The Desolventizer-Toaster Process for Soybean Oil Meal

ENDRE SIPOS and N.H. WITTE, Central Soya Company, Decatur, Indiana

THE DESOLVENTIZER-TOASTER (D-T) process which was first used for soybean oil meal on a commercial scale in 1950 has since been adapted by probably a majority of the U.S. processors of soybeans. More recently foreign processors have also shown considerable interest in D-T's and are converting many of their plants to this modern process.

One of the principal advantages of the D-T process is that the soybean oil meal produced by it has uniformly excellent nutritional characteristics. Since the early 1930's the heating or toasting of soybean oil meal to improve its nutritional value has been studied and reported from many laboratories. However there has been little, if any, work published on soybean oil meal toasting as accomplished in the D-T process. It is the purpose of this paper to examine and report some of the nutritional work carried out in Central Soya laboratories in this field as it pertains to practical D-T operation, also to discuss some of the operating characteristics of the process. The discussion is divided into four parts: a) optimum conditions for toasting desolventized flakes, b) description of D-T machine and process, c) optimization of toasting conditions by D-T process, and d) practical installations.

Optimum Conditions for Toasting Desolventized Flakes

Many investigators have studied the heat treatment of extracted soybean flakes, and evidence is clear that heat-treated meals are superior to raw-extracted flakes from the standpoint of protein utilization in most species of animals.

In attempting to arrive at the optimum time and temperature for this toasting, it must be recognized that these two variables are obviously interrelated, that the optimum relationship between the two may vary for different species of animals, and that laboratory findings cannot be directly incorporated into production-sized equipment because of variations in the amount of heating surface per unit of holding volume and the variation of temperature during the toasting process. Many investigators have studied cooking in the laboratory by means of toasting under atmospheric pressure conditions or by autoclaving at pressures higher than atmospheric. These tests indicate clearly that some heating is required to produce the highest protein quality in soybean oil meal and that overheating will result in a meal with lower nutritional value.

As an example, the data of Evans and McGinnis (1) demonstrates that soybean flakes autoclaved at 100°C. for 30 min. are superior to flakes receiving greater amounts of heating. Within the limits of the experimental data however the optimum amount of heating is not narrowly defined, and it appears that soybean oil meal is rather tolerant to a reasonable amount of underheating or overheating from the optimum.

TABLE I

Effect of Moisture Level at Toasting on Nutritional Value of Soybean Oil Meal for the Rat

	% of Control		Water sol. protein (5)%	Urease pH change (4)
	Gain	Gain/ protein		
Control meal (plant toasted at 20.4% H_2O)	100.0	100.0	......	0.05
Raw-extracted meal	45.9	59.6	27.3	2.11
Extr. meal toasted @ 7.78% H_2O	53.6	62.5	14.5	2.02
10.0	49.5	61.4	13.1	1.80
15.0	71.0	76.1	7.7	1.60
20.0	90.8	89.6	5.7	0.32
25.0	85.2	93.9	5.0	0.03
30.0	96.0	101.8	5.3	0.02
35.0	90.3	85 8	4.6	0.02

All samples toasted except plant toasted for constant time in Laboratory Toaster at atmospheric pressure.
Ration was fed at the 15% protein level.

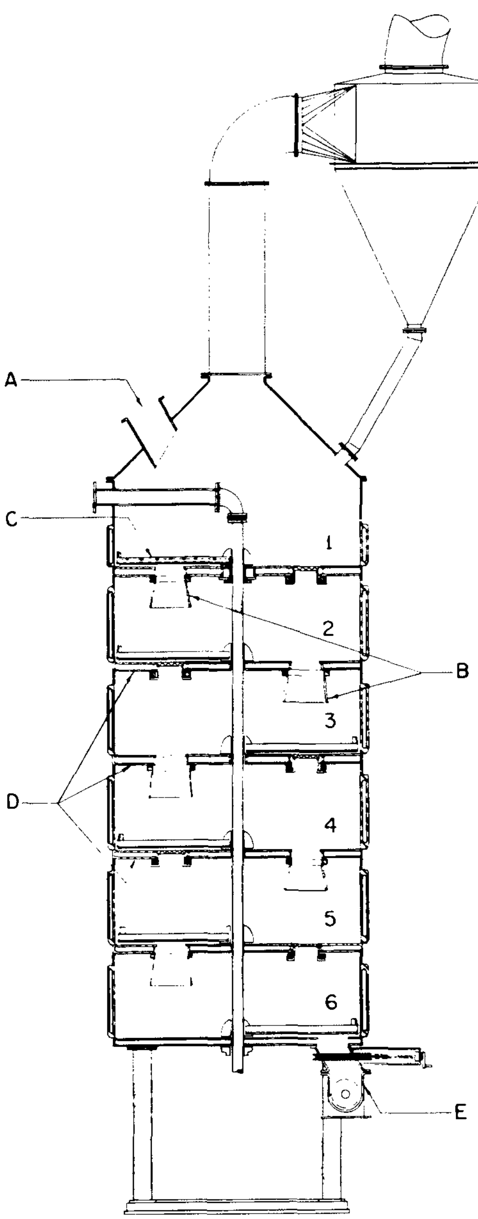

FIG. 1. Early Desolventizer-Toaster design.

Several investigators (2,3) have also noted that some moisture must be present in the extracted flakes to make the toasting effective although moisture has not been studied extensively as a variable in the laboratory. It is known however that the presence of moisture during the toasting step increases the rate of destruction of the urease enzyme and the antitrypsin factor and also results in accelerated changes in the protein leading to reduced water solubility. The following data representative of laboratory atmospheric toasting tests under relatively high moisture conditions illustrate this effect (Table I).

From this experiment it will be noted that the optimum moisture level, in the laboratory toasting equipment used, is in the range of 20–30% moisture; at this moisture level the laboratory-prepared product had equivalent nutritional value to a plant-toasted product prepared at 20.4% moisture. The effect of added moisture on reduction of water-soluble protein and urease enzyme is clearly illustrated.

Description of D-T Machine and Process

Pilot-plant studies and the first commercial D-T machines were of the type shown in Figure 1. This machine, and a later improved design, will first be described from the mechanical and operating aspects as usually applied in soybean meal processing. Later the toasting conditions actually existing in the D-T will be discussed on the basis of the information given in a).

As will be seen in Figure 1, the basic Desolventizer-Toaster design consists of a series of stacked kettles arranged so that the meal can flow successively from the top kettle to the bottom kettle. Meal flow through the individual kettles may be controlled by the chute arrangement (B) shown, or by automatic gates. The solvent-wet flakes from the extractor enter the machine through feed opening (A). Open steam is injected into the solvent-wet material in kettle No. 1 *via* the hollow shaft and the steam sweeps (C) attached thereto. Since the solvent on the flakes boils at a lower temperature than the condensing temperature of the steam, the injected steam condenses on the flakes in the No. 1 kettle, furnishing the heat required to vaporize the solvent. It is common practice to use sufficient live steam to vaporize all of the solvent in the No. 1 kettle so that the flakes passing from the No. 1 kettle to the No. 2 kettle have reached a temperature in the range of 180–200°F.

TABLE II

Desolventizer Toaster Heat and Material Balance

Reference temperature: 140°F.	To		From	
	Lbs./hr.	BTU/hr.	Lbs./hr.	BTU/hr.
Temperature:				
Flakes and hexane to D.T. — 140°F.				
Meal from D.T. 220°F.				
Vapor from D.T. 166°F.				
Solids:				
Flakes/meal (dry basis)	53,622	......	53,622	906,000
Water	7,436	......	12,891[a]	1,022,000
Hexane	29,734	......	......	......
Vapors:				
Live steam (condensed)	5,455	5,787,000	......	......
Live steam (not cond'd)	3,545	3,761,000	3,545	3,640,000
Hexane	......	......	29,734	4,655,000
Jacket heat input	......	676,000	......	......
Total material	99,792		99,792	
Total BTU's		10,224,000		10,223,000

* Exit meal moisture ... 18.7%
Allowance for flash ... 0.7%

Exit moisture used in balance ... 19.4%

In the lower kettles the temperature of the meal is further increased by the heat input through the steam jackets on the bottoms (D) and on the sides of the kettles (if jackets are provided here). As will be shown later, the toasting action takes place in the lower kettles under optimum conditions for the production of a high quality of meal. In addition to raising the temperature of the meal, the heat input through the jackets in the lower kettles reduces the moisture content of the meal; the extent of drying depends on the amount of heat actually supplied. The meal in the bottom kettle leaves the D-T machine *via* the variable speed screw (E) shown in the figure or by an automatically-controlled gate.

Figure 2 shows a later improved design Desolventizer-Toaster, in which the desolventizing (upper) portion of the machine has been modified to reduce the live steam required for this step of the process and to make this treatment more effective. The meal flows through the first three kettles of this design through disc and doughnut type of openings (A) rather than through chutes or gates as in the earlier design. The live steam is injected at the No. 3 bottom location, preferably by making this bottom into an actual steam sparging plate by drilling a large number of holes in the upper surface (B). In order to provide adequate cross-sectional area for the upward passage of live steam and solvent vapors through the relatively deep bed of meal carried in this design, a louvered enclosure (C) is provided for the side walls of the No. 2 kettle. The live steam and solvent vapors from the No. 3 kettle pass upwards into the annular space outside of the louvers and then through the louvers into the meal in the No. 2 kettle. This prevents the possibility of having a high vapor velocity in the doughnut opening in the No. 2 bottom, which might interfere with the proper flow of meal at this location. The lower kettles of the machine in this design are identical to the lower kettles for the simpler design shown previously.

The improved design shown in Figure 2 has two main advantages. First, the enlarged upper portion of the machine, which is called the vapor dome (E), lowers the velocity of the vapor leaving the upper surface of the meal, thus preventing bed fluidization, enabling the machine to operate at a higher capacity. This also can be viewed as facilitating a more optimum sizing of the desolventizing and toasting zones of the machine. The second advantage of this design is that it reduces the quantity of live steam required for the desolventizing function because the live steam is required to flow through a deeper bed of meal before leaving the unit, thus giving improved contact between the live steam and the meal.

A number of studies have been made in Central Soya's plants to gain practical information on the material and heat balance relationships existing in machines of both types. Since the improved machine is currently the design of choice for a high-capacity operation, a complete heat and material balance based on the average of many individual tests for this unit is shown in Table II.

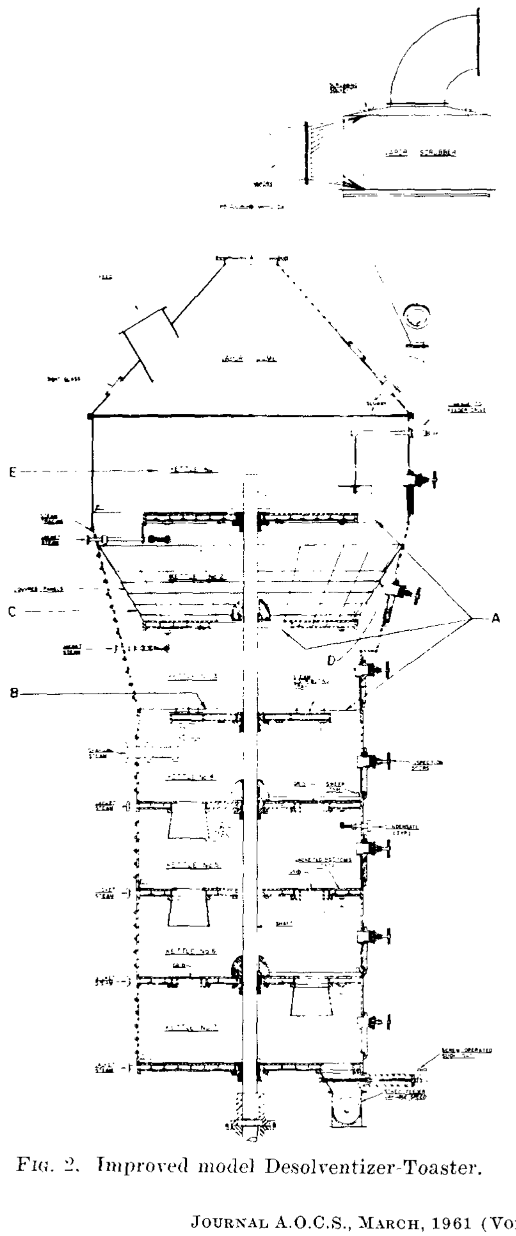

FIG. 2. Improved model Desolventizer-Toaster.

This unit has the following basic dimensions:

Inside diameter of top vapor dome	12 ft.
Inside diameter of lower toasting zone	8 ft.
Operating meal volume	829 cu. ft.
Normal operating capacity	1,000 tons soybeans/day

The heat balance uses a reference temperature of 140°F. (the temperature of the wet flakes entering the unit) in order to help highlight the relative heat contributions. It will be noted that almost 90% of the heat input for the entire operation comes from the live steam injected into the No. 3 bottom. This large heat input from condensing live steam is charactristic of Desolventizer-Toaster operations on soybeans, where subsequent toasting at a high moisture content is required to optimize meal quality. Data illustrating this point will be discussed later. Condensation of live steam is not necessarily desirable in the case of desolventizing cottonseed or other vegetable oil meals, where toasting is not desired.

Optimization of Toasting Conditions by D-T Process

Numerous feeding tests on rats, chickens, and hogs have shown that the Desolventizer-Toaster process produces a meal of excellent nutritional value, which in many trials surpassed meals produced by other toasting processes. In examining the variables for obtaining a good quality meal, it was found that time in the toasting step is not at all critical and can be varied through rather wide limits without seriously affecting the meal quality; the moisture content during the toasting step is also rather easily controlled in normally operating plants since this is primarily a function of the solvent content of the extracted flakes at the inlet of the machine.

There are two factors in the operation of the machine which are apparently responsible for this excellent quality of protein: metering of moisture to individual flake particles and cellular explosion due to the rapid steaming.

The feed to the Desolventizer-Toaster consists of hexane-wetted flakes from the extractor. Each flake is wetted with absorbed solvent, the quantity of solvent being proportional to flake size and weight.

In the desolventizing zone of the Desolventizer-Toaster, heat must be supplied to each individual flake particle to vaporize its individual solvent content. In the steam environment which characterizes the desolventizing section of the unit, this heat is furnished by live steam condensing upon the individual particles. Thus, in contrast to older types of toasting where water as a liquid was mixed with dry flakes in an attempt to achieve equal distribution of water by means of high speed mixing, in the Desolventizer-Toaster the water as condensed steam is automatically "metered" properly to each flake particle based on its weight. As a result, each flake particle responds uniformly to treatment in the later toasting sections, preventing overtoasting of some particles and undertoasting of others, and minimizing the loss of valuable nutritional factors.

Histological studies of soybean meals processed by the Desolventizer-Toaster process have demonstrated that this process results in an unusual destruction of the cellulosic cell walls and agglomeration and coalescence of the protein grains present within the individual cells into large protein masses. This almost total destruction of cell walls is due to the explosive vaporization of solvent in the desolventizing zone and is characteristic of the Desolventizer-Toaster process. A histological rating system, wherein meals are rated from 0 to 10 on the basis of completeness of the destruction of the cell walls, has been used in Central Soya's laboratories for a number of years as an aid in studying the protein quality of meals. In this system a rating of 10 indicates a meal wherein the cell walls are almost completely obliterated and the protein coalesced to amorphous masses, and a rating of 0 indicates a completely intact cell wall and undenatured protein grains as found in the raw soybean.

Representative microscopic sections showing the raw-extracted soybean flake, a poorly toasted meal, and a Desolventiser-Toaster meal are shown in Figures 3A, 3B, and 3C.

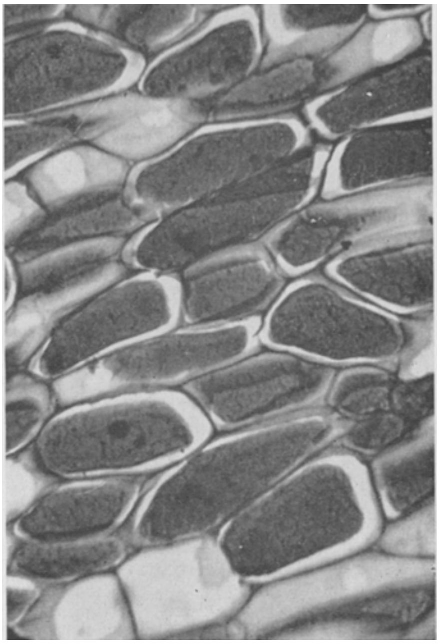

FIG. 3a. Microscopic section of raw-extracted soybean flake.

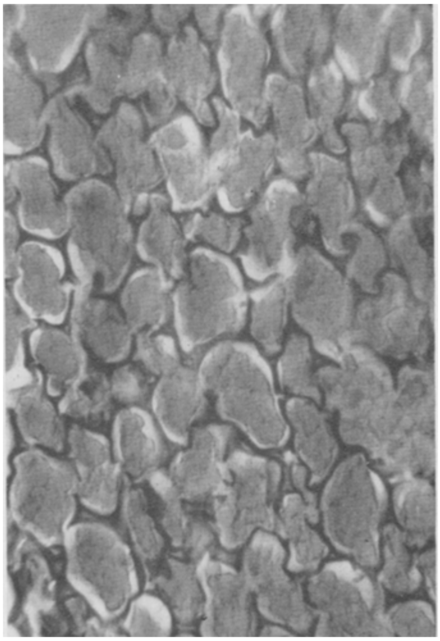

FIG. 3b. Microscopic section of poorly toasted meal.

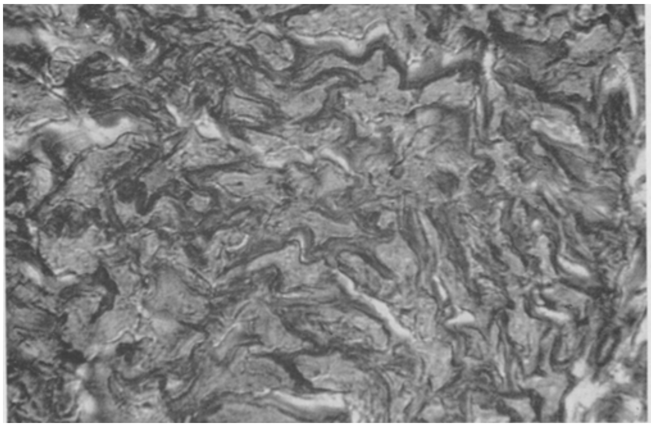

FIG. 3c. Microscopic section of Desolventizer-Toaster meal.

In these sections the protein masses have been stained with safranin, and cell walls are stained green with fast green. The stained product was then photographed by color photography, and black and white prints were made from the color negatives to produce Figures 3A, 3B, and 3C. In the black and white reproductions the green or cellulose material shows up as strong black streaks representing the cell wall structure; the red protein material appears as a "mottled" greyish area of various intensities. It will be noted that there is little remaining cellular organization in the Desolventizer-Toaster meal. Meals showing this type of complete cellular disruption have always produced excellent results in feeding tests whereas meals showing the incomplete destruction labelled "Poorly Toasted" generally give inferior results.

In general, the major variable under the control of the designer for a Desolventizer-Toaster is the toasting time. A large number of feeding trials on rats have been conducted on meal samples taken from various kettles of the Desolventizer-Toaster in an attempt to determine the optimum time. The data for one such test, which is believed to be fairly typical, is shown in Figure 4. It will be noted that

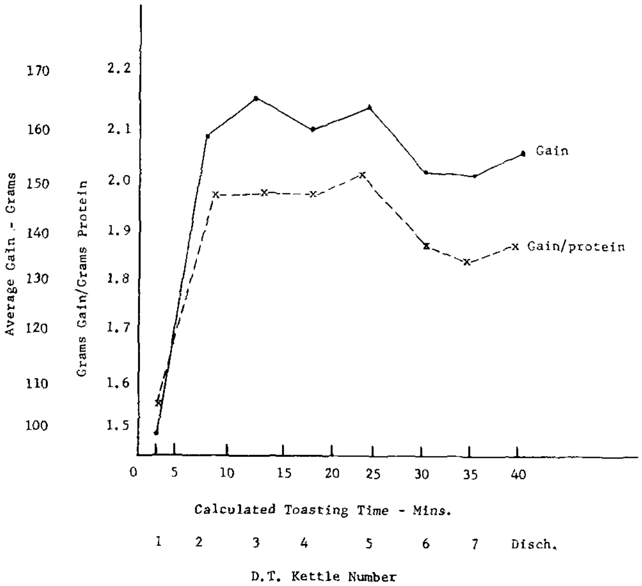

FIG. 4. Effect of holding time on nutritional value (rats fed at 15% protein level in the ration).

the optimum nutritional value appears to be obtained rather quickly, after only about 10 min. of processing, and that there is only a slight reduction in either gain or protein efficiency (gain/protein) at the maximum of 40 min. Actually the differences shown between 15 and 40 min. are probably not significant for this test alone, but the data are quite typical and, when the large number of tests showing a similar pattern are considered, the repeated finding of a slight decrease in value at more than 30 min. of toasting time appears to be rather significant. No doubt, trade demands for a darker brown meal have at least partly influenced toasting to this degree.

The chemical characterization of the meal samples tested in Figure 4 is shown in Table III. It will be noted that

TABLE III

Chemical Characterization of Meals After Various Toasting Times

Sample	Water sol. prot. (5) %	Thiamine (6) mcg./g.	Urease (4) pH rise	Trypsin inhibitor (7) % destroyed	Time in D-T min.
Kettle No.					
1	23.19	12.81	2.22	0	2
2	14.66	12.24	1.52	47.8	7
3	11.38	10.25	0.05	92.7	12
4	8.10	8.54	0.02	97.1	18
5	9.85	8.35	0.03	97.1	23
6	4.16	5.37	0.01	97.1	28
7	7.00	5.48	0.01	98.5	34
Discharge	7.44	6.21	0.02	100.0	40

there is a steady decrease in water-soluble protein, thiamine, and urease as the toasting progresses. The two principal determinates of minimum toasting time have often been considered to be urease activity and trypsin inhibitor. The data show that these two factors are both almost completely destroyed in the No. 3 kettle position, corresponding to approximately 12 min. of toasting time. While urease in itself is considered to be only an indirect measure of the protein quality of the meal, it is nevertheless important from the standpoint of having the meal compatible with urea and therefore must be watched closely.

On the other hand, thiamine, which is slowly destroyed during the toasting process, has of itself some significance in nutrition and furthermore is often used as a measure of the destruction by heating of other valuable nutritional factors. Therefore it is believed desirable to choose a toasting time in the minimum range compatible with adequate deactivation of the urease enzyme. Mixed feed manufacturers generally consider that a meal having a urease activity of less than 0.1 pH rise by the Caskey Knapp method (4) is satisfactory for all formulations involving urea. Accordingly the optimum toasting time in the Desolventizer-Toaster is considered to be the minimum which will produce a urease activity below this figure.

A comparison of the meals produced by the Desolventizer-Toaster process and other widely used processes is shown in Table IV. The chemical factors generally used in judging meal quality together with the rat assay for protein quality by Central Soya's standard method is shown. The domestic samples were collected during the past year, but the data are fairly typical of the comparisons made between the Desolventizer-Toaster meal and conventional meals in 1950–52 when the Desolventizer-Toaster process was first used on a commercial scale. It will be noted that Samples 1, 2, and 3 show the effects of overtoasting as measured by each of the chemical indices (water-soluble protein, thiamine, urease, and trypsin in-

TABLE IV

Analyses and Nutritional Values of Meals Toasted by Various Methods

No.	Test No.	Sample	Water sol. prot. (5) %	Thiamine (6) mcg./g.	Urease (4) pH rise	Trypsin inhibitor (7) % destroyed	Histological rating	Gain in grams	Feed/gain in grams
		Domestic samples							
1	204	1—U.S.	3.5	2.8	0.02	100	6	97	4.34
2	204	2—U.S.	4.4	2.2	0.00	100	5	81	4.76
3	204	3—U.S.	4.8	2.0	0.01	100	8	94	4.52
4	204	Chattanooga D-T (Control)	10.1	6.7	0.04	99	10	100	4.12
		Foreign samples							
5	204	Schnecken	23.8	9.4	2.2	5	2	48	6.86
6	206	Decatur D-T (Control)	8.7	7.9	0.1	91	10	88	4.20
7	206	Pot-extracted No. 1	5.3	6.2	0.04	100	4	75	4.45
8	206	Pot-extracted No. 2	6.1	5.3	0.03	100	3	80	4.27

Rat tests; protein level in the ration was 10%.

Histological evaluation is rated numerically. A rating of 10 indicates a well-toasted meal with complete cellular breakup. Protein masses are released from the cellulose capsules and flow together into confluent masses. A numerical rating of 1 however indicates an untoasted, raw meal. The cellulose remains in a uniform pattern, containing the individual protein masses in a granular form.

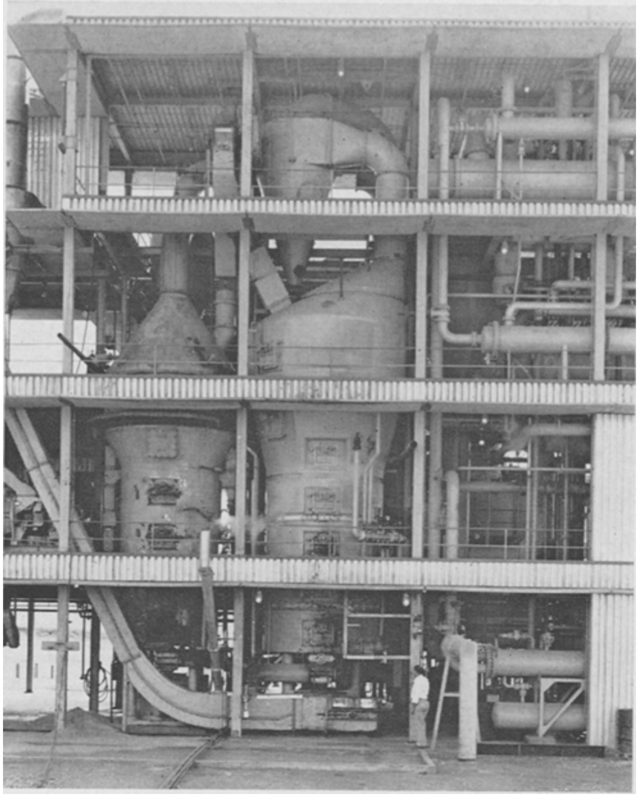

FIG. 5. U.S. installation of design shown in Figure 2.

hibitor) but that the histological rating for cellular breakdown indicates incomplete destruction of the cellular walls. Feeding tests show the Desolventizer-Toaster meals to be significantly better than two of the other meals (Nos. 2 and 3), both on the basis of total gain and on the basis of efficiency (feed/gain).

The pot-extracted meal samples shown in lines 7 and 8 were furnished by two processors in Germany. The samples are interesting because the desolventizing step in the pot extractor is also accomplished by the use of open steam. Although the chemical indices for these meals seem to show that the toasting time is approximately optimal, it will be noted that the histological rating and the feeding results for these meals are quite inferior to the Decatur control (Desolventizer-Toaster meal from Decatur, Ind.). Two reasons have been advanced for the deficiency of the pot-extracted toasting process. The rate at which steam is admitted to the pot extractor is relatively low compared with the rate used in the Desolventizer-Toaster so that the meal does not receive as violent a steaming action, and the process is not a continuous one so that the meal near the live steam inlet at the bottom of the pot is subjected to different toasting conditions from those of meal at the upper part of the bed.

Sample No. 5 is representative of Schnecken-processed meals in Europe, which receive a minimum, if any, toasting. This is evidenced by high water-soluble protein content and a high residual urease and trypsin inhibitor activity. These meals are also characterized by a light color, dustiness, and low bulk density. As the feeding data show, this type of meal is markedly inferior to properly toasted meals.

Practical Installations

Since the first installation of the Desolventizer-Toaster process in 1950, a large number of U.S. processors have installed D-T machines, and this process is now the one of choice for soybean meal toasting. While the discussion of benefits of the process in this paper has been limited to the production of meal of optimum nutritional value, the process has many other attractive features for the processor. Among these are lower solvent loss than can be achieved by other processes, minimum amount of desolventizing equipment resulting in simpler operation and lower costs, less building space, safer plant operation because of simplicity and ease of control of desolventizing operation, and substantial reduction of over-all plant steam usage by utilizing the heat content of D-T vapors for miscella evaporation or other processes because these vapors are dust-free.

The Desolventizer-Toaster process is also gaining acceptance from foreign processors as feed manufacturers in these locations begin to recognize the importance of properly toasted meal for use in their feed formulas.

Many units of the type shown in Figure 2 are already in operation in the U.S. and other countries, and it is expected that many additional units will be installed. A U.S. installation of the design shown in Figure 2 is pictured in Figure 5 (8).

In summary, the Desolventizer-Toaster process has proved itself to be capable of producing meals of superior nutritional quality and to have many other practical advantages for the processor.

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