designed primarily for interior uses, for regions of comparatively low relative humidity, and for bonding plywood which may be used in building forms which may be discarded after several times of use.

Acknowledgment

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REFERENCES

1. A.S.T.M., "1946 Book of A.S.T.M. Standards," American Society for Testing Materials, Philadelphia, 1946.
2. Burnett, R. S., and Parker, E. D., Trans. Am. Soc. Mech. Eng., *68*, 751-756 (1946).
3. Hogan, J. T., and Arthur, J. C. Jr., J. Am. Oil Chem. Soc., *28*, 20-23 (1951).

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A New Continuous Solvent Extractor for Oleaginous Substances

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IT has long been recognized that the most efficient method of removing the oil from oleaginous materials, on the basis of oil recovery alone, is by extraction with solvents (1). That this method is not applied more widely today is due, in part, to design problems associated with the physical characteristics of some of the most common materials, e.g., the "fines" problem found in the extraction of vegetable seeds and nuts.

The complications that the "fines" problem has introduced into the design of the extraction plant, particularly the extractor, are well known. Also it is well known that this problem has been most difficult to solve for the so-called "high oil" seeds, which comprise the bulk of the world's production of oil seeds. Recent advances in preparing such materials for extraction, both the whole seed and forepressed seed cake, have reduced the "fines" problem to a matter of materials preparation and have made possible the development of an extractor which will operate efficiently in those installations where, by reason of economics, two or more seeds must be processed in the one unit (in sequence).

For this purpose a continuous percolation extractor was conceived in which the solids would be deposited upon a porous belt conveyor running horizontally. Extraction would be carried out by percolating the solvent through the solids in stagewise, countercurrent fashion. The extractor would be constructed as simple as possible and, above all, would be easily controllable.

Continuous, countercurrent operation was considered necessary from the standpoint of operating efficiency. Stagewise operation was considered advantageous for reasons which will be pointed out later. Extraction by percolation was decided upon because advantage could be taken of the self-filtering property of a bed of solids to reduce the fines content of the strong solution. And lastly, since the bed of solids would not be disturbed in passing through the extractor, it was believed that "fines" production within the unit could be minimized.

Certain engineering data are necessary, of course, for the design of any extractor. For a percolation extractor of the type visualized, a knowledge of extraction rates, the amount of solution retained by the solids in passing from stage to stage and in leaving the extractor, the rate at which solutions will percolate through the solids, the rate at which the solids are wetted by the solution, and bulk densities of the solids are of most importance. Each must be determined for the materials the extractor will be expected to process, taking into consideration a suitable range of bed depths and the various solvents which may be used.

Extraction rates and the amount of solution retained by the solids enter into the determination of the number of stages and have a direct bearing upon the size of the extractor. Also the latter must be known before the solvent-to-solids ratio can be determined. Wetting rates determine the minimum time required for a solution thoroughly to wet the solids. The amount of percolating solution per stage and the size of the stage pumps are determined by the rate at which solution will percolate through the solids. The relationship of bulk density and bed depth to capacity is apparent.

SINCE little of the data were available at the time and since all had an effect upon design, a research program for the purpose was sponsored at Armour Research Foundation, Chicago. The present continuous extractor, illustrated in Figure 1, is the result. Although six stages are shown, the actual number of stages will vary with conditions. For simplicity, details of mechanical construction have been omitted.

Briefly, the extractor consists of a continuous porous belt installed horizontally within a vapor-tight housing. The upper half of the belt acts as the carrier for the solids, the whole being driven by a variable speed, high reduction drive. The space above the belt is divided into a series of chambers by vertical partitions which extend to within a short distance of the solids, the clearance varying with bed depth. Solution is sprayed over the solids through manifolds installed in alternate chambers. The intermediate chambers are equivalent to short, free drainage periods between periods of active spraying and act to separate the stages. Nozzles in the manifolds direct the solution upward against a distributor, which breaks the force of the liquid spray and distributes the solution evenly over the solids. The porous construction of the belt allows free drainage of the solution into pans situated between the belt halves. The pans serve as reservoirs from which the solution may be withdrawn by stage pumps and re-

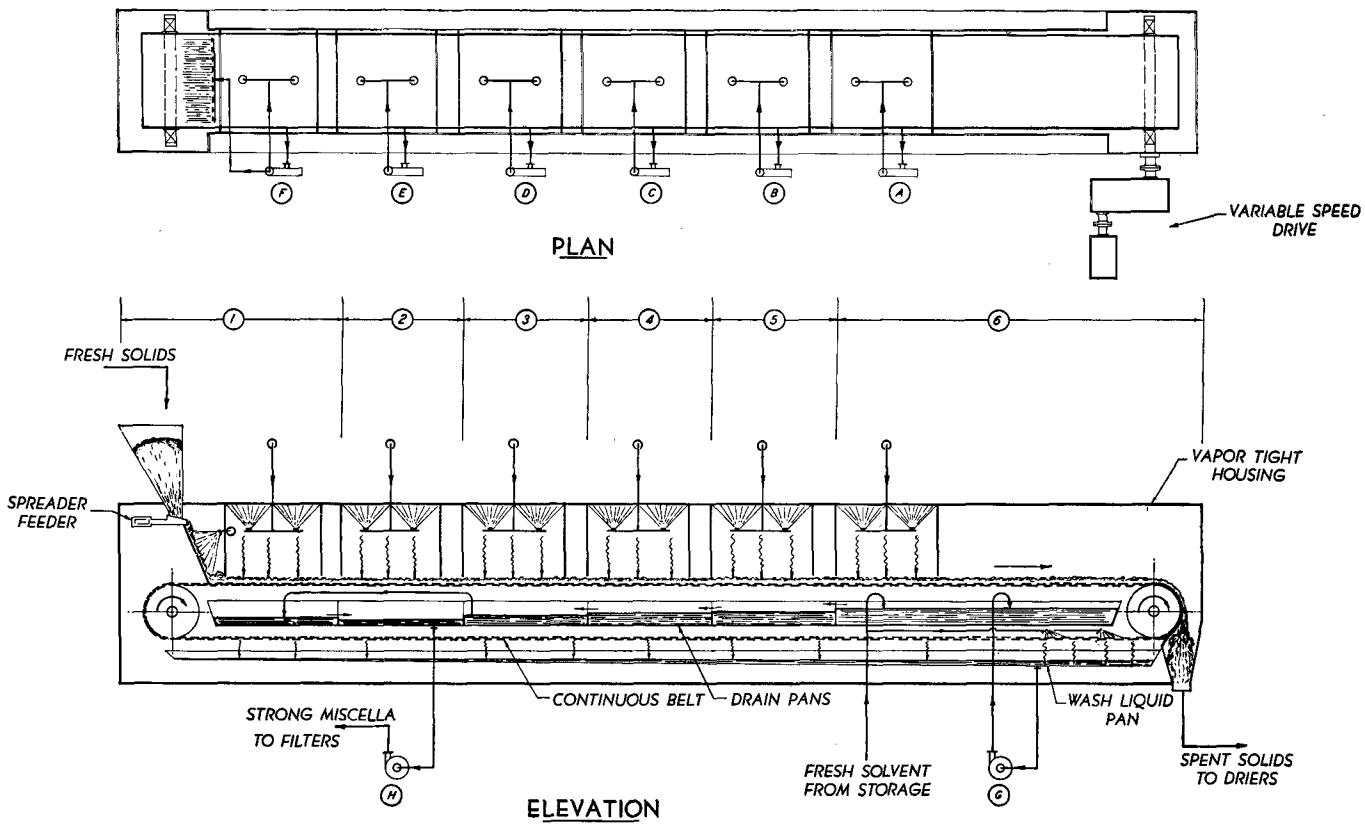

FIG. 1. Continuous belt extractor.

circulated over the solids. Except for that retained by the solids, passage of solution from stage to stage occurs in the pans through suitable overflows. The pans are constructed so that "fines" which may have passed through the belt with the draining solution will settle toward the suction line of the stage pumps.

As mentioned above, motive power for the belt is supplied by a variable speed drive. Because the upper half of the belt is the carrier, it must be kept tight; and for this reason the motive power is applied at the discharge. Power requirements will seldom exceed ¾ HP since the speed of the belt is very slow, on the order of 6 inches per minute. The variable speed feature permits adjustment of the belt speed to that corresponding to the desired degree of extraction for the material being processed.

Prepared solids are fed continuously into the feed hopper, from which they are deposited across the belt by the spreader-feeder, forming a bed of uniform depth. Before striking the belt, the solids are thoroughly wetted by a portion of the solution being circulated in the first stage. As the solids are carried slowly along by the belt, they are sprayed by a series of solutions which, after Stage 2, are of decreasing concentration. Finally the solids are sprayed with essentially fresh solvent, allowed to drain by gravity for a time, and then discharged.

Fresh solvent is fed continuously into the pan of Stage 6, where it mixes thoroughly with liquid draining from the belt. A small part of the fresh solvent is by-passed to clean the lower half of the belt of solids, which may not have discharged. This solvent, together with the solids, collects in the drip pan and is transferred to the pan of Stage 6, there combining with the bulk of the fresh solvent. Since the amount of oil extracted in Stage 6 is very small, the solution in the pan is essentially pure solvent. While a substantial portion of the solution is being withdrawn by the stage pump and transferred to the spray chamber above to percolate through the moving bed of solids, a smaller portion overflows to the pan of Stage 5. In the meantime "fines" settling in the pan enter the solution being withdrawn by the stage pump and are filtered from the circulating solution by the bed of solids.

In Stage 5 similar processes take place, with a substantial portion of the solution being withdrawn and sprayed over the solids by the stage pump, and a smaller portion overflowing to the pan of Stage 4. As in Stage 6, the "fines" settling in the pan enter the solution being withdrawn by the stage pump and are filtered from the circulating solution by the bed of solids. The oil content of the solution in the pan of Stage 5 has increased above that of Stage 6 by an amount equal to the quantity of oil extracted from the solids. These processes continue throughout the remaining stages with the concentration of the solution increasing gradually until it is withdrawn as strong miscella.

STRONG miscella is not withdrawn from Stage 1 however since experimental work has shown that, for most materials, the proportion of "fines" present in the pan at that point will be high. Therefore to provide extra filtration through an established bed of solids the pan overflows are arranged so that solution passes from Stages 3 to 1 to 2; the strong miscella is withdrawn from Stage 2.

Thus the flow of solvent through the extractor relative to the solids is stagewise and, except for the

first two stages, countercurrent. If conditions warrant, the concurrent flow through Stages 1 and 2 may be made countercurrent by a simple rearrangement of the overflows. The flow pattern shown however retains the advantage of being countercurrent and, in addition, delivers a clearer strong miscella than is possible otherwise. Also stagewise operation has an outstanding advantage, namely, the circulation rate of the free solution within any stage is independent of the feed rate of the solution to that stage. The reasons for including this feature in the design of the extractor will be discussed because of their importance to operation.

From the standpoint of channeling, it is desirable that the free solution be circulated at a rate approaching the percolation rate of the solution through the solids at the flooding condition. For the materials and bed depths studied, the data indicate that the percolation rate at the flooding condition will be several times the feed rate of fresh solvent to the extractor. Since the latter, in turn, determines the feed rate of solution to any stage, it is apparent that the desired circulation rate cannot be attained without stagewise operation. As a corollary, any required circulation rate may be obtained in stagewise operation regardless of bed depth, material being processed, or solvent ratio being used. Again, in any stage, circulating the solution over the solids at a higher rate than that at which the solution enters acts to extend the contact time between solution and solids. As a result, equilibrium between the solution retained by the solids leaving the stage and the draining solution will be approached more closely, which means that less stages will be required for a given extraction.

Design Data

Although a complete treatment of the data as applied to the design of the extractor is beyond the scope of this paper, typical data on solution retention will be presented and their applications to design pointed out.

When a solution is first added to a bed of solids, none will drain until a definite quantity is soaked up. Upon addition of solution at an increasing rate, more solution is retained until the bed becomes flooded. Upon further addition, a head of solution gradually builds up above the level of the solids. The point at which the levels of solution and solids coincide is known as the flooding condition. Figure 2 shows the relation of retention to drain time for a bed of soybean flakes which is initially flooded and then allowed to drain by gravity. The various curves represent different concentrations of the solution. "0% Oil" refers to pure solvent.

These curves show two distinct phases: a) during the first minute or so the rate resembles that of free flow through an orifice under falling head and is affected chiefly by the static head and pressure drop across the bed; and b) on continued drainage a much slower rate prevails which, at any instant, is a function of the amount of solution remaining on the solids. Since the curves are not straight lines on logarithmic paper, it is evident that physical properties of the solution such as viscosity, surface tension, and density are affecting the rate at which the liquid is displaced from the voids in and between the solids. On draining indefinitely, the retention approaches a minimum value asymptotically. This value, called static retention, is represented for pure solvent by

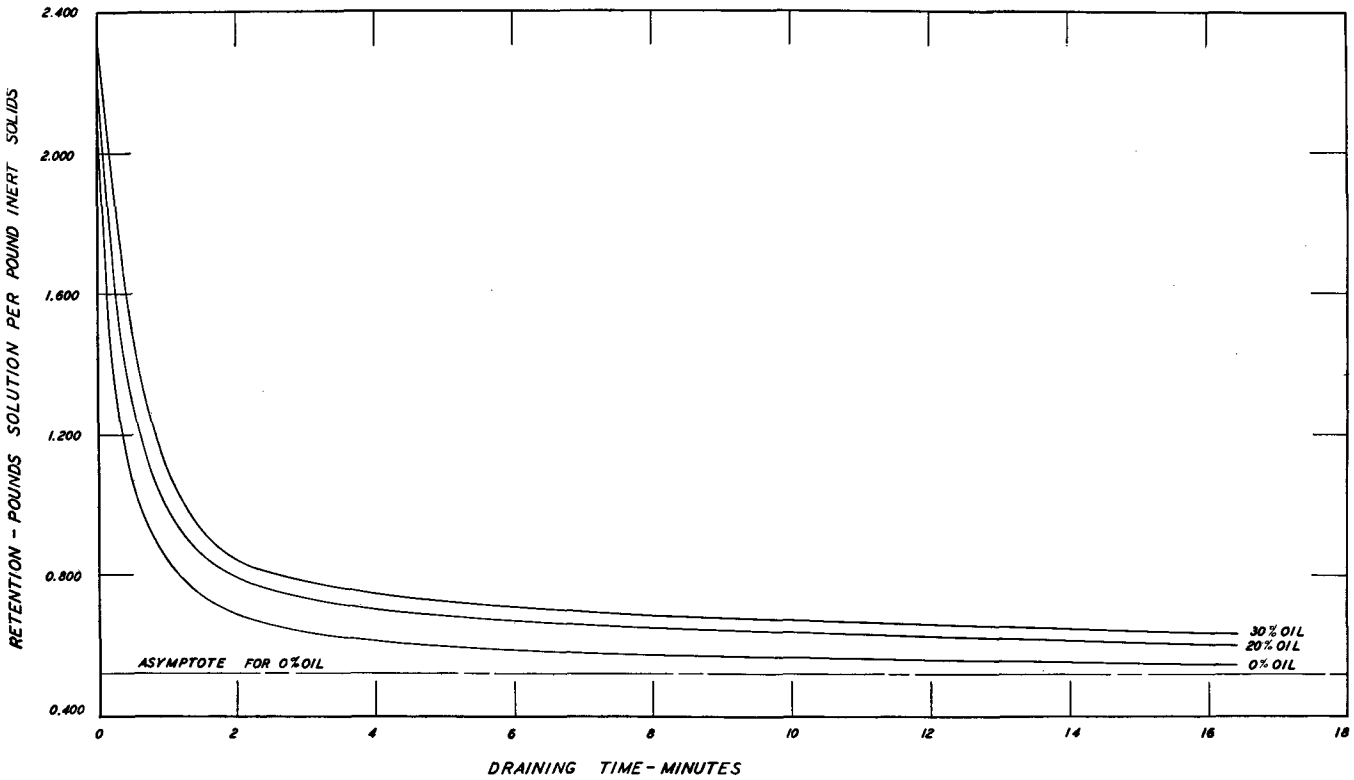

FIG. 2. Solution retention vs. draining time for soybean flakes, 0.009 inch thick, 12 inches bed depth, at 140°F., using Skellysolve B.

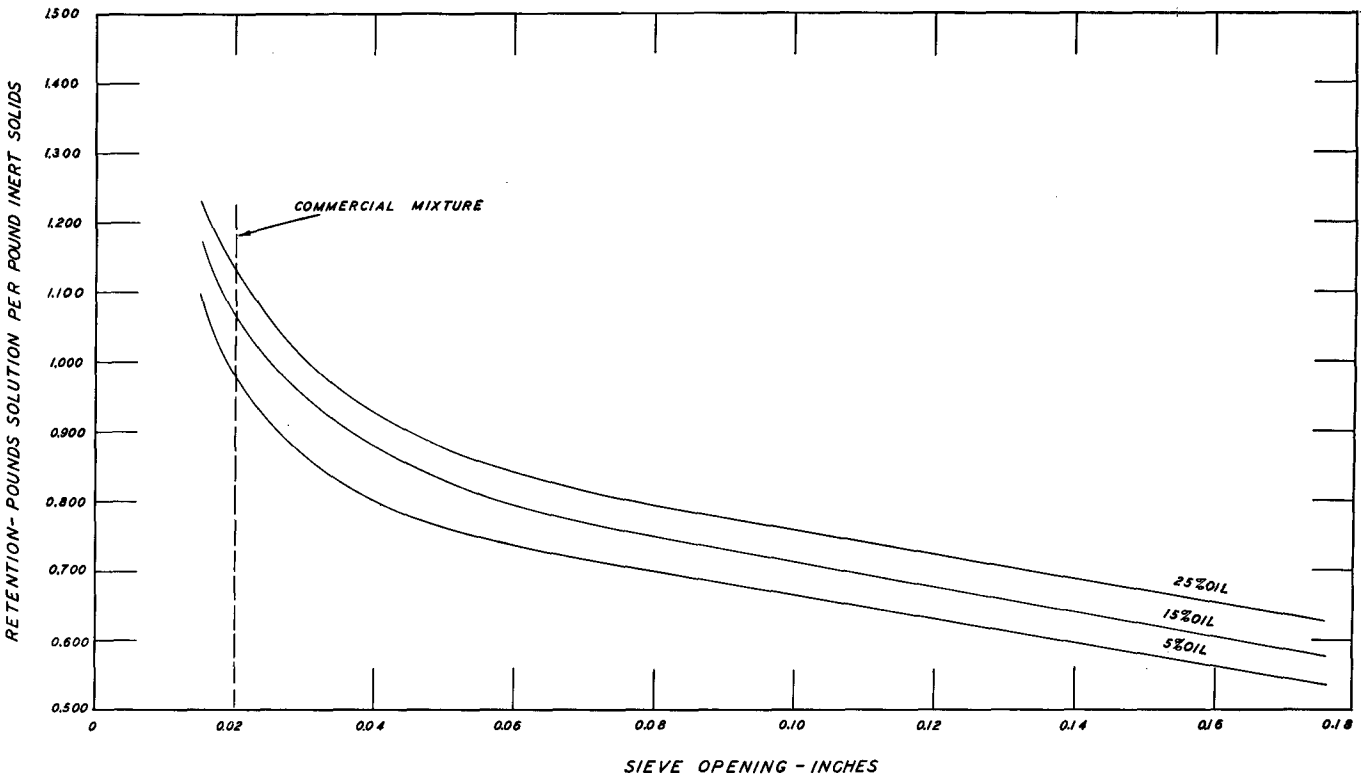

FIG. 3. Effect of flake size upon retention for cottonseed flakes, 0.008 inch thick, 6 inches bed depth, 8 minutes drain time, at 70°F., using Skellysolve B.

the horizontal line at the bottom of the plot (denoted "asymptote for 0% oil"). Clearly, static retention will vary with the concentration of the solution. Total retention is the sum of two quantities: a) static retention; and, b) a dynamic retention, which is the difference between the total retention at any time and static retention. Dynamic retention is the quantity of solution which is considered to be actively percolating through the solids.

Various methods of applying these curves to the material balances of stagewise calculations are contained in the literature (2, 3). A visual inspection suggests however that the length of the interstage and final drain periods may be estimated immediately. For example, the fact that the solution drains very rapidly at first indicates that a short drainage period will separate the stages reasonably well. Again the fact that so very little drainage occurs after a relatively short time (approximately 10 minutes in this case) clearly shows that a longer final drainage period will increase the size of the extractor unnecessarily.

Various factors in addition to the physical properties of the solution also affect retention. The effect of flake size, or diameter, is illustrated in Figure 3, for a 6-inch bed of cottonseed flakes. The curves represent the total retention after draining for six minutes from the flooded condition. The vertical line at the left refers to the average of the flake sizes found in a commercial mixture. For ground materials, the effect of particle size is analogous to that of flake diameter. Further, a deep bed will drain more slowly than a shallow bed, and materials which become heavily packed on charging retain more solution than materials which do not.

Summary

The design of a new continuous extractor for oleaginous substances has been described. Various details of the design have been pointed out, which indicate that the extractor may be applied to a wide range of operating conditions. Typical engineering data on solution retention by solids have been included, and their application to the design of the extractor has been indicated.

Acknowledgment

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REFERENCES

1. Goss, W. H., Oil & Soap, *23*, 348-354 (1946).
2. Armstrong, R. T., and Kammermeyer, K., Ind. Eng. Chem., *34*, 1228-1231 (1942).
3. Ruth, B. F., Chem. Eng. Prog., *44*, 71-80 (1948).

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