate	* significant at 5%
M_0 = initial mass deposit to be cleaned	N.S. not significant at 5%
(a) mean confidence interval at 95%	

4. The absolute values of the coefficients of the cross product and squared terms are clearly lower than the linear ones. The test at the 5% level confirms that only the linear term coefficients are significant. The quadratic model can thus be simplified to five terms in Eq. (8):

$$\log k = -1.01 + 0.27x_1 + 0.20x_2 + 0.16x_3 - 0.67M_o \quad (8)$$

The response surface denoted in the parameter space is then a plane. It is interesting to compare the increase in each parameter leading to the same rate constant increase for these results can be applied on the whole experimental space. By decoding Eq. (8), it can be calculated that a soda concentration increase of 1% causes the same increase of k as a temperature increase of 8°C or a circulation rate increase of 0.5 m/s for a given constant mass.

Discussion

In the kinetic model, the reactive pattern proposed consists of two first order reactions in series. It should be emphasized that this result was derived from the rate increase phase at the beginning of cleaning. This pattern cannot be compared to that proposed by Schlusser (1970), who, limited by the wettability test used, compared the kinetics to a zero order reaction. As for Jennings (1959b), he described the beginning of cleaning as a first order reaction. In contradiction with our results, he considered that the rate was continuously decreasing. Several facts may explain this difference.

The deposits cleaned are not similar; it should be noticed that Jennings dried a few milliliters of milk by steaming. He showed that this deposit can be cleaned only by circulating hot water at different temperatures, without adding any detergent (Jennings 1957). In the present case, the deposit obtained during raw milk pasteurization was not removed by hot water rinsing. It is obvious then that the composition and structure of the two types of deposits are different. Using radioactive counting, Jennings drew the curve of the remaining deposit mass to be cleaned. On this integral curve, it is extremely difficult to estimate whether the initial rate is null. On the contrary, in the present case, the information supplied by the optical sensor gives a clear picture of the cleaning rate.

As far as the influence of the parameters is concerned we shall compare successively the influence of each of them on cleaning with results from the literature.

According to Schlusser (1970) the cleaning rate increases to an

optimal temperature of about 85°C in the case of chocolate milk and buttermilk; then, it becomes stabilized when the temperature increases. In the case of milk he observed that the optimal cleaning temperature is 65°C; the cleaning rate rapidly decreases for higher temperatures. On the contrary, Jennings (1959b) showed that any temperature increase between 36°C and 82°C improves the cleaning; a 10°C increase of the temperature multiplies the cleaning rate by a factor of 1.6. Our results are very similar to those of Jennings since, for temperatures ranging from 55°C to 95°C, we found a multiplicative factor of 1.8 for a temperature increase of 10°C.

It is almost impossible to compare our results concerning the influence of the detergent concentration on the cleaning rate with those obtained by Jennings (1959b) who only studied soda concentrations below 0.6%. However, for Schlusser (1970), the cleaning rate increases with the detergent concentration up to a limit concentration (estimated to 0.8% for high alkaline detergents), then it becomes stabilized or decreases. Our study cannot confirm those results since any soda concentration increase between 0.1% and 3.9% had a favorable effect on cleaning. However, we showed that the higher the concentration, the lower the cleaning rate increase, although it does not tend to a maximum limit or even decrease. If a soda concentration increase always improves the cleaning, the improvement obtained can be limited due to slower penetration of the soda inside the deposit because of a viscosity increase.

Jennings *et al.* (1957) and Schlusser (1970) agree on a threshold below which the influence of the mechanical effect can be considered as negligible. Jennings characterized this threshold by a Reynolds' number of 25,000. According to our results, for Reynolds' values ranging between 10,000 and 70,000, any increase in the circulation rate, and therefore any increase in the mechanical effect improves the cleaning rate.

CONCLUSION AND PROSPECTS

Use of an optical sensor for on line measurement of the amount of milk deposit eliminated during cleaning enabled us to determine the cleaning rate. The development of this rate relative to time is rather complex; its rapid initial increase gradually slows down to a value beyond which the cleaning rate decreases more or less rapidly until it becomes null. The experimental conditions do not change the general aspect of the phenomenon, but they have a considerable influence on the numerical values of the cleaning rates observed. A reactive pattern,

taking as a hypothesis the formation of an intermediate compound during cleaning and consisting of two first order reactions in series with respect to the deposit quantities present, is suggested to explain the experimental observations. This pattern is characterized by an equal reaction rate constant.

In the experimental range studied (temperature 55°C to 95°C, soda concentration 0.1% to 3.9%, circulation rate 0.3 m/s to 1.9 m/s) it was possible to set up a linear mathematical model showing the influence of these three parameters on the cleaning rate constant. Thus, it became obvious that an equivalent increase of the rate constant can be obtained by increasing the soda concentration by 1% the temperature by 8°C or the circulation rate by 0.5 m/s with a constant deposit mass.

This model and the information obtained show the possibility of an important improvement in the cleaning of industrial pasteurizers. This information is an essential step to the technico-economical optimization of the processes. However, it gives only few details on the fundamental mechanisms of the processes involved in cleaning; penetration and wetting of the deposits by the cleaning solution, reactions of the compounds of the cleaning solution with the different compounds of the deposit, reactor hydrodynamics and so on. Since the understanding of these mechanisms seems to be necessary for a better control of the cleaning process, further investigations are in progress in our laboratory.

REFERENCES

- BOURNE, M. C. and JENNINGS, W. G. 1961. Some physicochemical relationships in cleaning hard surfaces. *Food Technol.* *15*, 495.
- BOURNE, M. C. and JENNINGS, W. G. 1963a. Existence of two species in detergency investigations. *Nature* *197*, 1003.
- BOURNE, M. C. and JENNINGS, W. G. 1963b. Kinetic studies of detergency. I. Analysis of cleaning curves. *J. Amer. Oil. Chem. Soc.* *40*, 517.
- BOURNE, M. C. and JENNINGS, W. G. 1963c. Kinetic studies of detergency. II. Effect of age, temperature and cleaning time on rates of soil removal. *J. Amer. Oil. Chem. Soc.* *40*, 523.
- COCHRAN, W. G. and COX, G. M. 1957. *Experimental Design*. Chapter 8a. John Wiley & Sons, New York.
- CORRIEU, G., LALANDE, M. and FERRET, R. 1980. New monitoring equipment for the control and automation of milk pasteurization. In *Food Process Engineering*, Vol. 1 (P. Linko *et al.* eds) pp. 165-171, Applied Science Publishers, London.
- GALLOT-LAVALLEE, T. 1979. Evaluation des coefficients de transfert de chaleur dans un échangeur tubulaire. D. E. A. ENSIA-MASSY.
- GALLOT-LAVALLEE, T., LALANDE, M., and CORRIEU, G. 1982.

- An optical method to study the kinetics of cleaning milk deposits by sodium hydroxide. *J. Food Process Engineering* 5, 131.
- GALLOT-LAVALLEE, T. 1982. Contribution a l'étude de la cinétique du nettoyage des pasteurisateurs de lait. Thèse de Docteur Ingénieur. ENSIA-MASSY.
- JENNINGS, W. G., MCKILLOP, A. A. and LUICK, J. R. 1957. Circulation cleaning. *J. Dairy Sci.* 40, 1471.
- JENNINGS, W. G. 1959a. Circulation Cleaning. II. Effects of entrained air. *J. Dairy Sci.* 42, 476.
- JENNINGS, W. G. 1959b. Circulation cleaning. III. The kinetics of a simple detergent system. *J. Dairy Sci.* 42, 1763.
- JENNINGS, W. G. 1960. Effect of pressure on circulation cleaning. *Food Technol.* 14, 591.
- JENNINGS, W. G. 1961. A critical evaluation of in vitro radioactive phosphorus additions for estimating soil deposits. *J. Dairy Sci.* 44, 258.
- JENNINGS, W. G. 1963a. An interpretive review of detergency for the food technologist. *Food Technol.* 17, 7.
- JENNINGS, W. G. 1963b. A kinetic approach to detergent synergism. *J. Amer. Oil Chem. Soc.* 40, 17.
- JENNINGS, W. G. 1965. Theory and practice of hard-surface cleaning. *Adv. Food Res.* 14, 325.
- LALANDE, M. and CORRIEU, G. 1981. Fouling of a plate heat exchanger by milk. In *Proceedings of Fundamentals and Applications of Surface Phenomena Associated with Fouling and Cleaning in Food Processing*. (B. Hallström *et al.* eds) pp. 279-288. Lund University. Alnarp (Sweden).
- LONCIN, M. 1976. Génie Industriel Alimentaire. Aspects fondamentaux, p. 212, ed. Masson, Paris.
- NELDER, J. A. and MEAD, R. 1965. A simplex method for function minimization. *Computer J.* 7, 308.
- SCHLUSSLER, H. J. 1970. Zur Reinigung fester Oberflächen in der Lebensmittelindustrie. *Milchwissenschaft* 25, 3, 133.
- SCHLUSSLER, H. J. 1976. Zur Kinetik von Reinigungsvorgängen an festen Oberflächen. *Brauwissenschaft*. 29, 9, 263.
- VUATAZ, L. 1979. Experimental design and response surface method in process optimization. In *Food Process Engineering*, Vol. 1 (P. Linko *et al.* eds) pp. 152-156. Applied Science Publishers, London.

ESTIMATION OF PARAMETERS FOR MOISTURE TRANSPORT IN FOODS¹

A. S. BAKSHI

*Department of Food Science and Nutrition
University of Minnesota
St. Paul, Minnesota 55108*

and

M. S. CHHINNAN

*Department of Food Science
University of Georgia
Experiment, Georgia 30212*

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ABSTRACT

The problem of estimation of transport parameters in food processing models is examined. A procedure is presented which consists of controlled experiments, application of theory to model the process and estimation of parameters by comparing the experimental and predicted data by the use of nonlinear optimization technique. The optimization program estimates a set of parameters in a food processing model which gives a minimum value of the sum of squares of the deviation between the observed and estimated values. The processes considered are drying, soaking and parboiling of rice and peanut drying. Depending on the complexity of the process, the solution of the mathematical model is given in the form of analytical, finite difference or finite element approximations. The precision of transport parameters determination is also discussed.

INTRODUCTION

The choice of appropriate equipment and method of food processing depends on many factors, among which are process cost and the desired

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product properties. Mathematical modeling approaches may be applied in determining the proper processing parameters for thorough analysis of a food process. Mathematical modeling aids in the reduction of experiments required to understand the influence of processing variables on the final product and thus saves time, cost and effort. One common phenomena in food processing is moisture transport. Moisture migration could occur during food drying, soaking, cooking or during storage and transportation of packed food. It is imperative to know the parameter values describing the transport phenomena prior to applying modeling techniques. These parameters can be estimated by conducting a series of experiments under controlled laboratory conditions. The experimental data are then compared with the estimated data as predicted by the mathematical modeling techniques. This optimization procedure involves adjusting the values of the transport parameters to minimize the squared error between the experimental values and the predicted values. In the past, linear optimization has been used due to computational ease. With the introduction of high speed computers, it has become feasible to use nonlinear optimization to estimate transport parameters. This gives a better estimate of the transport parameters, as the errors associated with transport measurements may not vary in a linear manner with experimental variables.

The objective of this paper is to describe a general approach to estimate the values of transport parameters from experimental data. The processes used for illustration are drying, soaking and parboiling, and the commodities considered are rice and peanuts. Nonlinear optimization techniques are employed in conjunction with the solution of equations describing the above processes. The examples considered involve solutions of mathematical equations by analytical, finite difference and finite element methods.

PROCEDURE

Model development is not limited to food processing operations alone. Tremendous amounts of literature are available on this subject matter and most of the approaches have the same basic underlying steps. In our study, a quantitative approach for parameter estimation based on the scheme suggested by Saguy and Karel (1980), is summarized below (Fig. 1).

1. The foremost step in mathematical modeling is defining the problem. This aids in achieving definite objectives.
2. The second step involves postulating a hypothesis and verifying the

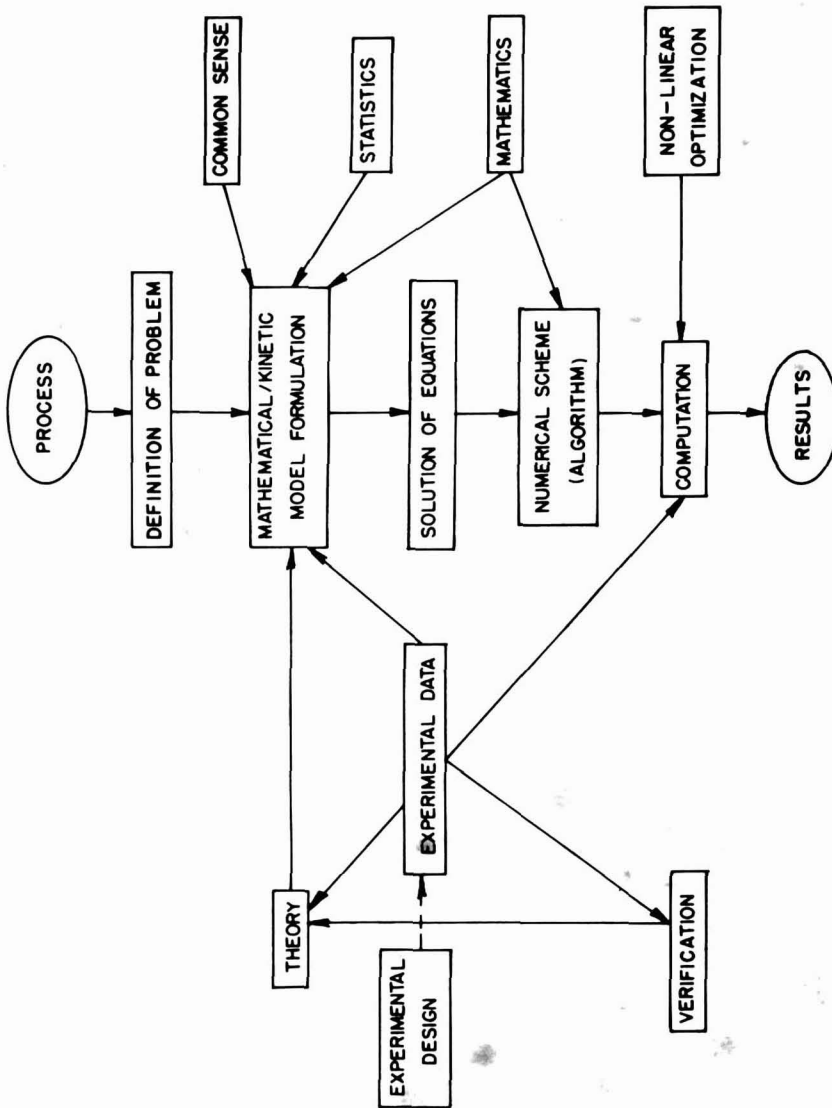


FIG. 1. MODEL DEVELOPMENT AND PARAMETER ESTIMATION.

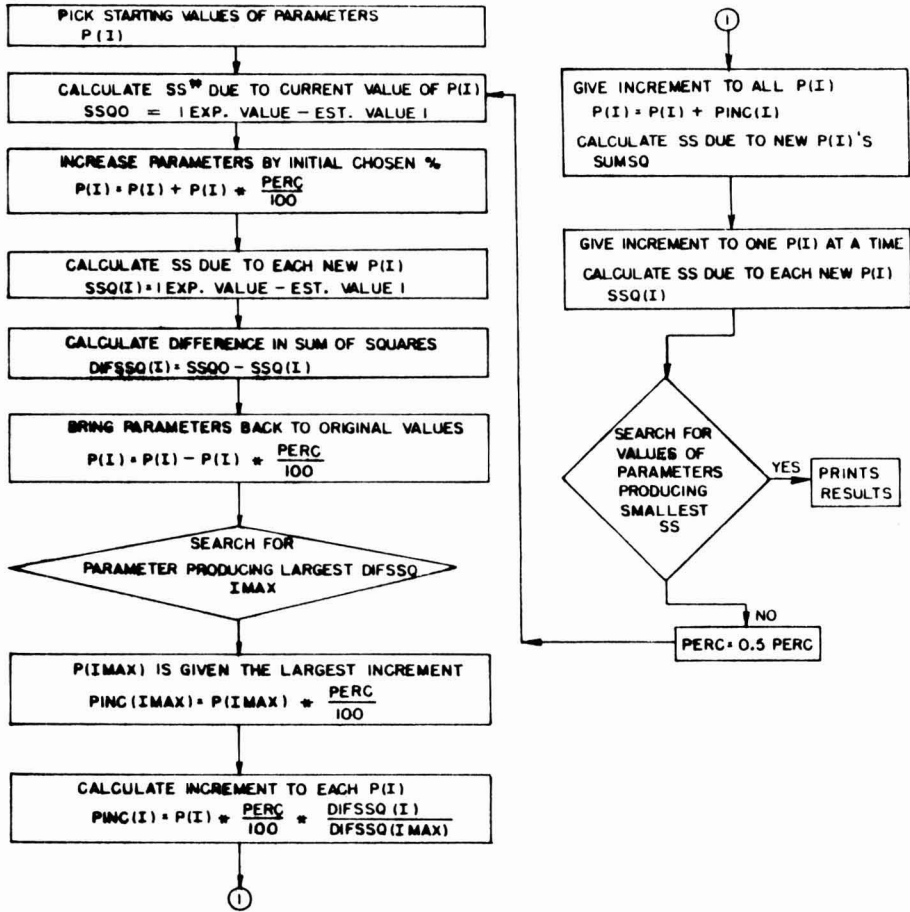
hypothesis describing the phenomena; or applying the theory, (if it already exists) that governs the phenomena.

3. Theory is written in terms of mathematical symbols that could be simultaneous algebraic and/or differential equations.
4. Depending on the complexity of the process, the differential equations are solved using analytical or numerical techniques.
5. After the solution is established, the algorithm is written.
6. Next, experiments covering the desired range of the variables are conducted to collect moisture transport data points. The final step is the estimation of transport parameters by minimizing the sum of square of deviations between the model predictions and experimental data.

Estimation of Parameters

There are several computer-aided subroutines and programs available for estimating the coefficients or parameters in mathematical models (Saguy and Karel 1980). A few examples are SAS (Helwig and Council 1979), IMSL and Marquardt (Kuester and Mize 1973). Each one of these programs has its own merits and demerits, the discussion of which is beyond the scope of this paper. A computer program in the form of a subroutine called SEARCH, written in Fortran, was developed by Chhinnan (1976) to estimate parameters of a model in any mathematical form. The program is based on the steepest ascent method for optimization. The logic diagram for that program is shown in Fig. 2. The details of the program are given below.

An initial set of parameter values is selected and the sum of squares of difference between the observed and estimated values is computed. A change is then made in the value of one parameter by a certain pre-defined percentage, say PERC, and the effect of change on the sum of squares is noted. The value of the parameter is then returned to its original value. The effect of change on value of each of the other parameters is then determined in turn, testing one parameter at a time. The relative change in the sum of squares produced by a parameter determines the relative amount of change in value of that parameter which should be made, in order to progress along a path of decreasing sum of squares. Now all the parameters are adjusted simultaneously, based on this relative amount of change in the sum of squares, and the new sum of squares is computed. This process of adjusting the parameters and computing the corresponding sum of squares is done iteratively until the sum of squares computed in the current iteration is greater than from the previous iteration. The above procedure is repeated by reducing the current



*SS - SUM OF SQUARED DEVIATION

FIG. 2. LOGIC DIAGRAM FOR SUBROUTINE SEARCH.

value of PERC by half to compute the next round of this optimizing scheme. The detailed listing of the program is available from the authors.

EXAMPLES

Some of the examples where the SEARCH subroutine was used to determine moisture transport parameters are discussed below. The last

example (rice parboiling) considers determination of the reaction rate constant also, in addition to the moisture transport parameter.

Peanut Drying

Chhinnan and Young (1977) considered peanut pod as a composite spherical body of two differing materials consisting of an inner spherical core of one component (kernel) and an outer concentric shell of another component (hull). The transfer of moisture from the peanut was considered to be diffusion, and the following equation describes the moisture concentration distribution at any radial distance r with time t :

$$\frac{\partial C}{\partial t} = D_j \left[\frac{\partial^2 C}{\partial r^2} + \frac{2}{r} \frac{\partial C}{\partial r} \right] \quad (1)$$

where C = the moisture concentration,
 D_j = the diffusivity of material j .

The Crank-Nicolson method (implicit form) of finite difference approximation was used for partial derivatives with respect to space (r) and time (t). The details of the finite difference scheme can be found in standard numerical analysis books like Carnahan *et al.* (1969). The solution of Eq. 1 gives the moisture concentration with time. These values when divided by density of the peanut provided the moisture distribution. The moisture distribution was integrated over the radius of the sphere (peanut) and average moisture content was determined. The simulated values were compared with experimental moisture content to determine the mass diffusivity of kernel (D_1) and that of hull (D_2) using SEARCH subroutine. The values of D_1 and D_2 are given in Table 1.

Rice Drying

Steffe and Singh (1980) used a similar approach as above for rough rice drying. They assumed rice as a composite sphere of three concentric shells. They designed three experiments to determine three parameters, one at a time, associated with drying of rough rice. These three parameters were moisture diffusivities of starch endosperm, bran and hull. The first experiment was to determine the diffusivity of the innermost material, starchy endosperm. They removed the bran and hull and obtained drying data. Analytical solution of Eq. 1 of the form

Table 1. Best estimate of mass diffusivities in a two-component drying model applied to peanuts (Chhinnan and Young 1977)

Dew point °C	Dry bulb °C	<u>Diffusivity</u>	
		$D_1 \times 10^6$ m ² /hr	$D_2 \times 10^6$ m ² /hr
8.9	26.7	0.1881	0.2062
	32.2	0.2706	0.2715
	37.8	0.4197	0.3200
	43.3	0.4534	0.4085
13.3	26.7	0.2141	0.2148
	32.2	0.2825	0.2875
	37.8	0.3837	0.3801
	43.3	0.4697	0.4198
17.8	26.7	0.2292	0.1691
	32.2	0.3344	0.2301
	37.8	0.4056	0.2741
	43.3	0.6815	0.3235
22.8	26.7	0.2627	0.1273
	32.2	0.5277	0.2162
	37.8	0.6568	0.2899
	43.3	0.8499	0.3606

D_1 = Kernel diffusivity

D_2 = Hull diffusivity

$$\frac{C - C_e}{C_o - C_e} = \frac{2R_1}{\pi r} \sum_{n=1}^{\infty} \frac{(-1)^n}{n} \sin\left(\frac{n\pi r}{R_1}\right) \exp\left(-\frac{D_1 n^2 \pi^2 t}{R_1^2}\right) \quad (2)$$

taken from Crank (1975), for spherical bodies, was used to estimate the diffusivity, D_1 , of starch endosperm from the experimental data. Next, they removed only the hull from rough rice and conducted drying experiments on brown rice. They considered brown rice as a two-component, composite spherical body and used the finite difference scheme outlined by Chhinnan and Young (1977). Two parameters associated with the brown rice drying model are D_1 and D_2 , diffusivity of endosperm and

bran, respectively. D_1 value estimated from the first experiment was substituted in the model and D_2 , the only parameter left to be determined, was estimated from the brown rice drying data. The last experiment involved obtaining the drying data for the rough rice. Rough rice modeled as a three-component, composite spherical body had three parameters associated with it; D_1 , D_2 and D_3 . D_1 and D_2 were known from the first two experiments and D_3 was estimated from the rough rice data. The values of mass diffusivities of endosperm, bran and hull are shown in Table 2.

Thin Layer Drying of Raw and Parboiled Rice

If rice is considered to be composed of simple material, a thin layer drying equation relating average moisture content, equilibrium moisture content, and drying air relative humidity and temperature can be developed (Bakshi and Singh 1980a). This equation can be integrated over the length and width of a dryer to simulated drying of rice. One such equation as suggested by Page (1949) is:

$$\frac{m - m_e}{m_o - m_e} = \exp(-Pt^{\varrho}) \quad (3)$$

Table 2. Best estimate of mass diffusivities in a three-component drying model applied to rice (Steffe and Singh 1980)

Dry bulb °C	Dew point °C	Diffusivity = $m^2/hr \times 10^7$		
		D_1	D_2	D_3
35	28.7	2.11	.492	.152
40	33.3	2.23	.507	.201
45	37.8	3.56	.652	.201
50	42.1	3.76	1.012	.394
55	47.2	4.24	1.558	.409

D_1 = Starch diffusivity

D_2 = Bran diffusivity

D_3 = Hull diffusivity

$$P = C_1 + C_2T + C_3Rh$$

$$Q = C_4 + C_5T + C_6Rh$$

where m = average moisture content, (dry basis), dimensionless
 m_e = equilibrium moisture, (dry basis), dimensionless
 m_o = initial moisture, (dry basis), dimensionless
 t = time, h
 T = temperature, C
 Rh = relative humidity, %
 C_i = i th constant ($i=1$ to 6)

The values of the six constants C_i were determined for raw and parboiled rice using the SEARCH subroutine and are shown in Table 3.

Rice Soaking

In the study of Zhang, Bakshi and Gustafson (1983), a finite element analysis was used to model simultaneous water absorption and expansion of rice during the soaking process. The solution of Eq. 1 for diffusion using finite elements is:

$$[K]\{C\} + [C_p] \frac{\partial C}{\partial t} = \{F\} \quad (4)$$

$[K]$, $\{C_p\}$ and $\{F\}$ are conductance, capacitance and force matrices. The form of these matrices are as given by Segerlind (1976). The nodal

Table 3. Best estimates of constants in the thin layer equation for raw and parboiled rice in the temperature range of 40–60°C and relative humidity range of 40–70% (Bakshi and Singh 1980a)

Rice	Constants					
	C_1	C_2	C_3	C_4	C_5	C_6
Raw rough	.74498	.00026	.00033	.09407	.00598	.01134
Raw brown	.43896	.00027	.00067	.09330	.00727	.01551
Parboiled rough	.50326	.000273	.00017	.06444	.00463	.01471
Parboiled brown	.01653	.00017	.00647	.77660	.00141	.07367

displacements (due to expansion) are obtained in the finite element by minimizing the potential energy of the system, which yields the following equation:

$$[k]\{V\} + \{f\} = 0 \quad (5)$$

$[k]$, $\{V\}$ and $\{f\}$ are the stiffness, displacement and force matrices respectively. The form of these matrices can again be found in Segerlind (1976). The authors assumed a concentration dependent mass diffusivity (D_F), given by the following equation:

$$D_F = D_o \left(\frac{\rho_o}{\rho} \right)^{n_1} e^{n_2(C - C_o)} \quad (6)$$

ρ is the dry mass density and subscript "o" refers to the initial condition. n_1 , n_2 , and D_o are constants to be estimated from the experimental data.

The simultaneous solution of Eq. 4 and 5 give the instantaneous concentrations and displacements of the nodes. Next, the volume of each element is calculated from the new node coordinates. The instantaneous mass diffusivity, D_F , is then calculated from Eq. 6 to evaluate the concentration for the next time step. The mass average moisture content from the finite element model is compared to the experimental values of water uptake using SEARCH subroutines to calculate the values of n_1 , n_2 and D_o , which are given in Table 4.

Rice Parboiling

In the parboiling process (Bakshi and Singh 1980b), rice is hydrated in water. The water diffuses into the rice and some portion of the water becomes immobilized due to absorption of water into starch structure and reacts causing gelatinization. If absorption of water and gelatinization are considered as first order irreversible reactions, the following equation can be used to describe the hydration process for a sphere:

$$D \frac{\partial^2 C}{\partial r^2} - KC = \frac{\partial C}{\partial t}$$

The solution of this equation in the form of amount of water absorbed in time t is given by:

Table 4. Best estimates of transport parameters during rice soaking at 60°C (Zhang, Bakshi and Gustafson 1983)

Initial diffusivity, D_0	$6.4 \times 10^{-7} \frac{\text{m}^2}{\text{hr}}$
Density exponent, n_1	2.59
Concentration exponent, n_2	0.815

$$Q = 8\pi a D C_o \sum_{n=1}^{\infty} \frac{(Ka^2 + Dn^2\pi^2)Ka^2t - Dn^2\pi^2a^2 \exp[-t(Ka^2 + Dn^2\pi^2)/a^2] + Dn^2\pi^2a^2}{(Ka^2 + Dn^2\pi^2)^2} \quad (7)$$

where D = Diffusivity, m^2/h
 C_o = Surface water concentration, m^3/kg
 a = Radius, m
 K = Reaction rate constant, $1/\text{h}$
 Q = Amount of water absorbed, kg

The values of D and K were determined using nonlinear optimization program SEARCH. The relationship of these parameters to the temperature in the form of Arrhenius equations is shown in Table 5.

Table 5. Arrhenius relations for mass diffusivities and reaction rate constants for rough rice (Bakshi and Singh 1980b)

Temp range, °C	Diffusivity m^2/hr	Reaction rate constant $1/\text{hr}$
70 - 85	$D_1 = 1.0075 \times 10^{-1}$ $\text{Exp}(-3.9723 \times 10^3/T_a)$	$K_1 = 3.1143 \times 10^{11}$ $\text{Exp}(-9.32695 \times 10^3/T_a)$
85 - 120	$D_2 = 6.2039 \times 10^{-3}$ $\text{Exp}(-7.9008 \times 10^3/T_a)$	$K_2 = 4.6461 \times 10^7$ $\text{Exp}(-5.2692 \times 10^3/T_a)$

T_a = Absolute temperature, K

ACCURACY OF PARAMETERS

The parameters as determined using the SEARCH subroutine were compared with parameters as determined by other methods. A given set of data was fitted to a straight line and second degree equation using linear and multilinear regression. The same data was then fitted to a model containing three parameters. The parameters in this model were determined using another nonlinear optimization program which used derivatives of the model with respect to each of the three constants. For all of the above cases, the percent error in the parameters was less than 5%. The error was defined as follows:

$$\text{Error} = \frac{\Delta p}{p} \times 100$$

where Δp is the difference between the parameter value determined by SEARCH and the other method. p is the parameter value as determined by the second method.

In another study, Steffe (1979) dried rough rice in a shallow layer at eight different drying conditions. He compared the experimental final moisture content of rice to the predicted values using transport parameters as shown in Table 2. He found the percentage error between the predicted and experimental moisture content to be less than 10%.

The above examples show that SEARCH optimization program is as good as other linear/nonlinear programs in estimating parameters for moisture transport in foods. However, most of the other nonlinear optimization programs require derivatives with respect to each of the parameters. The SEARCH subroutine does not require such information. One of the major advantages of the SEARCH subroutine is that it can easily be called by any other main computer program (using numerical analysis) to estimate transport parameters in foods for a given process.

The examples discussed here are for water absorption and desorption. However, this procedure can also be used for estimating kinetic parameters associated with other reactions.

REFERENCES

- BAKSHI, A. S. and SINGH, R. P. 1980a. Drying characteristics of parboiled rice. Drying 80. Proceedings of the Second International Symposium on Drying. 2, 282-288.

- BAKSHI, A. S. and SINGH, R. P. 1980b. Kinetics of water diffusion and starch gelatinization during rice parboiling. *J. Food Sci.* 45(5), 1387-1392.
- BENSON, S. W. 1960. *The Foundations of Chemical Kinetics*, McGraw-Hill Book Co., New York.
- CARNAHAN, B., LUTHER, N. A. and WILKES, S. O. 1969. *Applied Numerical Methods*. John Wiley & Sons, New York.
- CHHINNAN, M. S. 1976. Bulk thin-layer models for drying of peanuts in pods. Ph.D. Thesis, North Carolina State University, Raleigh, NC.
- CHHINNAN, M. S. and YOUNG, J. H. 1977. A study of diffusion equations describing moisture movement in peanut pods – I. Comparison of vapor and liquid diffusion equations. *Trans. ASAE.* 20(3), 539-546.
- CRANK, J. 1975. *The Mathematics of Diffusion*, 2nd Ed., Oxford University Press, Ely House, London.
- HELWIG, J. T. and COUNCIL, K. A. (ed.) 1979. *SAS User's Guide*. SAS Institute, Cary, NC.
- KUESTER, J. L. and MIZE, J. H. 1973. *Optimization Techniques with Fortran*, McGraw-Hill Book Co., New York.
- PAGE, G. E. 1949. Factors influencing the maximum rates of air-drying shelled corn in thin layers. M.S. Thesis, Purdue University, Lafayette, IN.
- SAGUY, I. and KAREL, M. 1980. Modeling of quality deterioration during food processing and storage. *Food Technol.* 34(2), 78-85.
- SEGERLIND, L. J. 1976. *Applied Finite Element Analysis*, John Wiley & Sons, New York.
- STEFFE, J. F. 1979. Moisture Diffusion and Tempering in the Drying of Rough Rice. Ph.D. Thesis, University of California, Davis, CA.
- STEFFE, J. F. and SINGH, R. P. 1980. Liquid diffusivity of rough rice components. *Trans. ASAE.* 23(3), 767-783.
- ZHANG, T., BAKSHI, A. S. and GUSTAFSON, R. J. 1983. Finite element analysis of nonlinear water diffusion during rice soaking. Paper presented at the 43rd annual meeting of the Institute of Food Technologists. New Orleans (Abstract #13). June 20-22.

BOOK REVIEW

Handbook of Package Engineering. Second Edition, 1984. By Joseph F. Hanlon. McGraw-Hill, New York, NY. \$59.50. app. 500 pp.

With forty-six years experience in packaging, Mr. Joseph Hanlon has been exposed to the world of packaging. And this book of approximately 500 pages reads like exposure. All of the world's packaging is there, probably, as if a stroboscopic light has flickered on as each packaging soldier marches by.

To compress virtually everything in packaging into twenty chapters is an achievement. And, on the surface, Mr. Hanlon's Handbook is a definitive compendium that encompasses everything you ever wanted to know about packaging.

But, the book is so evenly written that wood containers receives thirteen pages, the same as bags, pouches and envelopes. Aseptic and retort pouch packaging each receive two paragraphs and linear low density polyethylene barely a mention. Meanwhile, in sharp contrast to the almost scanty treatment of most subjects, printing of paperboard is detailed down to the removal of the steel straps on the skids.

The book was and is a grand idea, but it is too short to be an encyclopedia or a reference and too long and too terse to be a textbook. I tried to use the original as a reference for many years but found its writeups on subjects too short to provide needed information.

The tables are profuse and detailed, but with no source or authority. On what basis does packaging represent 22% of the manufacturer's selling price in the food industry? The photographic illustrations are generally old and not representative of the topic they are trying to portray. On the other hand, line drawings of concepts are well-done and generously distributed throughout the volume.

The most serious deficiency for the serious reader, however, is a total absence of any references. How either the author or the editors could assemble so much information, tantalize the reader with brief summaries and then omit any lead to further data is difficult to understand.

Mr. Hanlon's book is precisely what it says, a handbook, a referral volume that provides a quick answer. And that is too bad because Mr. Hanlon's knowledge and the world's needs far exceed what has been published.

AARON L. BRODY

LITERATURE ABSTRACTS

ABSTRACTS FROM JOURNAL OF FOOD SCIENCE

High Vacuum Flame Sterilization of Canned Diced Tuna: Preliminary Process Development and Quality Evaluation. S. T. Seet, J. R. Heil, S. J. Leonard, and W. D. Brown. *J. Food Sci.* 48, 364, 369 + 374.

A preliminary study of the potential of high vacuum flame sterilizing canned diced tuna was carried out. The investigation included inoculated experimental sighting packs study at five process levels, and comparative assessment of the physical, chemical and nutritional property of the raw, precooked, high vacuum flame sterilized (HVFS) and still-retorted canned tuna. The vacuum achieved in the HVFS packs was significantly higher ($P < 0.05$) than the control packs. Fatty acid and amino acid composition, in-vitro protein digestibility, and the Computed Protein Efficiency Ratio (CPEP) were similar for the raw, precooked and canned tuna. Available lysine was marginally decreased by precooking, and HVFS processing caused no measurable change. However, available lysine, thiamin, riboflavin, niacin and mineral concentrations were generally lower in the retort process control canned tuna.

Preconcentration of Apple Juice by Reverse Osmosis. M. J. Shfu, and R. C. Willy. *J. Food Sci.* 48, 422-429.

Single strength apple juices (10° Brix) were processed by reverse osmosis to 20-25° Brix, primarily at 20°C. A pilot scale plate and frame UI-RO system equipped with cellulose acetate (CA) membranes, CA-865 and/or CA-990, of high resistance (HR) membranes, HR-95 and/or HR-98, was operated at pressures of 35-45 bar. At 45 bar, the larger pore-sized CA-865 possessed the highest processing capacity of 26.9 L/m²/hr (from 10° Brix to 20° Brix) and concentration limits of 35° Brix, but had low recovery of solutes and flavor volatiles. The HR-95 and HR-98 had similar processing capacities of 15-16 L/m²/hr and concentration limits of 20-25° Brix at 45 bar. The recoveries of 97% solutes and 87% apple flavor volatiles were obtained using either the HR-95 or the HR-98.

Water Velocity Effect on Heat Penetration Parameters During Institutional Size Retort Pouch Processing. W. R. Perterson and J. P. Adams. *J. Food Sci.* 48, 457, 459 + 464.

Institutional size retort pouches (15 × 12 × 1'') filled with 10% bentonite were processed in water with overriding air pressure. The heat penetration parameter, f_h , was measured at seven flow rates from 10 gal/min ($Re = 3000$) to 110 gal/min ($Re = 33000$). Apparent convection heat transfer coefficients (h -values) were cal-

culated. Significant differences were found for both the h -value and observed f_h value as a function of flow rate. The h -values ranged from 33–48 BTU/hr ft² F and the observed f_h values ranged from 23.0–20.1 min for 10 and 110 gal/min, respectively.

Kinetics of Protein Quality Loss in Enriched Pasta Stored in a Sine Wave Temperature Condition. J. Y. Chen, K. Bohnsack and T. P. Labuza. *J. Food Sci.* 48, 460–464.

The rate of loss of protein quality in enriched pasta was studied at constant temperature (30, 37 and 45°C) and under a continuous sine wave temperature fluctuation (25/45°C with a 24-hr period). Both loss of lysine by the fluorodinitro benzene (FDNB) method and a bioassay (*Tetrahymena thermophila* growth) for protein quality were employed. Significant loss of protein quality occurs in about 1 yr at temperatures above 30°C. The bioassay method showed that nutrient losses other than lysine could be occurring. Data from the constant temperature studies were used to predict the losses that occurred for the sine wave condition using the Hicks-Schwimmer model as modified with an Arrhenius approach. The prediction model gave about 15% error in comparison to actual losses. In addition, the rate of loss for the sine wave (25/45°C) was greater as predicted than the rate of loss at a constant mean temperature of 35°C.

Characterization of Polymer and Solute Bound Water by Pulsed NMR. K. W. Lang, and M. P. Steinberg. *J. Food Sci.* 48, 517, 520 + 538.

Pulsed NMR signals from water in combination with two polymers and two solutes, individually and in mixtures, was measured over a_w range 0.75–0.95. Both spin-lattice (T_1) and spin-spin (T_2) relaxation curves showed negligible slopes for water with starch and casein (polymer water) and large for water with sucrose and salt (solute water). Mixtures of polymer and solute waters showed intermediate slopes. Dilution of a sucrose solution gave T_1 and T_2 responses approaching that of pure water. T_2 from NaCl indicated less and from sucrose more water structure than pure water. NMR data coincided with sorption isotherms. It was concluded that polymer and solute waters show different NMR responses and can coexist in a food.

Modeling of Residence Times in Continuous Fluidized Bed Freezers. A. Vazquez and A. Calvelo. *J. Food Sci.* 48, 1081–1085.

A longitudinal dispersion model is proposed for analyzing the movement of peas along continuous fluidized bed freezers. By comparing the model with experimental data, a dispersion coefficient is obtained which correlates satisfactorily with the bed height and the superficial air velocity. Thus, minimum residence times can be predicted in terms of bed dimensions and operating conditions in the

fluidized freezer. By adapting an individual particle model for freezing time prediction to the existing conditions in fluidized bed freezers, the analysis of production rate in terms of design parameters is performed. Thus, an optimum bed height which maximizes the production rate per unit of grid area is obtained.

The Finite Element Method in Thermal Processing of Foods. I. J. Kopelman and I. J. Pflug. *J. Food Sci.* 48, 1086–1093.

A variational finite element approach using triangular simplex and 2nd order quadrilateral elements was employed to analyze several problem areas that are of practical importance in the thermal processing of conduction heating products: (1) A method was developed to calculate conversion factors for thermal process design applicable to glass jars filled with conduction heating products. (2) The overshooting of temperatures after steam-off was studied, indicating that not including the contribution of overshooting to sterilization values in process design, can lead to gross overprocessing. (3) A method of correcting sterilization values to account for harmonious fluctuations in retort temperature was developed. (4) The air cooling of cans by natural convection was analyzed.

Development of High Vacuum Flame Processes for Sliced Peaches and Pears. J. R. Heil, P. A. Carroad, R. L. Merson and S. Leonard. *J. Food Sci.* 48, 1106–1112 + 1123.

Clingstone peach and Bartlett pear slices were successfully sterilized by high vacuum flame processes without the conventional covering of syrup or water. The processes developed are simple and continuous, and applicable to commercial use. With the exception of blanching and deaeration, the processes use existing canning practices. Through 18 months storage, more of the original flavor and texture of the fresh fruit was retained by HVFS packs than by the comparable conventional packs. No spoilage was experienced in any of the packs.

Ultrafiltration of Acid Whey in a Spiral-Bound Unit: Effect of Operating Parameters on Membrane Fouling. K-P. Kuo and M. Cheryan. *J. Food Sci.* 48, 1113–1118.

Membrane fouling by acid (cottage cheese) whey could be minimized by appropriate pH adjustment and removal of insoluble particulates. Acidifying pasteurized whey to pH 2 or 3 followed by conventional centrifugal clarification (e.g. 5000g for 20–30 sec) significantly improved flux over that of unadjusted whey. Neutralizing whey to pH 7 was also just as effective provided resulting insoluble particles could be removed efficiently. Operating at 50°C was slightly more beneficial than 40° or 30°C. High flow rates were beneficial only if transmembrane pressure was below some critical value (about 50 psig or 350 kPa in this case). At pressures higher than this, high flow rates significantly increased

fouling rates. After prolonged operating time, neither flow rate nor pressure appeared to have a significant effect, due perhaps to a change in the mode of fouling from surface deposition to pore adsorption.

Residence Time Distributions for Wheat Starch in a Single Screw Extruder. V. J. Davidson, D. Paton, L. L. Diosady and W. A. Spratt. *J. Food Sci.* **48**, 1157–1161.

Residence time distributions for wheat starch in a single screw extruder were measured for different operating conditions using a manganese dioxide tracer. Two flow models which differed in the definition of dead space were used to represent the flow pattern in the extruder. The parameters for each model were fitted using the experimental residence time distributions. Screw speed and the moisture level of the feed showed the strongest effects on the average residence time. A small fraction of the flow, 5–20%, was held up in the dead space region. The remainder passed directly through the active region with a residence time distribution close to plug flow. An apparent power law index for the starch melt was calculated and over the experimental range of extrusion conditions it varied from 0.2 to 1.0.

Some Theoretical Rheological Characteristics of the Mechanical Signals in Sensory Evaluation of Texture. M. Peleg. *J. Food Sci.* **48**, 1187–1191.

In sensory evaluation of mechanical properties, the gauged object and the tissues in contact (i.e. the hand, mouth, etc.) form a system that can be described by an in-line array of two models, the object's and the tissue's. The hypothetical rheological properties of such combined systems were studied qualitatively using simple phenomenological models with and without failure criteria. It is demonstrated that the mechanical stimulus reaching the human sensory system can be different in both kind and magnitude from the signal produced by testing machines irrespectively of the test geometry. It is also shown how the deformation rate can affect the rheological character of the stimulus and how damage to the sensory system (particularly the teeth) can occur if the deformation rate is not controlled.

Water Activity Measurements with a Capacitance Manometer. J. A. Troller. *J. Food Sci.* **48**, 739–741.

The design, use and performance of a capacitance manometer for the measurement of water activity (a_w) are evaluated. The device consists of a sensitive capacitance sensor for measuring the vapor pressure of a sample. This value is then divided by a known value for the vapor pressure of pure water at a specific temperature to obtain a_w . Precision and accuracy of this instrument are

determined and compared to a conventional electric hygrometer. These parameters are similar to the hygrometer, however, the principal advantages of the capacitance manometer may occur in circumstances in which direct measurements of a_w are required and situations in which contamination of hygrometric sensors could occur.

A Method to Measure Surface Heat Transfer from Steam/Air Mixtures in Batch Retorts. H. S. Ramaswamy, M. A. Tung and R. Stark. *J. Food Sci.* 48, 900–904.

A method employing transient heating was developed to determine surface heat transfer coefficients associated with steam/air mixtures in batch retorts. The method was based on instantaneous introduction of a highly conductive brick-shaped test block of uniform initial temperature into a heating medium which was prestabilized at the desired temperature and pressure conditions. The results of a study to verify the utility of the method revealed an exponential relationship between the heat transfer coefficient and the steam content of the medium.

A Hybrid Solar-Biogas System for Food Drying: Biogas Generation from Processed Papaya Wastes. P. Y. Yang, J. H. Moy and M. H. Weitzenhoff. *J. Food Sci.* 48, 905–908.

A solar-biogas system was designed to dry food more efficiently than with solar energy alone. Processed papaya waste was anaerobically fermented to produce methane to augment solar energy for food drying. A gas with a minimum of 50% methane was produced at a rate of 0.38 liter methane per liter of digester volume per day with an organic loading rate of 1.60g of total volatile solids in the waste per liter of digester liquid volume per day in a once-through system. Results indicate technical feasibility.

Freezing Time Predictions for Brick and Cylindrical-Shaped Foods. A deMichelis and A. Calvelo. *J. Food Sci.* 48, 909–913 + 934.

A simplified model previously developed for freezing time calculations in plate freezers is extended to systems with two or three dimensional heat flow. The model combines Plank's equation with the unsteady heat transfer solutions for bodies with constant properties, through the addition of pre-cooling, change of phase and tempering times. Average thermal properties, different for each period are used in order to take into account their change with the ice content along the freezing process. Freezing time predictions show a maximum difference of 10% with respect to freezing experiments performed with meat blocks shaped as cylinders or rectangular bricks. Processing times from 0.7–5 hr were compared with satisfactory agreement.

Storage Stability of Intermediate Moisture Apples: Kinetics of Quality Change. R. K. Singh, D. B. Lund and F. H. Buelow. *J. Food Sci.* **48**, 939-944.

Storage stability of intermediate moisture apples was studied as a function of storage temperature and water activity. The criteria for storage stability was based on three quality factors, namely, non-enzymatic browning reactions, vitamin C degradation and microbial growth. Analysis of kinetic data suggested a zero order reaction for nonenzymatic browning, and a first order reaction for vitamin C degradation. The effect of temperature on the rate constant followed the Arrhenius relationship. Based on this study, it was not possible to generate a kinetic model for microbial growth. However, growth/no growth regions based on temperature and water activity were identified.

The Energy Balance: A Diagnostic Tool for Energy Optimization. E. Rotstein. *J. Food Sci.* **48**, 945-950.

The energy balance is shown to be a combined statement of the first and second laws of thermodynamics. It provides insight into the energy performance of industrial operations, showing the ideal and actual energy bounds (energy change and production of entropy) as well as electrical and other utilities consumption. Calculation of energies in different situations within the food industry is shown. A tomato paste plant and two heat-optimized configurations of the same are evaluated by means of the energy balance. A similar analysis is carried out for the case of whey drying. It is concluded that the energy balance is a useful diagnostic tool for the energy analysis and optimization of the food industry.

Predicting the Texture of Liquid and Melting Semisolid Foods. J. L. Kokini. *J. Food Sci.* **48**, 1221-1225.

Magnitude estimations of a variety of dairy foods show that sensory assessments scores of "creaminess" can be predicted from scores of "smoothness" and "thickness." The empirical equation found for these predictions is very close to that found earlier for model solutions. Assessments of "smoothness" can be related to instrumental measurements of contact friction. Assessments of "thickness" for melting foods are related to estimates of shear stresses in the mouth generated during the melting of foods.

A Deviant Heat Process Applied to Canned or Packaged Liquid Food. F. Huang and K. Hayakawa. *J. Food Sci.* **48**, 1229-1234 + 1241.

A new procedure was developed for predicting the correction factor of a deviant thermal process applied to canned or packaged convection heating food. This development was accomplished through a combined application of a

mathematical model for estimating process lethality and statistical procedures. Through a dimensional analysis of the mathematical model it was found that there were nine independent dimensionless parameters required to define uniquely correction factors. The influence of each parameter was determined by applying a statistical design of screening tests. Of the nine dimensionless parameters, only two parameters, which contained a magnitude of drop in heating medium temperature, duration of this drop, the slope index of thermal death time curve, and the slope index of heating curve influenced significantly the correction factor. Those of no significant influence included initial food temperature, retort temperature, cooling water temperature, drop location, and normal processing time. A simple polynomial equation was obtained for predicting the correction factor by applying a central composite design of experiments and a statistical regression analysis. The reliability of this equation was verified through heat transfer experiments by using canned distilled water, 0.1% bean gum aqueous solution, and tomato juice.

Calorimetric Studies on Whey Freeze Concentration. A. S. Bakshi and R. M. Johnson. *J. Food Sci.* 48, 1279–1283.

The freezing point of whey was determined at 3, 5, 10, 15 and 20% solids content in an automatic Osmometer, and effective molecular weight of the solute was determined to be 235 using freezing point depression equations. Differential Scanning Calorimetry was used to estimate the specific heat of whey in the temperature range -40 to 20°C . The frozen water fraction and refrigeration requirements are predicted as a function of temperature. Correlations of enthalpy and the freezing point of whey are presented. With these correlations, energy required for freezing whey can be computed. The application of thermodynamic data to whey freeze concentration is demonstrated.

Prediction of Come-Up Time Correction Factors for Batch-type Agitating and Still Retorts and the Influence on Thermal Process Calculations. M. R. Berry, Jr. *J. Food Sci.* 48, 1293–1299.

A come-up time correction factor of 42% has been traditionally accepted for thermal processing, and was found to be applicable for model foods heated in cans in a Steritort and a still retort when the retorts were heated to processing temperature with a constant rate of temperature rise. Correction factors were larger when both retorts were heated with an initial rate of temperature rise faster than linear heating. A 77% correction factor was measured during Orbitort processing, and was more conservative for predicting processing time than assuming 42%. Product initial temperatures of 70 and 160°F resulted in correction factors of 70 and 45% when the still retort was heated linearly, and reached 83 and 69% with normal venting. The experimental procedure for predicting the come-up factor does not require instantaneous retort heating as a baseline for comparison.

Thermal Stability of Vitamin B6 Compounds in Liquid Model Food Systems. J. F. Gregory III and M. E. Hiner. *J. Food Sci.* **48**, 1323–1327 + 1339.

The degradation of pyridoxine (PN), pyridoxal (PL), and pyridoxamine (PM) during thermal processing was evaluated in casein-based liquid model food systems. Limited evaluation of various potentially reactive ingredients suggested that vitamin B6 stability is not strongly a function of food system composition. Rapid interconversion of PL and PM was observed. Kinetic analysis of B6 vitamers degradation revealed approximately 2.5- to 3.5-fold greater stability of PN than the other nonphosphorylated vitamers, with activation energies of 27.3, 23.7 and 20.8 kcal/mol for the loss of *total* vitamin B6 after initial fortification with PN, PM, and PL, respectively. Limited studies with pyridoxal 5'-phosphate indicated that it is approximately 1.5- to 2-fold less stable than PL.

Effect of Temperature on Water Diffusion in Soybean. K. H. Hsu. *J. Food Sci.* **48**, 1364–1365.

Influence of temperature on the concentration-dependent diffusivity of water into soybean was investigated. At a constant water content, Arrhenius relation existed between the water diffusivity and temperature. The activation energy for diffusion was found to be between 9 and 13 Kcal/mole. The activation energy also was found to vary linearly with the water content.

A Method for Predicting Gelation of Aseptically Packaged Steam Injected UHT Milk. K. R. Swartzel. *J. Food Sci.* **48**, 1376–1377.

The gelation of sterile UHT steam injected dairy products was investigated by determining the time of gelation onset and the gelation rate. Fat percentages of the products were 0.5, 3.25, and 10.5. Each product was processed at 411°K for 20.3 sec, 416°K for 6.9 and 20.3 sec and 422°K for 3.4, 6.9, and 20.3 sec. Products were stored at 277 and 297°K. Viscosity measurements were taken with four commercial viscometer assemblies and viscosity data compiled at a shear rate of 1 sec⁻¹. Velocity rate constants (*k*) were determined using regression analysis. Prediction equations were formulated for the time of gelation onset and the rate of gelation depending on the severity of the thermal treatment, percent fat and storage temperature.

A New Model for Describing the Water Sorption Isotherm of Foods. J. Chirife, R. Boquet, C. Ferro Fontan and H. A. Iglesia. *J. Food Sci.* **48**, 1382–1383.

This work investigated the applicability in the food area of a new sorption equation recently developed by Ferro Fontan *et al.* (1982). The equation may be writ-

ten, $\ln(\gamma/a_w) = \alpha(m)^{-r}$, where, γ , α and r are parameters to be determined, m is the moisture content, and a_w is water activity. It was found that the three parameter equation is able to describe the water sorption isotherm of 18 different foods in an extensive range of a_w (up to about 0.95) with only 2–4% error (average) in the predicted moisture contents. Foods examined comprised, among other, oilseeds, starchy foods, and proteins.

The Water Activity of Canned Foods. S. M. Alzamora and J. Chirife. *J. Food Sci.* 48, 1388–1390.

This work reports the a_w values of a diversity of commercially canned foods (54 samples), including fruits and vegetables and cured and uncured meat products. The a_w of canned fruit products (pieces in syrup, purees and juices) ranges between 0.950 and 0.992. Canned cured meats (i.e., deviled ham, meat and liver pastes, corned beef, cooked ham) have a_w values in the range 0.970–0.984, while uncured canned meats display a_w values above 0.982.

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HASSON, E. P. and LATIES, G. G. 1976. Separation and characterization of potato lipid acylhydrolases. *Plant Physiol.* 57, 142-147.

ZABORSKY, O. 1973. *Immobilized Enzymes*, pp. 28-46, CRC Press, Cleveland, Ohio.

Journal abbreviations should follow those used in *Chemical Abstracts*. Responsibility for the accuracy of citations rests entirely with the author(s). References to papers in press should indicate the name of the journal and should only be used for papers that have been accepted for publication. Submitted papers should be referred to by such terms as "unpublished observations" or "private communication." However, these last should be used only when absolutely necessary.

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