AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523
BIBLIOGRAPHIC INPUT SHEET

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BATCH 74

1. SUBJECT CLASSIFICATION

A. PRIMARY
Serials — Y-A010-0000-0000

B. SECONDARY
Food production and nutrition--Food processing

2. TITLE AND SUBTITLE
Evaluation of low-cost extrusion cookers for use in LDCs; quarterly report, July-Oct., 1977

3. AUTHOR(S)
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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1977	35p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

USDA/ERS

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

(Activity summary)

9. ABSTRACT

A PROJECT: To evaluate low cost extrusion cookers for use in LDCs.

DURATION: 1976 - 1978

DEVELOPMENTS: The Brady Crop Cooker and direct contact type roasters using heated agitated granular beds of sand or salt are evaluated. The Brady cooker was evaluated with respect to several extrusion parameters: rotational speed of screw, screw geometry, and throughput. Selected dependent variables were measured including: energy, throughput, temperature of extrusion, temperature distribution along the barrel, output product characteristics, and residence time. Results indicated that temperature and rotor geometry have a greater influence on product characteristics than do rotor speed and feed rate. Rotor geometry was found to be a major parameter affecting modifications to starch molecules. A mechanical evaluation of the Brady extruder is also included. The cooker has been installed in Costa Rica and Tanzania. Data is reported on the physical and chemical properties of corn or sorghum blends with cottonseed extruded on the Insta-Pro extruder with lower temperatures than the Brady. During this quarter laboratory time was devoted to methodology development. Attention was directed at lipoxidase, available lysin and mineral analysis by atomic absorption. The granular bed roaster studied at Colorado State University is the heat sand parboiler. Schematic drawings are included with the evaluation.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAF-082	

12. DESCRIPTORS
Evaluation
Extruders

13. PROJECT NUMBER

14. CONTRACT NUMBER
RSSA 1-74 GTS

15. TYPE OF DOCUMENT

AID 590-1 (6-74)

RSSA 1-74 GTS
USDA/ERS
PN-AAF-082

Quarterly Report

Departments of Agricultural and Chemical Engineering
and Food Science and Nutrition
Colorado State University
Fort Collins, Colorado 80523

303-491-1101

October 31, 1977

Evaluation of Low-cost Extrusion Cookers for Use in LDC's

Reported by: J. M. Harper
G. R. Jansen
J. D. Kellerby
R. E. Tribelhorr

PARAMETERS AFFECTING THE PERFORMANCE OF THE BRADY

Mr. Jaime F. Sahagun recently completed the requirements for his ter's degree. His thesis work was involved in evaluating the Brady Crop Cooker with respect to several extrusion parameters:

1. Rotational speed of screw
2. Screw geometry
3. Throughput

The effects of these parameters on extrusion performance were examined through measurement of selected dependent variables:

1. Energy (torque, speed)
2. Throughput
3. Temperature of extrusion
4. Temperature distribution along the barrel

5. Output product characteristics

6. Residence time

A mixture of 70% whole corn and 30% whole soybeans was used throughout the experiment and the evaluation. Raw ingredients were ground in the Modern Mill to a +40 mesh.

Results of Research

Temperature profiles.--Thermocouples attached to the extruder barrel surface at selected lengths were used to record the temperatures along the barrel. Temperature profile changes were measured under varying extrusion conditions. Figures 1 and 2 represent typical temperature profiles for the extruder when running at 600 and 1000 rpm for outlet product temperatures of 149, 163 and 171°C. The increased rpm's of the screw caused higher temperatures at the feed section of the extruder, which indicates an increase in the extruder's energy requirements. In general, the first 60 cm of the barrel from the feed input showed a profile 20°C higher for the 1000 rpm runs than for the 600 rpm runs. This increase was due to higher shear and mechanical forces in the feed region which occurred because of greater backfilling of the screw at 1000 rpm. Once the material entered the last 20 cm of the extruder, the profiles were essentially equivalent.

Examination of Figures 1 and 2 indicate that the product was exposed to relatively high temperatures for only a short barrel length and that variations in temperatures at the orifice had only negligible influence on the temperatures in the first 60 cm of the extruder barrel.

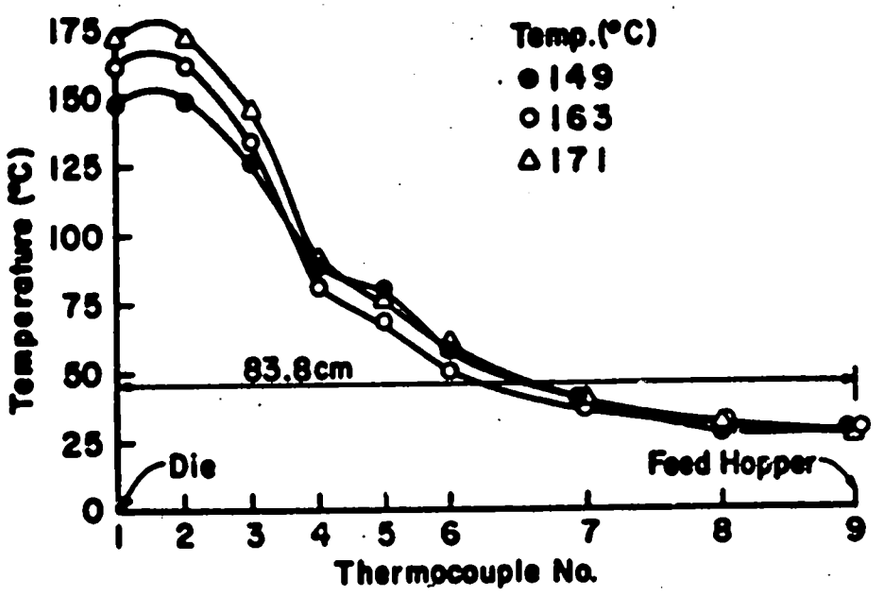


Figure 1. Temperature profile along the barrel for three final temperature settings (N=600 rpm, $\dot{m}$=6 kg/min, original screw).

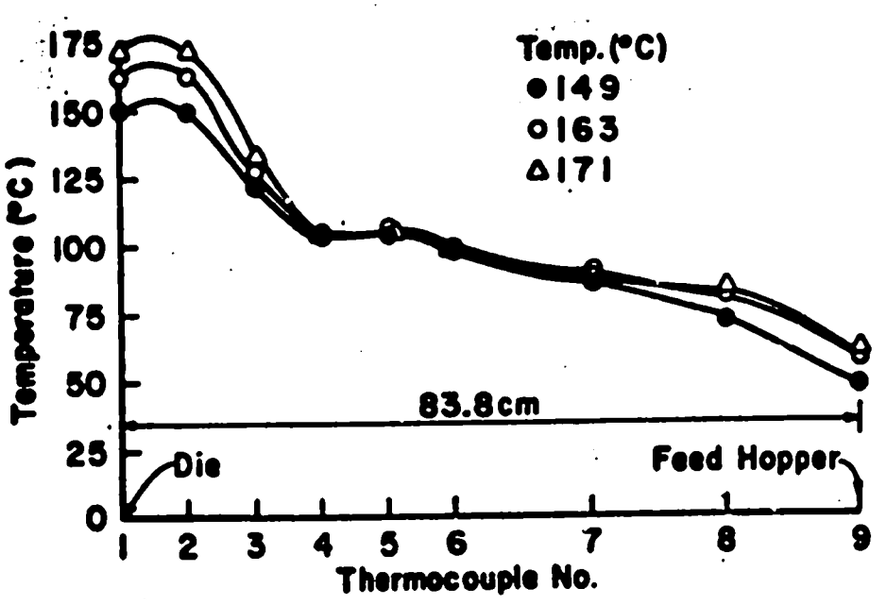


Figure 2. Temperature profile along the barrel for three final temperature settings (N=1000 rpm, $\dot{m}$=7 kg/min, original screw).

The rapid decrease in temperatures measured in the last 7 cm of the barrel length can be attributed to heat transfer from the product to the large steel mass of the cone at the output (acting as a large heat sink). The cone was cooled because the extruded product lost temperature rapidly once it left the annulus around the cone and its pressure became ambient.

Effects on the temperature profile due to changes in throughput can be found in Figure 3. In all instances, the temperatures at each point along the barrel were higher for the lower feed rates. Since residence time was increased at lower feed rates and the energy input per unit length was roughly constant, higher product temperatures at the feed end should be expected. High temperatures at the feed inlet of the barrel could cause sticking of material and plugging in this region. Feed rates below 5 kg per minute are, therefore, not recommended for continuous operation.

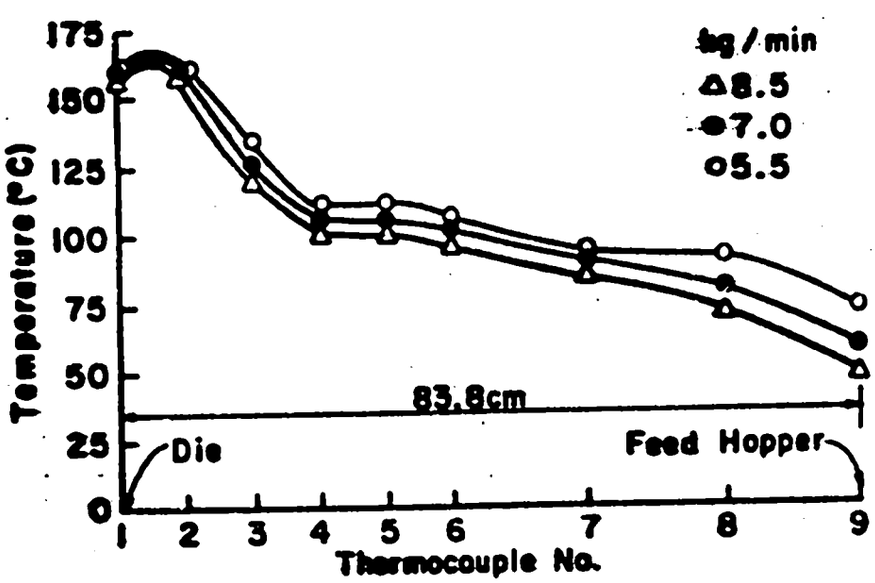


Figure 3. Temperature distribution along the barrel as a function of mass flow rate (N=1000 rpm, T=163°C, original screw).

A series of rotor weldment configurations were evaluated (Fig. 4). Beater bars [welded ridges placed across extrusion screw (flights)] were added or deleted selectively to determine the effects of their numbers and locations on extrusion. Typical temperature profiles for the various screw configurations are shown in Figure 5.

Results indicate that additional beater bars at the discharge end of the screw (configuration 2) created control problems while in the case of configuration 4, where beater bars were located further down the screw, no appreciable change could be detected.

The conclusion was that beater bars that were placed closer to the discharge end of the extruder had greater effect on conditions of operation than bars placed further down the screw channel. Products with high oil or moisture contents were better processed through the addition of beater bars.

Energy input to extruder.--Power measurements were made using the BLH torque sensor and Servo-Tek generator for rpm. Thus, specific energy could be determined.

Energy was measured for the following extrusion variables:

1. Product temperature
2. Screw speed
3. Throughput
4. Screw configuration

Energy measurements for different feed rates at different temperatures indicated that the energy increased approximately 12% when extrusion temperature increased from 149° to 163°C and from 163° to 171°C. Energy increases were found to be linearly proportional to feed rates, as would be expected, assuming a constant heat capacity for extrusion feed materials.

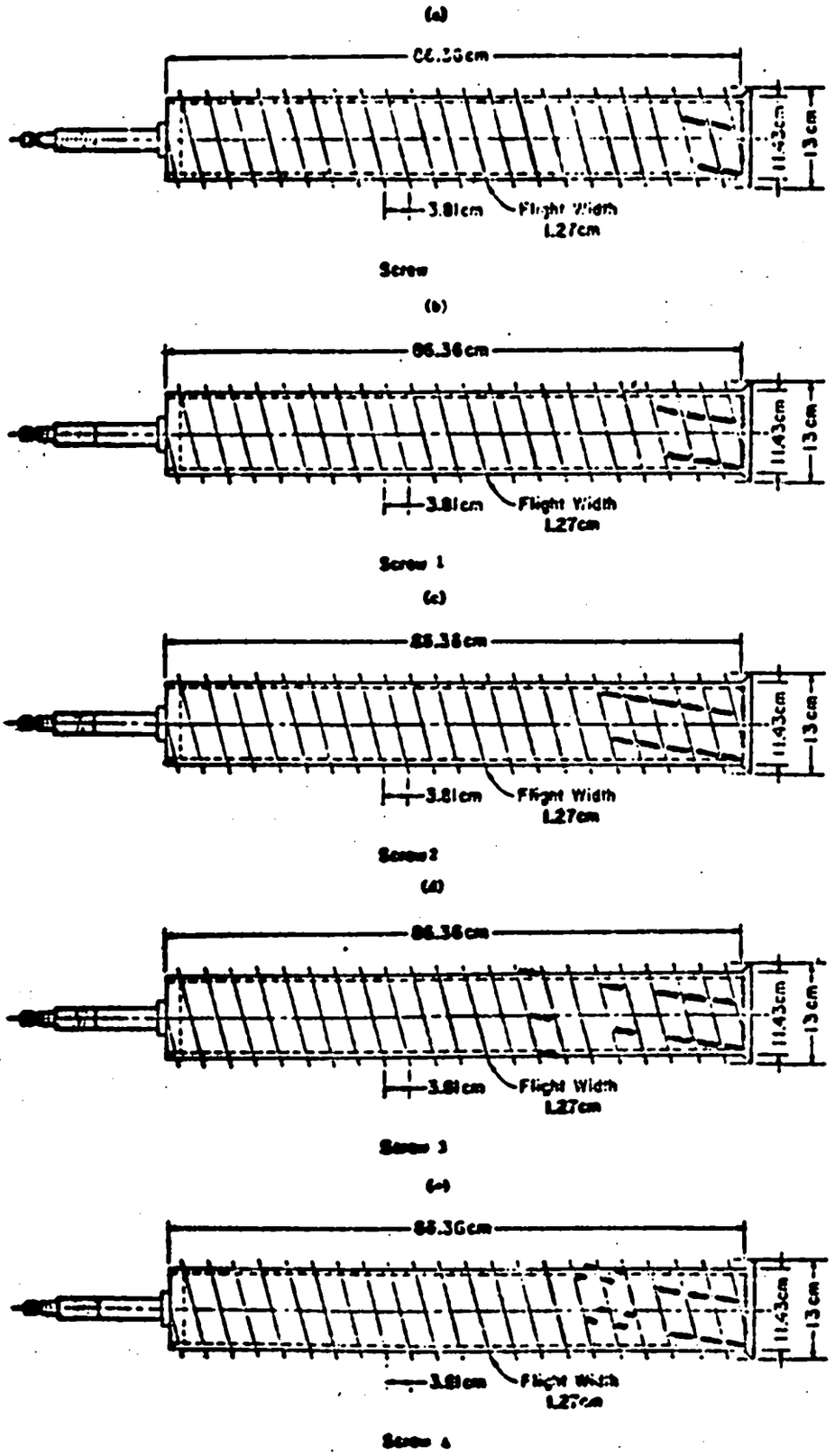


Figure 4. Beater bars placement in the original screw (a) and in each one of the four configurations tested (b, c, d, and e).

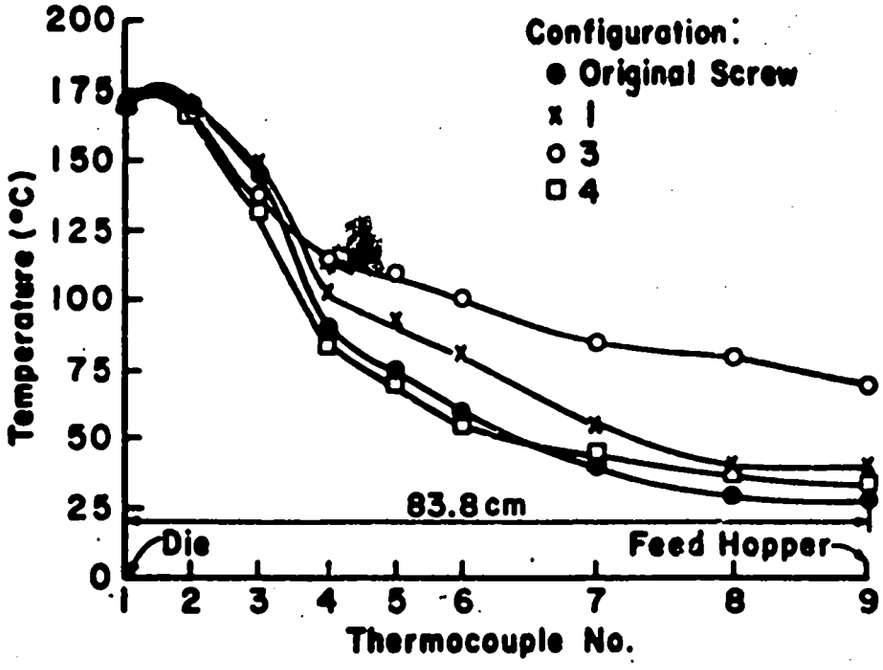


Figure 5. Effects of screw geometry on temperature distributions along the barrel (T=171°C, $\dot{m}$=5.5 kg/min, N=600 rpm).

Specific energies were found nearly independent of rotor speeds at constant temperature. Slight increases in energy were found when the rotor speed was higher than 1000 rpm due to higher shear and mechanical forces leading to increased starchy component modification. The relationship between specific energy and rotor speed at constant temperature and feed rate is shown in Figure 6.

Figure 7 indicates the specific energy of each of the four rotor configurations that were tested. Each configuration affected energy requirements differently. Higher specific energy demands were consistently required with increased number of beater bars closer to the discharge end of the screw (configuration 1, 2 and 3 were higher than the original screw). With bars located in helix turns close to the discharge end, the increased power

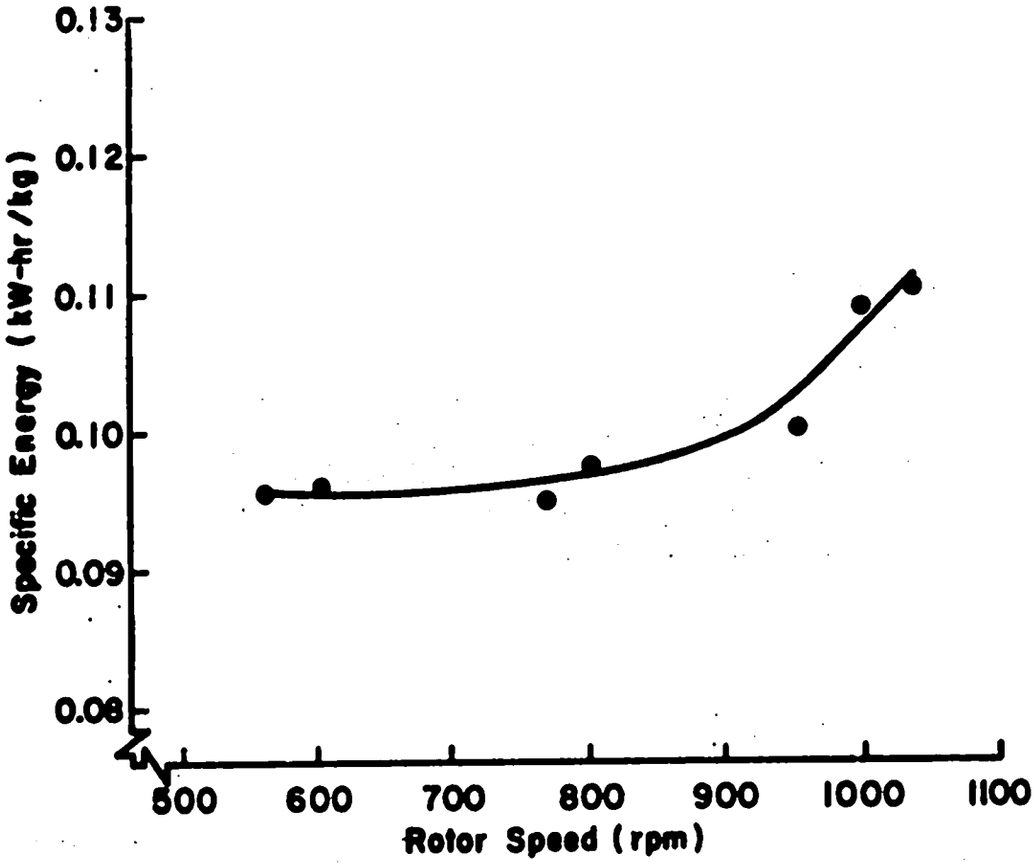


Figure 6. Specific energy as a function of rotor speed (T=149°C, original screw).

requirements made extruder operation extremely sensitive to adjustments therefore, use of such configuration is not recommended for all but high moisture or high oil content ingredients.

Minimum specific energy demands were attained when using screw configuration 4, where bars measuring half of the length of the conventional bar size were located at opposite sides of the screw channel, allowing for better mixing while reducing the back flow in the channel.

Product characteristics.--Tests were performed on the extruded products to determine how the functional properties were affected by extrusion

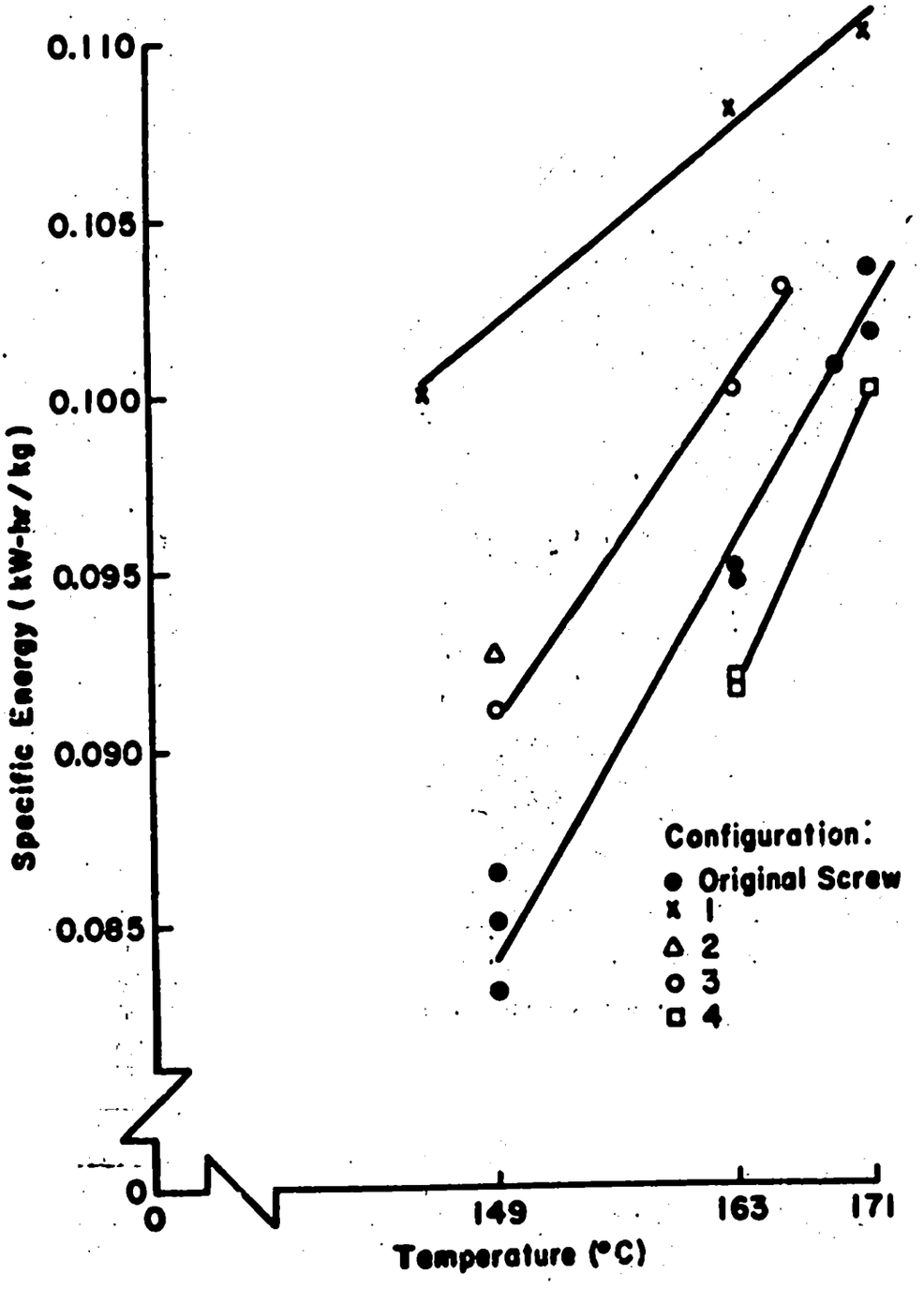


Figure 7. Specific energy as a function of temperature of extrusion and screw geometry (N=600 rpm, $\dot{m}$=5 kg/min).

parameter variations. Results indicated that temperature and rotor geometry have a greater influence on product characteristics than do rotor speed and feed rate.

Damaged starch tests were performed on the extruded products. Results are shown in Figure 8. Cleavage of starch molecules (as measured by concentration of reducing sugars) was higher when the temperature was increased. Rotor geometry was found to be a major parameter affecting modifications to the starch molecules. The addition of more beater bars to the screw increased the shear stress and energy input, resulting in a greater number of damaged starch molecules. Using the original screw as a reference, percentage increases in starch damage were tabulated below.

Rotor configuration	Temperature °C	% increase in glucose concentration (starch damage)
Original	163	0
1	163	-29
2	163	46
3	163	30

The negative value for screw configuration 1 can only be attributed to unobserved variations in the ingredient formulation used in the run.

Consistency tests on the extruded products are shown in Figure 9. In all instances, lower processing temperatures resulted in higher consistometer readings. Changes in rotor configuration altered consistometer values as would be expected. As more shear force was applied to the product with increased beater bars near the discharge end of the screw, the product had a higher viscosity and a smaller consistometer patty diameter. Potentially,

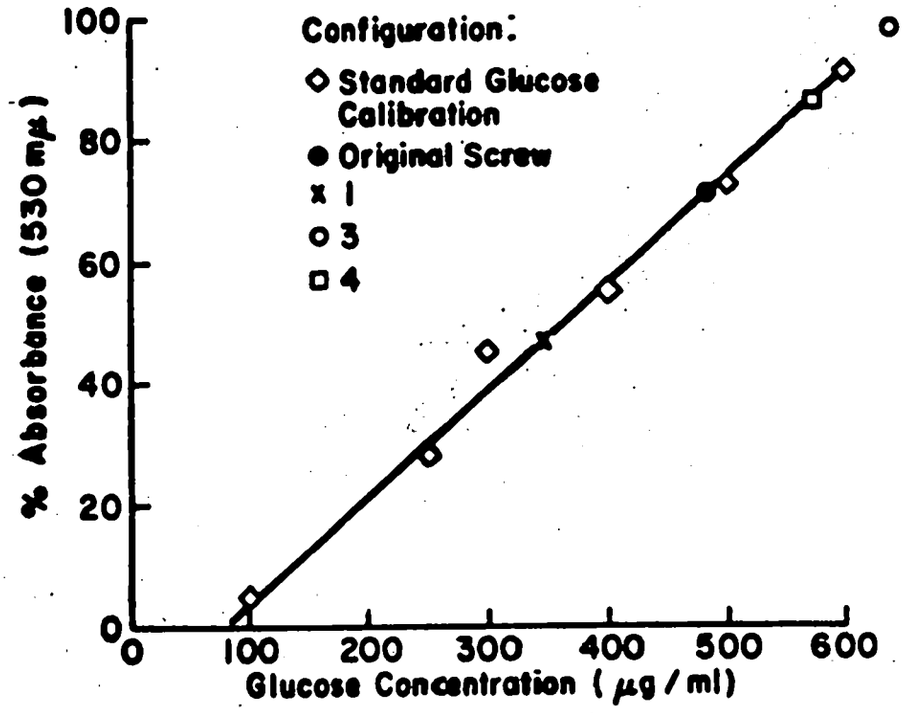


Figure 8. Variations on the reducing sugar concentration of products extruded with different screw configurations.

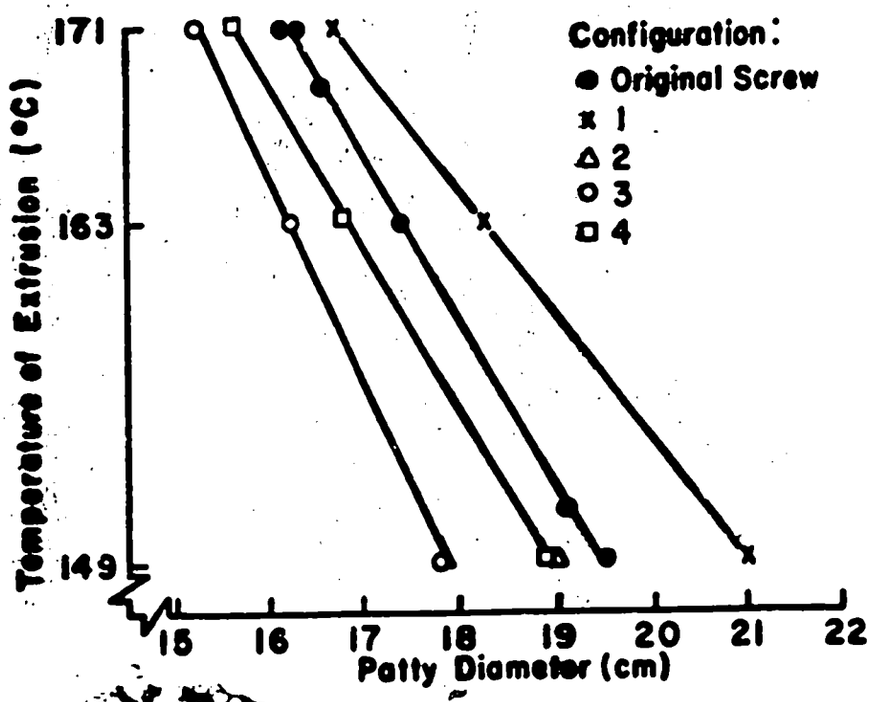


Figure 9. Consistometer test results for five screw configurations and three temperatures of extrusion.

changes in the number and location of the beater bars on the screw could allow the operator to control the viscosity of the resulting cooked product.

In summary, the tests on beater bar locations on the screw of the Brady extruder showed that their location near the discharge end greatly affected the product by increasing energy input. Feed rate and screw rotational speed were also important parameters. Based on these studies, it is now possible to better recommend optimal operating conditions and screw configurations to achieve the desired results from the extruder.

MECHANICAL EVALUATION OF THE BRADY EXTRUDER

The mechanical evaluation of the Brady Crop Cooker has been completed by Dr. James L. Smith, Department of Agricultural and Chemical Engineering, Colorado State University. The objectives were:

1. To evaluate the mechanical components of the Brady with respect to duty rating and longevity (time before major overhaul and replacement of parts).
2. To recommend minor alterations to the Brady that would increase the duty rating and longevity of the equipment.

The Brady extruder was initially designed for intermittent duty under farmstead conditions. Areas which limit continuous duty applications are:

1. Hydraulic system
2. Bearing housing weldment lubrication
3. Drive train components

The hydraulic system was found to be adequate for intermittent duty. Improvement of the hydraulic system could be made by upgrading components such as pumps, motors, and valving with continuous duty components. An

alternative would be to remove all hydraulic components by replacing current feeder with an open-hopper system directly above the screw feed port.

Although the bearing housing weldment is of a continuous duty design, lubrication while the extruder is running is quite difficult. A design which could utilize an automatic lubrication system would solve a majority of the bearing problems stemming from lubrication difficulties.

Drive train components have been primarily designed for farm duty operation. Power transmission through the drive train of the extruder presently involves high torque loadings. Although the components were designed for the continuous load, our experience would indicate universal bearing failure after 1,500 hours running due to shock loadings. It is felt that the easiest way to overcome problems with the drive train would be to drive the extruder with belts. The belt drive coupled with a gear reduction at the extruder would reduce the high torques transmitted through the present drive train. In addition, some safety over-ride protection would exist with belt slippage at high loads.

The above recommendations for minor modifications which will require little additional cost and should increase the longevity of the equipment to at least 10,000 hours. After this period of time, replacement of major components such as the barrel and bearings, and rotor weldment would be required. A complete report documenting the evaluation and specifying the recommended alternatives will be issued in approximately one month.

PLANT INSTALLATIONS

Costa Rica

Mr. Ron Badilla of CARE/Costa Rica visited Colorado State University, October 14, 22, for the purposes of:

1. Briefing CSU on the progress of plant construction.
2. Assisting in the preparation of plant operation and training manuals and the equipment uncrating procedures.
3. Becoming familiar with the operation of the soybean roaster.
4. Finalizing arrangements for plant start-up.
5. Attending an appropriate technology conference on October 21-22.

According to Mr. Badilla, the building construction at the Costa Rican site is proceeding on schedule with the walls and roof currently in place. The access roads will be constructed before the end of the year.

The equipment has been ordered and most will be shipped soon to New York for oceanic transport to Costa Rica. The current dock strike is not anticipated to delay shipments more than two weeks. The mechanical evaluation of the roaster has been completed, and the roaster will be shipped by November 15. The operation, maintenance, and training manuals for LEC operating plants, for use in Costa Rica and other sites, are currently being prepared. The list of personnel and required individual qualifications were prepared during Mr. Badilla's visit. The required vitamin and minerals should also be on-site in time for plant start-up.

The plant start-up is planned for early January 1978, as previously scheduled. Both Kellerby and Tribelhorn plan to be present for the start-up, degugging, and training phases of the operation.

Tanzania

A number of delays have been encountered which have appreciably delayed the final debugging, training and start-up of the LEC plant to produce CSB in Dar es Salaam, Tanzania, located at the National Milling Corporation (NMC).

Marvin Stone spent most of the month of July assisting with installation prior to start-up. His trip report (July 7-30, 1977) details his activities during this period. Start-up could not begin in July because the main line transfer was not installed to power the plant equipment, and vitamin and mineral premixes were not on hand.

The specific status of items delaying start-up are as follows:

1. Installation of line transfer--availability and installation not expected until March 1978.
2. Vitamin/mineral premixes--quotations for suitable supplies forwarded to NMC. An initial two-month supply has been purchased by AID/W for shipment to Tanzania. Delivery not expected before January 15, 1978.
3. Additional plant equipment--Belt conveyor and blender purchases by CSU for shipment to Tanzania were delayed in the CSU Purchasing Department until September 22, 1977. The conveyor will be delivered in November and the blender in January. Contingent plant start-up plans have been made if they do not arrive in Tanzania before transformer installation and vitamin and mineral premixes.
4. Packaging line--Packaging line specifications have been drawn and were forwarded to Tanzania. Based on new information from Tanzania, we are also looking for and will be purchasing bag sealers and scales for the packaging line.
5. Missing parts--Missing pulleys on the bucket elevator have been purchased and are at CSU. These parts will be hand carried to Tanzania at the time of start-up.

RICE BRAN

Mr. Rodney Hanagrith (Bond Engineering, Houston) visited CSU on October 24 to review our test facility and to be briefed on the LEC program. Mr. Hanagrith will serve as the consultant on a feasibility study looking at stabilizing rice bran using a LEC in Pakistan. Using a LEC for rice bran stabilization had been previously investigated by Texas A & M, who found a substantial potential for the extrusion system. Drawing on this research and the limited experience gained in the Philippines LEC testing program, Mr. Hanagrith was briefed on the operation and capability of LEC's, experience to date with rice bran, and possible processing equipment that would be required to complete the process. Recommendations will be made to Hanagrith on maintenance, spare parts, and labor requirements.

A cooler for rice bran that will not break up the stabilized brittle chips formed during extrusion will also be designed. Cooling experiments will be run on rice bran to determine the requirements necessary to cool the extruded chips down to 52°C. The design will be such that in-country construction may be considered. In addition, equipment specifications and costs, labor requirements, and operation costs will be estimated and provided by CSU.

VITAMIN AND MINERAL SUPPLIERS

The production of a CSB-type product in a LEC plant requires the addition of vitamin and mineral supplements as specified in the CSU Annual Report dated April, 1977. Prior to plant start-up, it is necessary to have a two- or three-month supply on hand.

A list of vitamin and/or mineral supplements suppliers and current prices (10-15-77), where available is given. The list is representative

of suppliers but may not include all potential suppliers. Naming suppliers does not imply endoresement by CSU, USDA/ERS OR AID. Prices are subject to change, and price quotations are required prior to ordering.

Vitamins Only

1. American Roche
   340 Kingsland Road
   Nutley, New Jersey 07110
   Phone: (201) 722-5550
   Telex No.: 138292 or 133417
   Attention: Mr. David Petrillo

   Price: $4.60/lb
   Delivery: 5 weeks after receipt of order

2. Vitex American
   106-116 Trenton Avenue
   St. Louis, Missouri 63132
   Phone: (314) 426-2611
   Telex No.: 985358
   Attention: Mr. Jay Thaman

   Price: $4.68/lb

Minerals Only

1. Roland Industries
   2280 Chaffe Drive
   St. Louis, Missouri 63141
   Phone: (314) 567-3800
   Attention: Mr. Charles Becker

   Price: $0.39/lb

2. Stauffer Chemical Company
   Latin American Division
   Nyala Farm Road
   Westport, Connecticut 06880
   Phone: (203) 222-3000
   Telex No.: 234464
   Attention: Mr. John Rush

   Price: $28.75/100 lb

3. M. D. Canterbury
   P. O. Box 88
   Grayslake, Illinois 60030
   Phone: (312) 223-4281
   Attention: Mr. Canterbury

   Price: $0.29/lb in 54-lb paper bags

4. Mallinckrodt Chemical Works
   P. O. Box 5939
   St. Louis, Missouri 63160
   Phone: (314) 895-0123
   Telex No.: 447245

Vitamins and Minerals

1. Thompson-Hayward
   2 East Madison
   Waukegan, Illinois 60085
   Phone: (312) 623-1600
   Telex No.: 253080
   Attention: Dr. John Berbeck

Price: Vitamins - $4.70/lb
Minerals - $0.31/lb

With the exception of American Roche, most of the companies can deliver the product within two weeks after receipt of the order.

As specified in the CSU Annual Report, the vitamins and minerals may be added prior to or after extrusion of the CSB-type product. If added prior to extrusion, however, vitamins should be added at 125% of the AID recommended levels to make up for losses during the cooking process.

PRODUCT EVALUATION

Cereal/Cottonseed Blends

In the last quarterly report, data were reported on the physical and chemical properties of corn or sorghum blends with cottonseed extruded on the Brady. These experiments have been repeated using the Insta-Pro extruder with lower temperatures and these data are given in Tables 1-3.

The results are generally consistent with the earlier results using the Brady. Uncooked viscosity decreased with increasing temperature or an increased percentage of cottonseed in the blend. Nitrogen solubility was decreased by increasing temperature but was relatively insensitive to the percentage of cottonseed in the blend. As previously found, the use of sorghum in the blends reduced uncooked viscosities considerably as compared with corn. It would appear that a blend of approximately equal parts of

Table 1. Cottonseed/cereal blend samples produced on Insta-Pro extruder.

FSN Code #	AERC Sample #		Moisture	Fat	Total Nitrogen	Water Soluble N	NSI	% Free Gossypol	Water Absorption
2-69-2	F84	70% corn/30% glanded cottonseed, 138°C	5.86	13.72	2.86	0.28	9.79	0.107	203
2-69-8	F85	70% corn/30% glanded cottonseed, 143°C	4.53	--	3.32	0.24	7.23	0.058	164
2-69-1	F86	70% sorghum/30% glanded cottonseed, 147°C	3.77	13.78	3.06	0.23	7.52	0.046	208
2-69-3	F87	70% sorghum/30% glanded cottonseed, 138°C	3.48	--	3.01	0.24	7.97	0.048	224
2-69-7	F88	60% sorghum/40% glanded cottonseed, 138°C	3.00	15.79	3.21	--	--	0.077	--
2-69-6	F89	60% sorghum/40% glanded cottonseed, 149°C	2.96	--	3.36	0.26	7.74	0.067	213
2-69-5	F90	60% corn/40% glanded cottonseed, 149°C	4.20	15.80	3.27	0.25	7.65	0.073	213
2-69-4	F91	60% corn/40% glanded cottonseed, 138°C	4.70	--	--	--	--	0.083	--

Table 2. Uncooked viscosity data for cottonseed/cereal blends produced on Insta-Pro extruder.

Code #	AERC Sample #		Centipoise	No.-rpm	Centipoise	No.-rpm	Bostwick value
2-69-2	F84	70% corn/30% glanded cottonseed, 138°C	980 0	3-20 7-20	1,820	3-50	19.4
2-69-8	F85	70% corn/30% glanded cottonseed, 143°C	>1,000 5,200	3-20 7-20	>2,000 3,440	3-50 7-50	4.2
2-69-1	F86	70% sorghum/30% glanded cottonseed, 147°C	78 0	3-20 7-20	72	3-50	>24
2-69-3	F87	70% sorghum/30% glanded cottonseed, 138°C	65 0	3-20 7-20	58	3-50	>24
2-69-7	F88	60% sorghum/40% glanded cottonseed, 138°C	55 0	3-20 7-20	48	3-50	>24
2-69-6	F89	60% sorghum/40% glanded cottonseed, 149°C	100 0	3-20 7-20	78	3-50	>24
2-69-5	F90	60% corn/40% glanded cottonseed, 149°C	735 0	3-20 7-20	578	3-50	19.5
2-69-4	F91	60% corn/40% glanded cottonseed, 138°C	1,540 0	3-20 7-20	1,108	3-50	13.1

Table 3. Cooked viscosity data for cottonseed/cereal blends produced on Insta-Pro extruder.

Code #	AERC sample #		Centipoise	No.-rpm	Centipoise	No.-rpm	Bostwick value
2-69-2	F84	70% corn/30% glanded cottonseed, 138°C	2,207	4-20	1,396	4-50	17.4
2-69-8	F85	70% corn/30% glanded cottonseed, 143°C	1,710	4-20	1,023	4-50	18.3
2-69-1	F86	70% sorghum/30% glanded cottonseed, 147°C	3,420	4-20	2,028	4-50	13.1
2-69-3	F87	70% sorghum/30% glanded cottonseed, 138°C	4,190	4-20	2,292	4-50	12.6
2-69-7	F88	60% sorghum/40% glanded cottonseed, 138°C	2,133	4-20	1,216	4-50	16.9
2-69-6	F89	60% sorghum/40% glanded cottonseed, 149°C	2,053	4-20	1,137	4-50	17.0
2-69-5	F90	60% corn/40% glanded cottonseed, 149°C	1,313	4-20	777	4-50	18.4
2-69-4	F91	60% corn/40% glanded cottonseed, 138°C	887	4-20	557	4-50	21.3

corn, sorghum and cottonseed (or soy) might have a desirable uncooked viscosity for use as a gruel.

Extrusion temperatures were lower on the Insta-Pro than they had been on the Brady. This related to the characteristics of the particular machine and a difficulty in getting the temperatures higher with the wetter feed required by the Insta-Pro. Consistent with the lower temperatures, higher levels of free gossypol were found. It may be that gossypol can be reduced to acceptable levels using the Insta-Pro if a higher temperature could, in fact, be achieved by changing operating conditions or the screw configuration without resulting scorching of the product. To date, no such combinations have been found. Another possibility is to reduce free gossypol by addition of iron salts. Such a procedure could minimize lysine reductions which currently occur with gossypol inactivation.

Chickpeas

A chickpea/corn/NFDM formulation (44/44/10) extruded on the Brady at 160°C was evaluated for protein quality in a four-week rat growth study. Weight gain and corrected PER for the sample were 162.1 ± 5.1 and 2.84 ± 0.05, respectively. Corresponding values for AHRC Casein were 121.2 ± 5.9 and 2.50, respectively.

Methods Development

During this quarter, laboratory time has been devoted to methodology development. Attention was directed at lipoxidase, available lysine and mineral analysis by atomic absorption. In addition, procedures had to be worked out to grind and sieve roasted soy samples for viscosity determination. At the present time, the evaluation for an extensive series of roasted soy

samples is in progress. Results including chemical and physical properties and a rat growth evaluation will be available before the next quarterly report.

Fortification Levels for CSB

G. R. Jansen has prepared a position paper on vitamin/mineral fortification of LEC-produced CSB in Sri Lanka, Tanzania and Costa Rica. In addition, he is working on a paper dealing with protein/energy characteristics of these products. Plans are under way to use these papers as a beginning discussion point with a group of nutrition experts consisting of Dr. George Graham, Dr. Sam Kahn, Dr. Herbert Sarett, Dr. Samuel Foman, and Dr. Gerry Combs.

GRANULAR BED ROASTER EVALUATION

Roaster Design

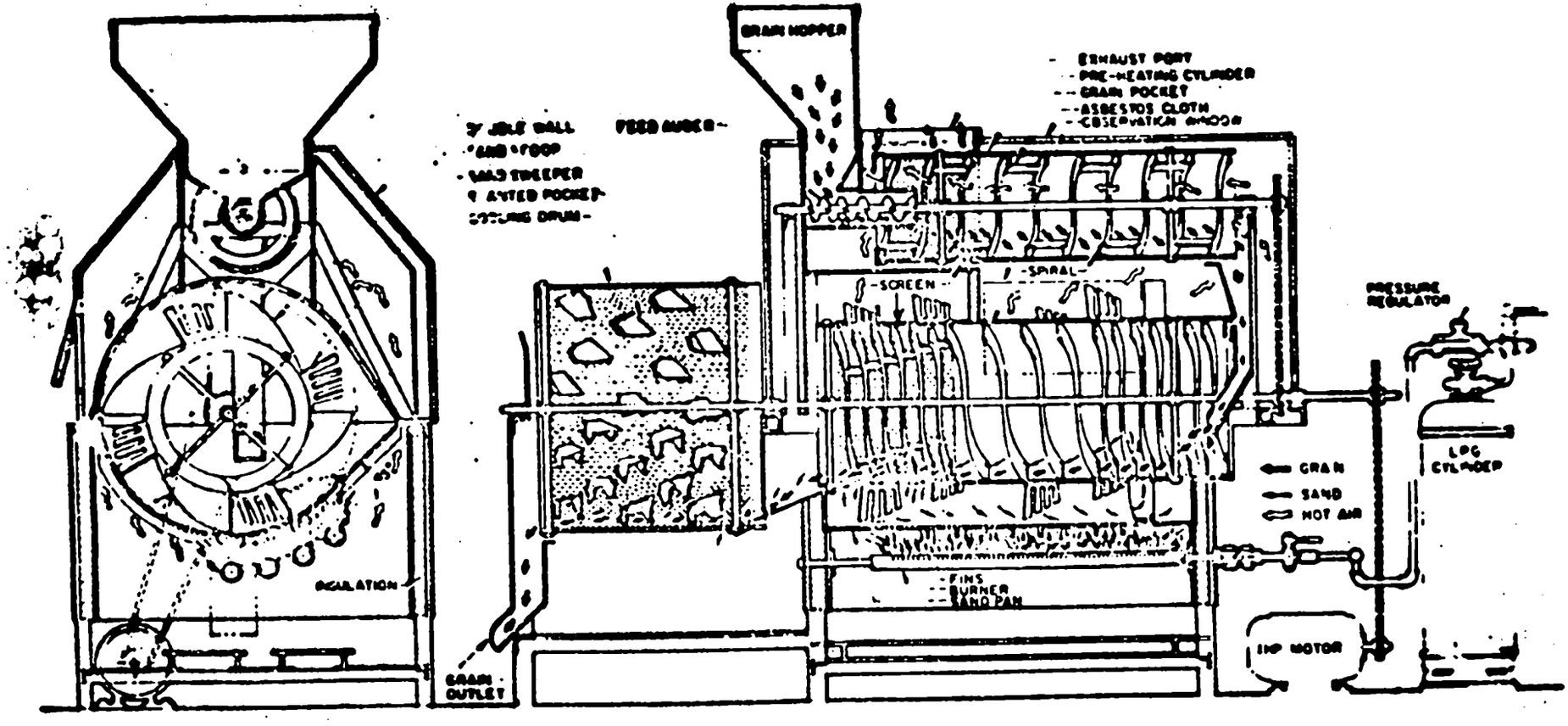
Colorado State University has evaluated several roasters for heat treating soybeans during the past year. These roasters have all used a heated agitated granular bed of sand or salt which co-mixed with the soybeans to accomplish the roasting.

One type of roaster tested was designed with a granular bed heated in a separate heating chamber, conveyed into a contacting chamber where beans and bed mix, followed by a separation and recirculation of the granular bed. In this case, heat transfer occurs between the heated granules of salt or sand and the cold beans when the two materials are mixed. Also, the beans are never exposed to direct flames. Typically, these roasters have the following characteristics:

1. A constant quantity of granular bed material exists in the machine which means that the recirculation rate of the bed is constant.
2. Residence time of the beans in the bed is generally fixed by the rotational speed of the contacting chamber which is equipped with an internal helix.
3. Bean throughput is variable, however, as throughput is increased, the volumetric ratio of sand to beans is reduced which can change roast uniformity detrimentally.
4. Temperatures of granular bed can be changed by simple burner control.

The roaster of the type studied at CSU is the heat sand parboiler designed by IRRI, Los Banos, Philippines. The design is shown in Figure 10. Operational characteristics are as follows:

1. The granular bed is heated through contact with a steel plate which is directly heated with propane burners underneath.
2. A single drum is used with an internal helix as the contact chamber between the agitated bed and beans. Attached to the outside diameter of the drum are fins which drag the granular bed over the heated plate, conveying them in an opposite direction to the helix in the contacter.
3. The heated bed granules enter the contact chamber through small scoops near the inlet end.
4. The last third of the contacting chamber is screen which serves as a separator of sand and beans.
5. Throughput is approximately 300 pounds per hour.



SCHEMATIC DRAWING OF THE CONTINUOUS FLOW HEATED-SAND DRYING AND PARBOILING MACHINE

Figure 10. Heated sand parboiler designed by Dr. Amir U. Khan for the International Rice Research Institute, Los Banos, Philippines.

A second type of roaster, which has been evaluated, is a direct contact type roaster. Here a horizontal cylinder fixed with internal lifting flights is used to mix and convey beans and the granular bed. In this roaster, both the granular bed and intermingled beans cascade through hot air in the same chamber. Such a design improves mixing and thermal efficiency but reduces residence time control.

Typically, direct contact type roasters have the following characteristics:

1. The quantity of granular bed material in the roaster can be varied, therefore, a constant heated granule to bean ratio can be achieved with different roasting rates.
2. Residence time of contact may be varied by changing slope of the roaster and rotational speed of heat/contacting drum.
3. Temperature can be regulated by changing burner controls.

Figure 11 shows a direct contact type roaster, that will be evaluated in Costa Rica, which has been extensively tested at CSU during this quarter. The roaster is manufactured by Food Processes, Inc., Saginaw, Michigan. The roaster body is made using two concentric drums. Between the outside drum and inner drum is a helix which is used to convey the granular bed "S" back to the input end of the roaster. The bed is then scooped up to the inner drum where it comes in contact with the beans. The bean/bed mixture is then conveyed by lifting fligths to the output end, and cascades through hot air from a burner firing directly down the center of the drum. Air is moved through the cascade of sand and beans by a discharge blower and heated using a liquid propane burner located at the bean discharge end of the drum. The mixture is screened, with the sand falling through the screen, for recirculation while the beans exit the chamber over the top of the screen.

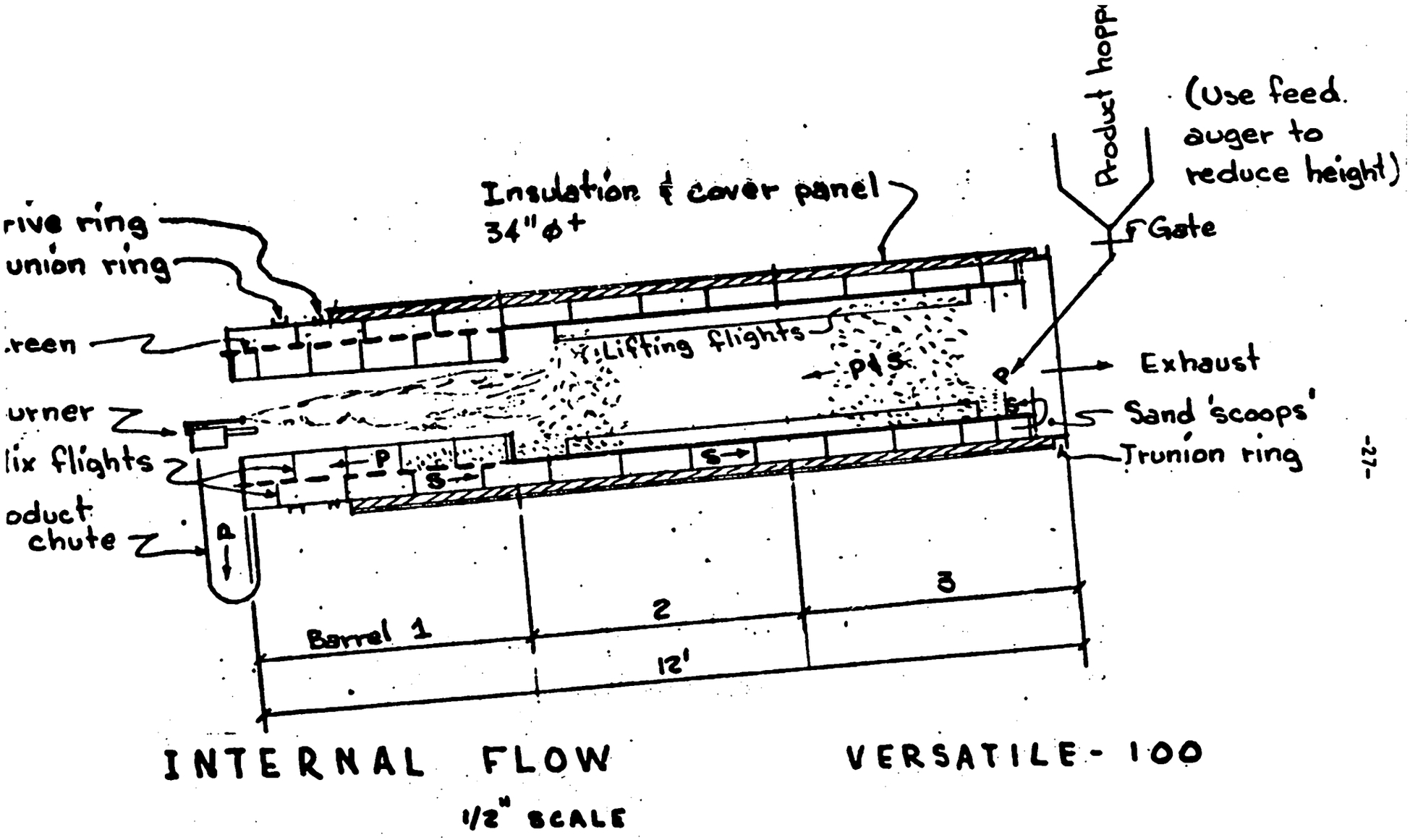


Figure 11. Schematic drawing of direct contact type roaster.

The granular bed, in the case of the direct contact roaster, is not the total heat transfer medium for the beans, but increases the rate of heat exchange to the beans, improves residence time control and enhances thermal efficiency of the roaster.

Costa Rica Roaster Evaluation

The roaster for the Costa Rican installation has been tested at CSU to determine the mechanical characteristics of operation. These tests included studies of the uniformity of soybean movement based on the following variables: rotational speed of drum, roaster incline, total sand loading and sand recycling rate. In addition, the energy balance of the roaster system was determined using the ambient and exhaust temperatures, the change in sand temperature, the change in bean temperature, propane gas consumption and amperage for each test. The results of these tests are given in the next section.

Chemical, physical and nutritional analyses of the roasted soybeans are being conducted to finalize the evaluation of the roaster for the purpose of specifying the best operating conditions. When specifying these conditions, an attempt will be made to match the optimum product quality with the most efficient mechanical operation.

During the evaluation tests of the roaster, it was possible to recognize and correct some mechanical deficiencies which existed in the original drive mechanism. These modifications should significantly improve the life of the roaster in continuous operation. This "hands-on" experience has contributed greatly toward the preparation of the operation and training manuals for the Costa Rican plant.

A summary of the roaster mechanical characteristics is given in Table 4. A total of four roaster inclines, five rotational speeds, and four sand loading rates were [illegible]ed to determine the effects on average bean

Table 4. Direct contact roaster mechanical variables.

Sand Loading (kg)	Speed (rpm)	Incline (cm/m)	Bean Residence Time (min:sec)	Sand Recycling Rate (kg/hr)
0	17.4	3.13	2:51	0
		4.69	2:00	0
		6.25	1.07	0
0	27.3	3.13	2:27	0
		4.69	1:40	0
		6.25	1:18	0
90	17.4	3.13	4:24	1,188
		4.69	2:59	1,494
		6.25	2:16	2,064
90	19.7	3.13	4:30	1,068
		4.69	2:47	1,368
		6.25	2:18	1,854
90	27.3	3.13	4:09	1,260
		4.69	2:36	1,860
		6.25	2:03	2,232
180	17.4	3.13	3:52	2,310
		4.69	2:41	3,006
		6.25	2:13	3,888
180	19.7	3.13	3:40	2,448
		4.69	2:32	3,438
		6.25	1:56	3,906
180	27.3	3.13	3:38	2,580
		4.69	2:21	3,978
		6.25	1:52	4,128

residence time and sand recycling rate. Table 4 presents selected variables and results that were investigated. Other variables investigated included 1.56 cm/m incline, 22.1 rpm and 24.6 rpm speeds, and 135 kg sand loading.

Several observations were made based upon data presented in Table 4 and on visual analyses of the roaster operation.

1. Effects of the sand loading into the roaster:
   a. As the sand loading was increased, the residence time of the beans was more narrowly distributed, creating a condition more closely related as "plug flow."
   b. The bean residence time was increased approximately 1 minute between corresponding tests with varying sand loadings. There was little noticeable difference in bean residence times when sand loadings between 90 and 180 kg were used.
   c. Sand spillage into the roaster outlet was noticeably greater with the 180 kg loading than with the 90 kg loading. This was attributed to a doubling of the sand recycling rate.
2. Effects of the roaster rotational speed:
   a. Increases of roaster speed from 17.4 rpm to 27.3 rpm at a constant incline had negligible effects on bean residence time.
   b. Increases of roaster speed by 50% generally caused increases of the sand recycling rate by at least 10%.
   c. Increases of roaster speed from 17.4 rpm to 27.3 rpm produced undesirable mechanical effects—such as large amplitude vibrations in the machine and projected shorter roller bearing life.

3. Effects of the roaster incline:

   a. An increase in roaster incline of 100% produced a 50% decrease in bean residence time for given values of speed and sand loading.

   b. For a sand loading of 90 kg, increases in incline of 50% and 100% produced increases in the sand recycling rate of 25% and 70%, respectively. For a sand loading of 180 kg, the corresponding increases in the sand recycling rate were approximately 40% and 60%.

A decision was made, based upon these observations, to fix the speed of the roaster at 17.4 rpm prior to the next phase of testing and for continuous operation in Costa Rica. Operation of the roaster at the lowest speed assured the longest operating life and the minimum operating costs without noticeably affecting its performance.

The next phase of testing involved roasting soybeans under controlled conditions for the determination of thr roaster energy balance and changes in product characteristics.

A summary of the average roasting conditions is given in Table 5. The following variables were measured for each test: ambient dry-bulb and wet-bulb temperatures, exhaust dry-bulb and wet-bulb temperatures, bean inlet and outlet (cooking) temperatures, exhaust air flow rate, and propane consumption. These variables were dependent on the bean feed rate and the propane input regulator, which were both fixed.

A computer program was developed to process the data and to calculate the energy balance and the efficiency of the system. The efficiency of the roaster was defined as the heat energy taken up by the beans and moisture

Table 5. Average soybean roasting conditions

Bean feed rate (kg/hr)	Bean cooking temperature (°C)	Number of tests	Ambient temperature (°C)	Ambient relative humidity (%)	Exhaust temperature (°C)	Exhaust relative humidity (%)	Propane consumption (kg/hr)	Efficiency (%)
[illegible]	120	6	11	76.8	98	5.1	7.6	51
	135	5	11	73.9	114	5.3	8.8	49
	150	6	12	70.1	118	5.0	9.3	52
865	120	6	12	78.7	72	13.1	8.2	58
	135	7	11	83.3	81	15.7	12.3	51
	150	5	12	78.2	89	11.1	11.4	57

evaporated divided by the heat energy provided by combustion of the propane. Efficiencies were difficult to determine because propane consumption could not be accurately measured. The percentages shown in Table 5 represent averages of several widely scattered values.

The bean cooking temperature was controlled by adjustment of the propane flow and pressure using the propane regulator system. As the cooking temperature was raised, the propane consumption gradually increased.

The average efficiency for the 865 kg/hr feed rate was higher than that for the 625 kg/hr feed rate which indicated that more of the propane energy was going directly into roasting the soybeans. This result was confirmed by the fact that the exhaust temperatures were lower and the relative humidities were higher in the case of the 865 kg/hr feed rate. Based upon these results, it appears that the roaster should be operated at 850-900 kg/hr bean feed rate for maximum efficiency. The recommended soybean cooking temperature will depend on the results of the chemical and functional properties, and nutritional analyses.

PLANS FOR NEXT QUARTER

1. Complete mechanical evaluation of Brady
2. Complete training manual
3. Start-up Costa Rican plant
4. Re-extrude vitamin/mineral formulas
5. Extruder high oil formulas
6. Write annual report
7. Publish third LEC newsletter
8. Extrude cottonseed samples on the Insta-Pro extuder

9. Write roaster report--including physical, chemical, nutritional and functional properties
10. Do rice bran cooking studies
11. Assemble panel for vitamin/mineral and protein/energy requirement discussions for LEC blended foods

VISITORS

Colorado State University continued to receive a substantial number of requests for information which have been promptly answered. Our mailing list has increased from the 50 persons who attended the LEC Workshop to over 250. In addition, we have had a number of visitors during the past quarter.

1. Ron Badilla, CARE/Costa Rica, San Jose, Costa Rica
2. Stephen A. Youngberg, Pan American Health Service, San Pedro Sula, Honduras
3. Rodney Hanagrith, Bond Engineering, Houston, Texas
4. Jim Frasche, Denver Research Institute, Denver, Colorado
5. Saluri Reza, Denver Research Institute, Denver, Colorado
6. Wes Gormley, Greeley Trading Company, Greeley, Colorado
7. Jim Seilbach, Greeley Trading Company, Greeley, Colorado
8. Larry Mertes, Country Bean Exchange, Inc., Northglenn, Colorado
9. Grant Kuhn, G. L. Kuhn, Inc., Saginaw, Michigan
10. Alvin Pyne, International Multifoods, Minneapolis, Minnesota
11. Barry Vermilyea, International Multifoods, Minneapolis, Minnesota
12. Dick Fulmer, Cargill, Inc., Minneapolis, Minnesota
13. Frank Coune, Cargill, Inc., Minneapolis, Minnesota
14. Gayle Knoke, Western Agri-Matics, Longmont, Colorado
15. P. R. Crowley, USDA/ERS, Washington, D. C.