Effects of Certain Operating Variables on the Continuous Solvent Extraction of Vegetable Oils

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THE lack of an adequate theoretical basis for the design of solid-liquid extraction equipment has made it necessary to determine the operating characteristics of this equipment experimentally. Pilot plant extraction equipment of a new design developed in this laboratory has been used in the design of commercial equipment for the solvent extraction of soybean oil (1). Smaller pilot plant equipment has since been built. This latter equipment was designed to be used in the determination of data on the effects of different operating variables in this type of equipment without the use of large quantities of solid material or solvent. Preliminary investigations have been carried out with this equipment on the continuous countercurrent extraction of soybeans by trichloroethylene.

Equipment

Description. In this extractor the soybean flakes are carried through the solvent by a continuous chain conveyor having circular skeleton-like flights (Figure 2) which produce a positive, non-agitated, conveying action and at the same time allow excellent countercurrent flow of solvent through the mass of flakes. Details of the pilot plant equipment are shown in Figures 1, 2, and 3. The chain conveyor is a roller chain having a pitch of 3/8 in. and a length of 24 ft., 9 in. to which are attached, at 3-in. intervals, circular flights shown in Figure 2. The loop casing through which the conveyor travels is constructed of standard 2-in. steel pipe interspaced by glass sections along the extraction section for close inspection of material flow. This casing is surrounded by a steam jacket of 4-in. pipe along its upper horizontal length to form one of three meal desolventizer, or drier, sections. Extracted meal is discharged from the conveyor chain at the left-hand end of this first drier section through a connecting chute into the second drier section. The second and third drier sections consist of 2½-in. pipe,

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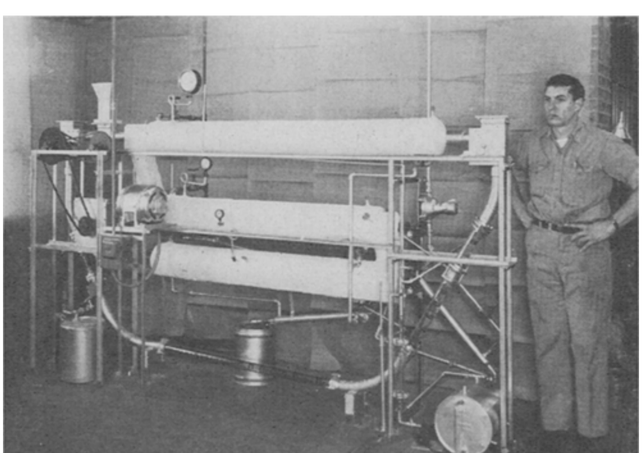

FIG. 1. Pilot plant extractor.

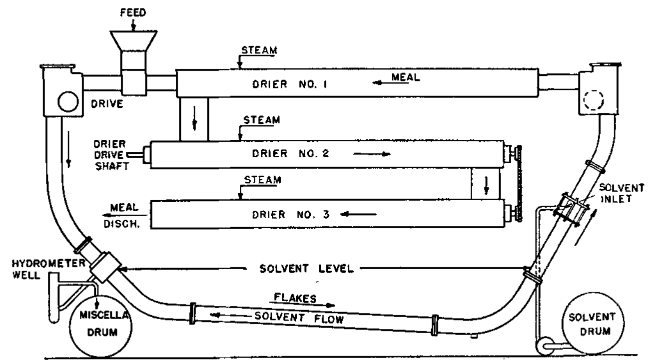

FIG. 2. Flow diagram of pilot plant extractor.

surrounded by 4½-in. steam jackets, and connected through another vertical chute at the discharge end of the second section. All sections are insulated by 1-in. layers of magnesia pipe covering. Extracted meal is conveyed through the second and third sections by means of specially constructed spiral ribbon conveyors which are driven by a pair of bevel gears connected to the main drive speed reducer. The last 12 in. of the final drier section consists of solid screw conveyor flights, which permit the formation of a plug of extracted meal at the final discharge opening, preventing excessive losses of solvent vapors.

The main drive section is a 1-horsepower electric motor operating through a speed reducer and a series of chains and sprockets to drive the chain conveyor drive sprocket. An ammeter in the power line to the motor indicates overloading and permits estimation of power consumption. A series of different sized interchangeable sprockets provides changes in conveyor speed.

Solvent is introduced at approximately the center of the right-hand riser leg of the extractor casing through a small, steam-jacketed heat exchanger and a rotameter. Final miscella is withdrawn through a screen in the left-hand leg of the extractor casing. A hydrometer well in this miscella line determines the concentration of oil in the exit miscella at any instant. Miscella is stored in a 5-gal. drum and filtered prior to being sent to an external solvent recovery unit. When the extraction path is filled with solvent, the level remains essentially constant for a given batch of flakes, forming an extraction path under conditions of these studies, 98 in. in length.

Two water-jacketed condensers, connected to the drier sections at points in the two connecting chutes, effect recovery of solvent vapors produced in the driers. By means of thermometers, located at solvent entrance, miscella discharge, meal discharge, and water discharge and entrance points, temperatures throughout the system can be checked at any time.

Operation. Steam is introduced into the drier section jackets and brought to the desired pressure prior to the beginning of each run. The extractor drive is set into motion, and flake feed is started at the same

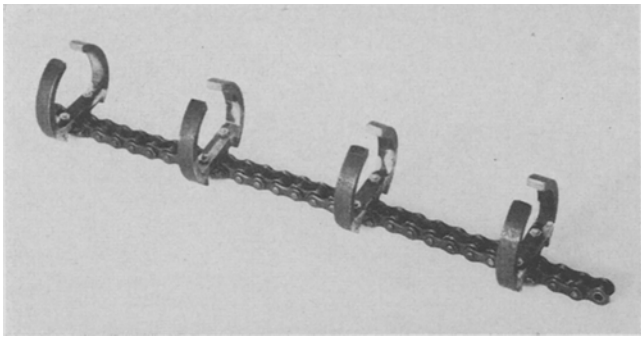

FIG. 3. Conveyor chain used in extractor.

time as solvent feed so that the extraction leg of the unit is filled with flakes and solvent simultaneously. Flaked soybeans are fed in 5-lb. batches, each batch being timed to determine the feed rate for each run. Solvent flow rate is controlled by a valve above the rotameter in the solvent delivery line and temperature by regulation of steam pressure in the heat exchanger.

In these experiments the time required from the first moment of feeding to the moment the first extracted meal began to emerge from the final drier section was noted. It was assumed that steady state conditions had been attained when operating conditions such as temperatures, miscella concentration, and feed, solvent, and miscella rates had become constant. Temperatures and miscella concentrations were then recorded at timed intervals over a two-hour period of steady state operation, and an average of these readings was taken as the value for that run. A composite sample of the meal produced over this period was analyzed for oil content. The total time consumed for each run was approximately four hours. All soybean flakes used in these studies were made from a common batch of beans and averaged 0.010 in. thick. All analyses and feed rates were recorded on a moisture free basis.

Results

Varying Chain Speed. Six runs were made at six different chain speeds. Solvent flow rate and temperature were held constant at 0.027 gal. per minute and 105°F. respectively. The most evident effects of chain speed variation were on feed rate and extraction time.

Since the conveyor was fed by gravity from the feed hopper, it operated almost completely full of flakes at all times, and thus the weight of flakes which could be fed into the unit in a given time interval was theoretically a straight line function of the chain speed for a given batch of flakes, as is shown by the dotted line in Figure 4. The experimental data fall along the solid line, showing good agreement with the theoretical assumption at low speeds. The lower capacity at 13 in. per minute may result from slight slippage at the higher speed or, what is more probable, from a failure to fill the chain completely. It is more difficult to fill the small conveyor casing completely than it is the larger casings used in commercial equipment.

The relation of extraction time to chain speed is given by $y = l/x$, where x = chain speed in inches per minute, y = the extraction time in minutes, and l = length of the extraction path in inches. Under the conditions of these experiments $l = 98$ in. Thus the data in Figure 4 represent extraction times from 7.5 to 58.0 minutes.

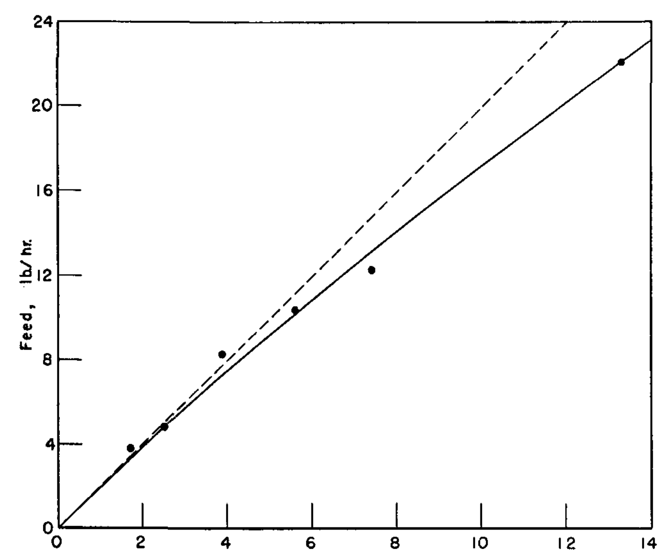

FIG. 4. Relation of rate of feed to speed of chain.

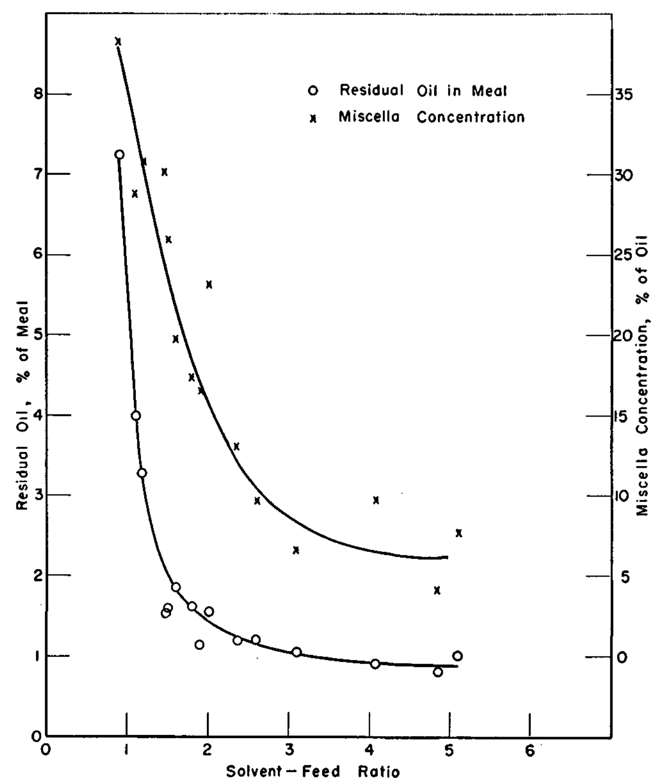

FIG. 5. Relation of residual oil to solvent-feed ratio.

Varying the Solvent-Feed Ratio. Changes in the ratio of solvent to flake feed can be made by holding either the chain speed or the solvent flow rate constant and varying the other. To obtain data on the effect of varying the solvent-feed ratio, nine additional runs were made at the same temperature used in the preceding runs, using extraction times of 7.5, 12.4, and 16.2 minutes. Using the data from these and preceding runs, the curves in Figure 5 were plotted to show the relation between solvent-feed ra-

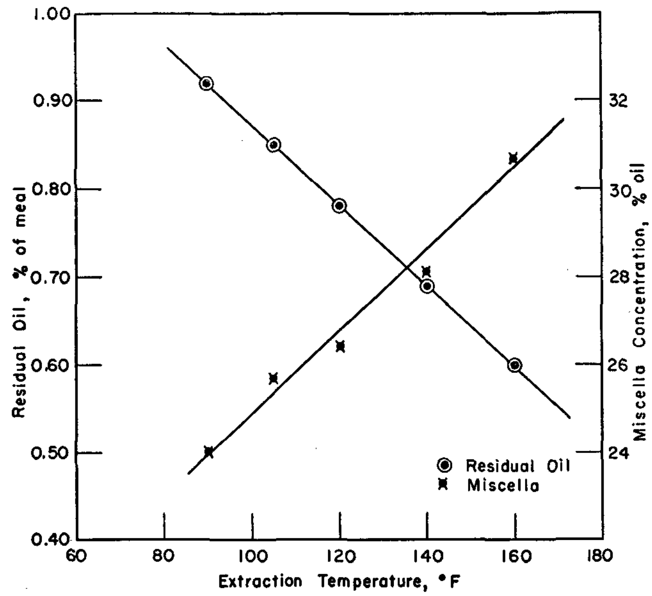

FIG. 6. Relation of residual oil in meal and oil in miscella to extraction temperature.

tios and residual oil. When feed solvent ratios (reciprocals of the solvent-feed ratios) were plotted against either the miscella concentrations or the residual oil percentages, the data fell fairly well along a straight line. Thus, over the range covered, the extraction time had apparently little effect, in comparison with the effect of the solvent-feed ratio, upon either the miscella concentration or on the residual oil content of the meal. This contrasts with the conventional concept of time residual oil relationships which have been determined with a constant solvent-feed ratio and which tend to give the impression that time is the controlling factor in solvent extraction. Oil extraction is fundamentally a diffusional operation and is dependent upon such familiar factors as driving force, distance, and time. In the present studies distance, represented by the flake thickness, was constant. Driving force, in addition to a constant, involves the variables of concentration and temperature. Temperature in these studies was constant, leaving concentration as the variable. The effect of concentration has been brought out by the family curves by King, Katz, and Brier (2), showing the effect of the increase in the residual oil content in the meal with the increase in the oil content of the solvent. Decrease in the solvent-feed ratio results in an increase in the oil content of the solvent at any point in the countercurrent extractor, which is an appreciable distance beyond the solvent entry point. Under certain ranges of solvent-feed ratios and times such as those used in the current studies, the effect of variations in concentration is sufficiently greater than that of time of extraction to obscure the time effect. In attempting any practical application of these data they must be limited to economical solvent-flake ratios. Under practical plant operations using commercial equipment of the same type as the pilot plant, solvent-feed ratios between 1.5 and 2.0 to 1.0 would be used.

Varying Extraction Temperature. Preliminary runs in which the inlet temperature of the solvent was varied showed erratic results since the temperature in the extractor was a function, not only of the inlet solvent temperature, but also of the heating effect of the chain and the cooling effect resulting from the loss of heat from the extractor to the surrounding air. To correct this the extractor portion of the loop was wrapped with electric resistance wire provided with controlling rheostats,thus making it possible to maintain a constant temperature throughout the extractor.

A series of five runs were made, using flakes from a common batch with a constant solvent feed ratio of 1.74 to 1 and temperatures from 90°F. to 160°F. The results, plotted in Figure 6, show a straight line relation between extraction temperature and residual oil in the meal and extraction temperature and miscella concentration. An increase in the solvent feed ratio should result in a temperature-residual oil line below that shown and at least partly parallel to it. Aside from reaching an uneconomical solvent feed ratio, the relation represented by this line is subject to two limitations: first, because of the high vapor pressure developed, it is not practical to raise the temperature much above 106°F.; second, as the residual oil content approaches zero, the line will curve tending to become horizontal.

Summary

Data have been secured on the countercurrent extraction of soybean flakes by trichloroethylene in a laboratory extraction pilot plant having a capacity of about 10 lb. per hour. Feed rates and extraction times departed only slightly from a straight line relationship with the speed of the chain used to move the flakes through the extractor. Over the ranges studied, changes in solvent-feed ratios had a much greater effect than the extraction time on the amount of oil extracted. Over a practical range of temperatures with the solvent-feed ratio constant, the residual oil content of the meal showed a straight line relationship with the temperature.

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