Solvent Extraction in the Soybean Industry[1]

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ABSTRACT AND SUMMARY

This paper comments on solvent plant operation with regard to maximizing grind rate and its effect on plant performance. Data is presented on a miscella evaporator and on extractor retention time vs. residual oil in the spent flakes. Calculations are presented to justify the investment for an oversize extractor in any existing or proposed plant installation based on product yield value. Attention is drawn to an existing publication by Othmer in 1955 which suggests some extractor design theory that would seem to warrant increased attention.

Comments on solvent extraction facilities for oilseed processing presented in this paper will dwell chiefly on soybeans, since the author has worked with the oilseed for 30 yr in the U.S. and abroad.

One item that is of chief concern to all soybean plant managers and superintendents—and one consultants are frequently called upon to give a professional opinion on—is the optimum throughput of plants consistent with machinery, performance standards, and other individual operating conditions peculiar to each mill. For purposes of discussion this item will be identified as:

Optimum Grind Rate vs. Performance

The solvent extraction industry in the U.S. for soybeans has grown from its start in the mid 1930s to about 100 mills presently. Over the last decade or two the number of mills has decreased with increases in total U.S. grind being accomplished by pushing up grind levels in existing plants or building larger competitive 2500 T/day plants which forces dismantling or sale of the smaller solvent plants to remote foreign areas where small throughputs are not such an economic handicap. Consequently, in an effort to hold down per bushel processing costs, the smaller plants are constantly trying to increase throughput. This is generally done at the expense of some operating variable such as residual oil, solvent loss, safety practice, housekeeping, etc. The soybean industry is constantly reexamining itself and readjusting its plants, which is characteristic of a growing industry offering challenges to its operating people.

One finds most operating plants (either new or old) have continuing deficiencies because as soon as one bottleneck is remedied another appears. The insufficiencies in the order of the flow chart are:

- cleaning, drying & conditioning of raw grain
- cracking capacity
- conditioning capacity
- flaking capacity
- extraction capacity
- miscella evaporation capacity
- desolventizing capacity
- solvent recovery capacity
- meal grinding capacity

A soybean extraction plant whose residual oil in flakes approached 1.5% requested help with this high oil in meal problem. The plant superintendent made assurances that everything was being done perfectly. Flake thickness soon came under scrutiny and in spite of the claim that all flakes were of .010-.012 in. thickness, actual measurement showed .017-.020 in. to be the range. Much effort was made to readjust the mills and the plant was left for the night. In the morning, the residuals were excellent, but the foreman said, "I can't get my assigned grind rate. My flakes are too fluffy and I can't get my volume throughput." This illustrates the constant seesaw that goes on in any solvent plant today because most plants operate 20-25% above design capacities. The pressure is especially severe on the superintendent in a company which has multiplants: the individual plants, their results and personnel are being constantly compared one to another. This enormous management pressure places great strains on plants and people to achieve, and consequently some very strange practices develop in individual plants, even, for example, cheating on the monthly reports.

There is scarcely a plant that does not have a deficiency in one, two, or three of the items above. The most common deficiency is in condenser capacity. Condensers in most plants are overloaded—partly because grind levels have been pushed up and also because of design problems which cause loss of efficiency. It is surprising how many condensers sold in the industry are improperly designed with respect to tube spacing, baffle spacing, condensate exit passages, etc. Hot condensers are warning signals for solvent losses and indicate real plant safety problems—that are often unappreciated by plant personnel whose personal safety is at stake.

Another common deficiency is the tendency to make thick flakes. These flakes have good drainage characteristics and are easy to process. Unless constant vigilance is applied on the operators, their tendency is to slack off on the flakes. Probably the most difficult item to keep operable in a plant is a flake micrometer which is always getting broken or lost.

Another common plant deficiency is that in the cracked bean conditioners. Many operators are unaware that their cracked beans are going to the flakers at 120 F (49 C) on a cold winter day when beans from storage are nearly zero F. Insufficient tempering makes for fragile flakes and fines which impedes the extraction process. Conditioning capacity is very expensive and hard to sell to management because the extraction results are not readily identifiable with proper bean tempering.

The pressure is on the plant superintendent to continually do more and these insufficiencies in equipment capacity or techniques creep in. The answer to this general problem is to emphasize to the superintendent that he must constantly be aware himself of approaching bottlenecks and in turn keep the manager informed constantly so that proper inclusions can be made in each year's budget for capital expenditure to increase machinery capabilities at the troublesome operating point. The superintendent must point out unmistakably and often the deficiencies in this plant, but not so pointedly that the impression is created that he is not agressive and is given to excuses. The good superintendent sees to it that he has good machinery together with good people to do a good job of getting capacity throughput within the parameters of good operating results.

One of the plants' deficiencies mentioned above is that

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of insufficient miscella evaporation capacity. Tube fouling sometimes occurs when there are excess fines in the miscella. This is more often a problem in rising film evaporators without recirculation legs.

Recently there was a problem in correcting a miscella evaporation unit with the addition of a recirculation pump on a rising film evaporator. Those who have watched secondary evaporators know that they surge on intervals especially if they are oversized (i.e., too many tubes). A recirculation pump always appeared to be a possibility to increase mass flow per tube.

Recently the opportunity existed at Lauhoff Grain Co. to install a recirculation pump on a secondary miscella evaporator in the dry corn germ extraction operation. This particular evaporator was prone to fouling due to fines in the miscella even after centrifugal cyclone treatment of the miscella. The mass flow of miscella in each tube appeared to be about 1/3 of normal. The plant superintendent (Marvin Woods) and a consultant studied the problem and decided to install a recirculation leg and a 45 gpm pump on this rising film evaporator with 875 sq ft of heat exchanger area. The results were dramatic in performance of the unit.

(a) Boil out intervals were extended from 1 to 6 mo.
(b) Steam chest pressure was reduced to 70 psig from a previous 140 psig.
(c) Exit oil concentration was improved from 90% to 98% oil.
(d) The U factor improved fivefold—from 14 to 74.

It is seldom that such documented dramatic improvements are seen in plant operating equipment. This may be applicable to miscella evaporation systems in other plants.

One deficiency in most soybean plants is most important:

Insufficient Extraction Retention Time.

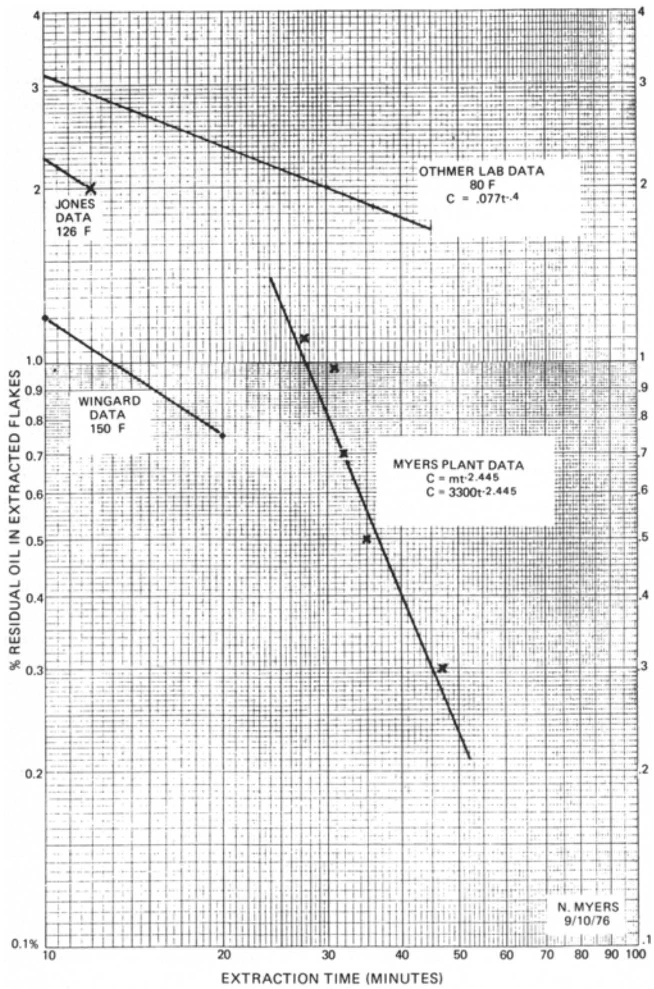
Most plants operate on the ragged edge of having enough retention time in the extractor, and consequently there is always a struggle to hold residual oil in the flakes to below 1%. This problem is widely recognized in the industry, and all sorts of devices are apparent to increase retention time in the extractors. Some of these are basket extensions, larger baskets, etc.

The theory of soybean extraction received a good bit of attention in the late 1940s, and some good articles were written. One of the best articles on soybean solvent extraction is little known and was published and read before the American Institute of Chemical Engineers and never appeared in the *JAOCS.* The title of the paper is "Extraction of Soybeans—Theory and Mechanism" by Donald Othmer and J.C. Agarwal of the Brooklyn Polytechnic Institute, Brooklyn, NY, published in *Chemical Engineering Progress,* August, 1955. Mr. Othmer is a widely recognized chemical engineer in applied technology in the chemical industry. It is somewhat of a surprise to see his outstanding work in the soybean field.

One of the problems is of establishing valid retention time data to obtain low residual oil content of extracted flakes in the order of 0.2-0.3% oil. This is because of the nature of the experimental error in determining oil content of the flakes by analyzing the oil content of the miscella and calculating backward to obtain residual oil content of the flakes. Most experimental data is above 1% oil. Here the question becomes one of enough trust in the slope of the extraction curve to extend it and calculate the size of an extractor to yield 0.2 or 0.3% residual oil in flakes—when considering the sizeable capital expenditure in a larger extractor necessary to reach these low residual oil levels.

The attached graph shows the following information:

1. Othmer curve (flakes @0.01 in., 80 F) } Lab Data
2. Jones curve (126 F) } Lab Data
3. Wingard curve (150 F) } Lab Data
4. Myers curve (plant data)



The Myers curve is based on a variety of typical plant data for a number of extractors correlating residual oil vs. extraction time corrected for (a) empty baskets and (b) fillage of the baskets. The two predominant points on the lower end of the curve are from a commercial extractor that ran at two different throughput rates for several years. One of these points is at 0.3% residual oil in spent flakes and the other at 0.5% residual oil. These two points establish the lower end of the curve.

This data thus yields an extraction curve equation of:

$C = m \cdot t^b$ where $C = \dfrac{\text{g residual oil}}{\text{g dry inert solids}}$

t = time of extraction (min)
m = intercept (.07 for .012 in. flakes)
b = slope of curve

$$C = m \cdot t^{-2.4}$$

This curve is considerably steeper than Othmer's which was done on a Kennedy extractor at an unknown temperature. Othmer's lab data was obtained at 80 F (27 C). It more nearly agrees with the Wingard data at 150 F (62 C). Most plants run higher temperatures than Othmer's in practice and this could account for the increase in extraction efficiency especially when considering that plant efficiency is generally better than lab efficiency.

The following conclusions may be drawn:

(a) The operating range for most soybean plants is bounded by oil residuals at 0.7-1.0% and extraction time between 25-35 min (based on effective volume).

(b) The operating curve drawn from Myers data shows a very steep slope compared to the initial extraction from 1-20 min retention time in the laboratory.

(c) The operating curve drawn from Myers data indicates a much higher extraction rate than that predicted from the extraction rate curve from 1-20 min retention time.

(d) The curve indicates that lower residual oil is obtained much more easily than formerly predicted from earlier curves. Hence, substantial gains can be made in residual oil with moderate extractor size increases.

The following economics of using an oversize extractor to obtain lower residual oil in flakes are based on points from the curve which indicate that:

32 min retention time will yield .7% residual oil in flakes
47 min retention time will yield .3% residual oil in flakes

This means that purchase of a 1500 T extractor for a 1000 T/day soybean plant would obtain an extra .4% oil yield (based on oil in meal analysis). It is estimated that additional cost of the larger extractor plus added installation and building costs would be of the order of $100,000.

Increased value of the additional oil yield is calculated as follows with the following assumptions:

1) meal = 9¢/lb, oil = 20¢/lb
2) increased oil yield is .3 lb/cwt. of beans
3) 1/2 of the additional oil yield is lecithin
4) Chromatographic loss is increased from 2.5 to 2.65% (Adjusted value of crude oil decreased from 20.50¢/lb to 20.47¢/lb.).

YIELD AND INCOME CALCULATIONS

1000T/da soybean plant
Yield = 1 bu = 47 lb meal, 11 lb oil
Basis = 100 lb beans

	Normal Extractor	Oversize Extractor
Meal	78.4 lb	78.1 lb
Oil	18.3 lb	18.6 lb

78.4 lb meal/100 lb beans x .4% oil yield increase = .3 lb oil recovered per 100 lb bean

Meal:	78.4 x 9¢/lb	= $ 7.0560	78.1 x 9¢/lb	= $ 7.0290
Oil:	18.3 x 20.5¢/lb	= 3.7515	18.6 x 20.47¢/lb	= 3.8074
		$10.8075		$10.8364

Difference $10.8364 - $10.8075 = .2089 $/cwt. of beans Yearly Advantage:
100 T/da x 220 da/yr x 20 cwt./T x .0289 $/cwt. = $190,740/yr advantage

Consequently the larger extractor cost of $100,000 initial capital investment yields an annual return of $190,740 without any significant increase in operating cost. This premise is fairly constant since oil is generally worth more than meal. Understand that this calculation has nothing to do with the value of lecithin since we are concerned with only the crude oil market value based on the standard chromatographic refining loss. This excerise says that any new or modernized soybean plant should contain a 50% larger than standard size extractor.

EXTRACTION THEORY FOR NEW EXTRACTOR DESIGN

Othmer says that "concentration of oil in the miscella has no effect on either total extraction or extraction rate." Also he adds that "the extraction operation is not improved by countercurrent operation. The principal requirement appears to be a fairly intimate mixture of solids and solvent for a specified time after which the retained miscella on the surface of the flakes be removed by washing. Based on these observed experimental facts and conclusions therefrom, both the probable mechanism of extraction and plant design can be developed." It is interesting to note that this work was published in August 1955.

This suggests that the massive size of present countercurrent extractors could be reduced with a properly designed soaking vessel followed by a streamlined pure solvent washing operation. Or conversely present extractors could be increased in throughput by addition of a "soaking" vessel. This concept ought to be investigated for large capacity plants in the future which are now becoming very expensive especially with regard to the initial cost of the extractor itself.

Attention is drawn to the present trend of building deep bed extractors. The original Rotocel had 6 ft deep beds but the new P Model has 10 ft beds, and it is reported that there are extractors of over 12 ft bed depth in operation. In order to obtain flake stability and acceptable drainage rates, it has been necessary to thicken the flakes. Let us assume the flake thickness has to be increased from .012 in. to .017 in. for the deep bed extractor, Othmer has something to say about this. He says, "The extraction rate decreases approximately as the flake thickness raised to the 4th power. Thus increasing the thickness by 3 times decreases the extraction rate by 80 times." Applying this finding to the above, increasing the flake thickness from .012 to .017 in. decreases the extraction rate $\left(\frac{17}{12}\right)^{3.97}$ or $(1.4)^{3.97}$ or 3.8 times at any specific time in the extraction operation.

It is doubtful in plant operations that the overall extraction rate is slowed 3.8 times due to a deep bed extractor, but the published data and personal experience indicate that extraction rate (or residual oil in a conventional extractor with a norminal retention time of say 30-40 min) is affected by thick flakes. Hence, there has to be some trade off in residual oil in flakes in a deep bed extractor. Deep bed extractors do have the advantage that they can be "cranked" up to high capacities in times of high margin grind and slowed in poor margin times to obtain improved oil recovery and this flexibility does affect the profit and loss statement. However, when one looks at the dollar cost per cu ft of retention time of these deep bed extractors, there is only a nominal savings of the order of 10% per unit of effective volume as the units get progressively larger in diameter. The importance of the choice of extractor size must be treated carefully and the point of this discussion is that extractor retention volume and shape has substantial economic relationship to residual oil in spent flakes and in turn the total oil recovery per bushel of soybeans.

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