

only does this factor in the original cost of paint, but projects its useful functional life, time lapse until repaint, substrate quality and preparation for repaint. Labor costs for each segment are included in overall cost calculation.

Oil usage in surface coatings already has experienced some decline due to performance and availability of alternate systems and the historical growth of the oil-free emulsion (latex) paint resins. While modest growth of total sur-

face coatings is anticipated, there is an expectation of flat to slightly reduced vegetable oil consumption.

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Growth Potential for Soybean Oil Products as Industrial Materials

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ABSTRACT

Crude soybean oil, as a major source of edible oil for the world, is available on such a scale that it serves additionally as the origin for many industrial applications and for such materials as phospholipids (lecithins, cephalins), tocopherols (for vitamin E), sterols (for pharmaceuticals) and recovered fatty acids from acidulated soapstocks. The latter always have offered the oleochemicals manufacturer a low cost source of valuable fatty acids, and soybean oil itself, after hydrogenation, serves as the most readily available, lowest cost source of 90% stearic acid from among all fats and oils. As an alternative to alkali refining and the soapstock produced, physical refining of the degummed soybean oil is a potential source for fatty acids and for recovery of larger amounts of valuable sterols and tocopherols, but this process severely degrades the oxidation stability of the fatty acids.

The largest potentials for growth in industrial applications are for soybean oil itself in pesticide dispersion and grain dust control; triglycerides and fatty acids split therefrom for 90% stearate oleochemicals and selected food additives; fatty acids from soapstocks up-graded medium-grade oleochemicals, medium-grade soaps for industrial cleaning operations, and in animal feeds and pet foods; phospholipid gums in fractionated and modified lecithins and cephalins; soy deodorizer distillates containing α -tocopherol (vitamin E) and sterol-derived sex hormones. Inclusion of food additives, feed and pet food additives with the more usual industrial markets results in the conclusion that industrial utilization of soybean oil could reach 12% of total consumption in the U.S. within five years.

INTRODUCTION

Price usually determines which fat or oil is used in an industrial C-18 application. Technology exists that permits interchangeable use of fats or oils to produce the desired oleochemical product. Cheaper, inedible, bleachable fancy tallow might be the preferred primary feedstock, but the manufacturer could use cheap fatty acids from acidulated vegetable oil soapstocks, if quality was not too objectionable.

In mid-1980, the price of crude soybean oil reached a low of 20-22¢/lb, and this material quickly came into competition with tallow. The oleochemical producer has an advantage over the edible product manufacturer because the latter requires a refined, deodorized grade of soybean oil, traditionally priced about 5¢/lb higher than the crude oil. However, degummed oil is usually a minimum requirement. Although low-cost soybean oil soon disappeared (30-40¢/lb range, May 1984), a number of vital lessons were learned. First, although priced substantially higher than inedible tallow and somewhat higher than edible tallow, soybean oil usually can compete with tallows as the more economical choice for the manufacture of 90% stearate-type derivatives. Second, in a growing number of cases, the distribution of fatty acids, both before or after hydrogenation, affords soybean oil a number of advantages that tallows do not possess.

PHOSPHOLIPIDS

U.S. raw material capacity for soybean phospholipids is quite large. The gum content of crude solvent extracted soybean oil varies from 1.5-2.5%. With a 1983-84 crop of about 2 billion bushels of soybeans, and exports accounting for about 50% of this, U.S. production of crude oil could amount to 11.2 billion lb. Assuming two-thirds of this oil is degummed, there is the latent potential for about 150 million lb of phospholipid material. Less than half of this has been deoiled with acetone in the past to yield commercial lecithin products. An even smaller fraction of these products, say 1%, is fractionated with aqueous ethanol to afford separated phosphatidylcholine (alcohol soluble), phosphatidylethanolamine (distributes between alcohol soluble and insoluble compounds), and inositol phosphatide (alcohol insoluble) products, which have applications in food emulsification and stabilization, feed amplification, as pharmaceuticals and for other uses.

Eichberg (1) reported that 1981 commercial lecithin production in the U.S. was 59.4 million lb (worldwide production, 200 million lbs; western Europe, 60 million lb). We estimate the 1984 U.S. production of commercial lecithins at about 65 million lb. Bulk prices for the six grades of commercial lecithins in the various "natural," "bleached" and "double-bleached" types for both fluid and plastic products ranged from \$0.26-0.36/lb, but specialty products can command premium prices: a 48% fluid in oil product for paint additive use, \$0.505/lb, and a special product, 35-38%, FDA-approved for sliced cheese use, \$4.80/lb. For the period 1980-84, it is apparent that the percentage growth of lecithins is slightly higher than that of soybean oil. Obviously, the production capacity for lecithin products far outweighs the present market for these products.

The existing uses for commercial lecithin products have been summarized by Socca (2), Eichberg (2), Niewenhuisen (3) and Szuhaj and List (4) and include functional applications such as an emulsifier, stabilizer, conditioning and release agent and antioxidant. Lecithin is used in foodstuffs such as baking products and mixes, in candy, chewing gum, chocolate, dehydrated foods, edible oils and fats, ice cream, instant foods, macaroni and noodles, margarine and whipped toppings. Industrial uses include applications in cosmetics and soaps, dyes, insecticides, paints, petroleum products, rubber, sealing and caulking compounds, textiles and pharmaceuticals and as a release agent in plastics. Animal feed applications are based upon its performance as an emulsifier, wetting and dispersing agent, caloric source, antioxidant, source of choline, organically-bound phosphorus and inositol and as a lipotropic agent.

Whenever a naturally-derived versatile product, such as

lecithin, is in greater or potentially greater abundance than markets warrant, there is increasing investment in research and development on new products, processes and applications. Lecithin and its derivatives appear to be in such a transitory state. We can expect to see an increased effort in the area of fractionated lecithins (for pharmaceuticals and medicinals), in modified lecithins (such as in enzymatically partially hydrolyzed derivatives), lecithin esters, in soy phosphatides in general, and in better technology for ethoxylated lecithin.

STEROLS AND TOCOPHEROLS

Second only to lecithins in importance as non-oil industrial raw materials, mixed sterols and mixed tocopherols in crude soybean oil represent to the refiner a source of considerable byproduct credit. To the margarine producer, however, the presence or absence of sterols in the raw materials is of no particular consequence, because they generally are relegated to the area of small or trace quantities of inert contaminant ordinarily having little or no effect on the quality of performance of the finished margarine. The total sterol content of crude soybean oil is generally 0.15-0.35%, whereas caustic-refining lowers the level by about one-third. On the other hand, the optimum quantity of tocopherol is significant, because the oxidative stability of the raw material and finished margarine depend to a considerable extent upon the content of γ - and δ -tocopherols. Thus, if the refiner removes too much tocopherol, refortification of the finished product may be necessary. Also, a certain content of vitamin E, α -tocopherol, in the product is desirable for other nutritive reasons. The total tocopherol content in crude soybean oil is about 0.168%, in caustic-refined soybean oil about 0.096%.

In conventional soybean oil processing, the mixed sterols and mixed tocopherol contents of the oil are progressively lowered across the unit operations of degumming, refining, bleaching and deodorizing. Generally, deodorization represents the largest decrease in both mixed sterol and total tocopherol contents, but somewhat less quantities of both are removed during caustic refining along with soapstock. In any event, about one-third of the sterol and tocopherol contents are removed in processing, and two-thirds remain in the oil. It is customary to reimburse the refiner on the price of the tocopherol content (ca 10%) of the distillate, which at \$6.50/lb (1984) for tocopherols, affords a byproduct credit of about \$0.65/lb. The refiner is not reimbursed for the sterol content of his distillate; this credit is retained by the sterol/tocopherol processor to cover the

costs of his sophisticated separative processing (5-12), including molecular and fractional distillation and solvent separation (13,14). Table I shows comparative compositional data for deodorizer distillate and physical refining distillate from some recent U.S. soy production. Currently, only about 2% of U.S. crude soybean oil is physically refined. Only eight pieces of physical refining equipment are known to exist in the U.S., and there is no certainty that all these are used for soybean oil refining. Furthermore, it is known that certain refiners have used deodorizers as physical refining units and vice versa upon occasion. Numerous samples, perhaps several thousand, represent the deodorizer distillate data, whereas the physical refining data represent only about a dozen samples from Henkel Corp. and seven samples from the author. The physical refining samples were obtained from distillates isolated and unmixed with other byproduct streams. The former data are reliable, the latter data are less definitive, preliminary and about all that are available. Nevertheless, it is clear that practically all available sterols and tocopherols are removed in a physical refining operation, but as a more fatty acid-diluted distillate. Therefore, the tocopherol/sterol processor would have to process a larger volume of distillate in order to recover the same quantity of sterols/tocopherols.

Herting (15) estimated 1980 world production of both natural and synthetic vitamin E to be 10.6 million lb; growth will depend on an increased awareness of nutritional requirements. The U.S. production in 1980 was 5.93 million lb. U.S. production for 1983 was about 8 million lb, and the (preliminary) 1984 U.S. production is estimated at 9.2 million lb.

The principal U.S. producers of natural vitamin E are Eastman Kodak (Rochester, New York) and Henkel Corporation (Kankakee, Illinois) and of synthetic vitamin E are Hoffman-La Roche and BASF-Wyandotte. International producers are BASF, Eisai, AEC (Rhone-Poulenc SA), Nisshin-Badische and Molecular Distillations.

Bulk prices for vitamin E have decreased steadily over the years. Per lb the prices for (R,R,R)- α -tocopheryl acetate were \$83.93 (1954), \$55.35 (1960), \$30.85 (1970), and \$30.85 (1982). For all *rac*- α -tocopheryl acetate per lb prices were \$61.70 (1954), \$40.83 (1960), \$22.68 (1970), and \$12.25 (1982). The higher prices for the (R,R,R)-form since 1954 reflect the higher potency of this form, and are influenced by the availability of suitable raw material for its production.

Naturally derived vitamin E competes well with the synthetic product in fortification of animal feeds, even as

TABLE I

Comparison of Soy Deodorizer and Physical Refining Distillates^{a,b}

	Deodorizer distillate	Physical refining distillate	Refined SBO
Acid value, mg KOH/gm	50	114	
Saponification value, mg KOH/gm	140	155	
% Unsaponifiables	30	22	
% Tocopherols	10	6.9	
% alpha	0.9 (9%)	0.5 (7.2%)	(10)
% beta + gamma	6.2 (62%)	4.5 (65.2%)	3 + 63 + (66)
% delta	2.9 (29%)	1.9 (27.5%)	(25)
% Sterols	14	9.2	
% Campesterol	4.0 (28.6%)	2.6 (28.3%)	(20)
% Stigmasterol	3.9 (27.8%)	2.4 (26.1%)	(20)
% Sitosterol	6.2 (43.6%)	4.2 (45.6%)	(55)
			Others (5)

^aHenkel Corporation, Minneapolis, Minnesota provided the majority of this data.

^bValues in parentheses are percentage distributions of tocopherols and sterols.

mixed tocopherol products, but there appears to be a preference for synthetic vitamin E for the pharmaceutical market (vitamin E deficiency therapy). The food markets are generally satisfied by naturally-derived products. In the next five years, a change in this pattern will depend upon improvements in separation and recovery technology (for the natural product) and on new developments in enzymatic biotechnology to improve several of the processing steps in the synthetic routes of production. At any rate, the anticipated 15-20% increase in the vitamin E market over the next five years probably will be adequately satisfied by the combined production of both natural and synthetic products.

Soybean oil possesses a unique distribution of sterol components approximating 20% campesterol, 20% stigmasterol, 53% β -sitosterol, 4% Δ^5 -avenasterol and 3% Δ^7 -stigmasterol. Within the last decade their pharmaceutical value has increased markedly because of partial synthesis of sex hormones or other intermediates from these naturally-derived sterol compounds. Examples include the use of pure stigmasterol from soybean oil in the manufacture of progesterone and corticoids. Progesterone can be converted in eight steps to hydrocortisone. β -Sitosterol, by means of uv-mutants of a *Mycobacterium* species, is used to produce androstenedione and androstadienedione. The latter sterol, after further reactions, affords estrogens, contraceptives, diuretics (spironolactone) and the male anabolic and androgenic hormones.

The world market for steroids in pharmaceutical and medicinal applications, including all naturally-derived and synthetic products, is growing rapidly (16):

Corticoids: 1963, 605,000 lb; 1975, 2,103 million lb; 1980, 2,838 million lb.

Sex hormones: 1963, 189,008 lb; 1975, 343,000 lb; 1980, 418,000 lb.

Contraceptives: 1963, 200,000 lb; 1975, 484,000 lb; 1980, 649,000 lb.

Spironolactone: 1973, 105,000 lb; 1975, 478,000 lb; 1980, 704,000 lb.

The 1980 worldwide sales of steroidal hormones was \$4 billion, which represents an average price for these products of \$869.75/lb.

For each of these products, production increased at least 30-35% for each of the five-year periods, and this growth rate might be expected to continue for at least the next decade. There has been a tendency on the part of steroid producers to balance their production between naturally-derived (partially synthesized products) and all-synthetic products, and to use these alternate production methods interchangeably depending upon the availability of raw materials and level of processing costs. This is unlike vitamin E production, where producers tend to be more "all-natural" or "all-synthetic" oriented.

Fatty Acids from Physical Refining and Deodorizer Distillates

Recovered fatty acids from deodorizer distillates are limited to non-food, non-feed, low-cost applications. This is because the distillate must be subjected to numerous steps to recover sterols and tocopherols, thus rendering the fatty acid quality substandard. Table II shows why physical refining distillates may constitute a problem in fatty acid recovery.

Physical refining distillates are inferior in peroxide and carbonyl numbers to both acidulated soapstocks and deodorizer distillates. Physical refining operations always follow an efficient degumming operation and remove material more volatile than triglyceride oil such as sterols, tocopherols, aldehydes and ketones, peroxide decomposition fragments, squalene and other hydrocarbons, color body

TABLE II

Quality Characteristics of Soy Deodorizer and Physical Refining Distillates and Soapstocks^a

	Deodorizer distillates	Physical refining distillates	Acidulated soapstock (dry)
Peroxide value, mmoles peroxide/1000 gm	3-20	15-40	0.5-5
Carbonyl number, mg KOH/gm	5-10	10-20	0-5

^aData ranges are from a five-year (1979-84) survey of American production (Sonntag, unpublished).

TABLE III

Food Additive Products Derivable from Soybean Oil

Soy monoglycerides (90%)	Ethoxylated monoglycerides
Hydrogenated soy monoglyceride (90%)	Succinylated monoglycerides
Partially hydrogenated soy monoglyceride (90%)	Lactylated monoglycerides
Soy mono-/diglycerides (60%)	Stearyl monoglyceride citrate
Hydrogenated soy mono-/diglycerides (60%)	Diacetyltartaric acid esters
Partially hydrogenated soy mono-/diglycerides (60%)	
Soy mono-/diglycerides (40%)	Brominated soy oil
Hydrogenated soy di-/monoglycerides (40%)	
Partially hydrogenated soy di-/monoglycerides (40%)	Calcium and sodium lactyl stearates

Figures in parentheses represent total monoglyceride content.

decomposition products, unknown volatiles and fatty acids. Fatty acids derived from distillates with characteristics indicated in Table II would have poor oxidation stability and are a difficult mixture for the oleochemical manufacturer to process and upgrade. Presumably, he would have to consider a secondary stream from a processor who already has removed the sterols and tocopherols. Fractional distillation and removal of more volatile forerun cuts, especially hydrocarbons, aldehydes and ketones, is inefficient based upon recovery experience with low-grade fatty acids in the past. Aldehydes and ketones, whose presence is very objectionable, could be reduced selectively to hydrocarbons by treatment with reagents like sodium borohydride, but these are expensive and are used only to remove trace quantities. Fatty acids containing small quantities of hydrocarbons might be upgraded by fractional distillation, but, in general, this method would be given poor prospects. The possibility of using fatty acids diluted with hydrocarbons or other inert material is not attractive: volatiles are objectionable in many lubricant and plasticizer fatty acid esters, because they contribute odor, color and taste problems to food additives and possess a low flash point. Thus, it is doubtful if a large shift to physical refining can be justified on the basis of greater recovery of both sterols and tocopherols, because of the deteriorated quality of the fatty acids in them. Developments in this area undoubtedly will represent a compromise between the viewpoints of the vegetable oil refiner, sterol/tocopherol processor and oleochemical producer.

Soybean Mono- and Diglycerides

The products in Table III are classified as industrial products because they are used not as triglycerides but as derivatives.

Soy monoglycerides are tabulated in three groups, unhy-

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TABLE IV

Industrial Applications for Soy Oil and Mono-/Diglyceride Products

Soy oil	Soy mono-/diglycerides
Epoxidized soy oil-plasticizers	Detergents
Acrylated epoxidized soy oil	Oil recovery agents
Alkyd resin coatings	Miscellaneous
Other coatings	
Soy methyl esters	
Grain dust control	
Pesticide dispersion	

drogenated, hydrogenated and partially hydrogenated, and in three levels of monoglyceride content.

The advantages of vegetable over animal monoglycerides are real but not always easy to demonstrate in baking performance, anti-staling properties or in other food emulsification properties. A lower cholesterol content cannot be ignored. There also is an increasing preference among Americans, including certain ethnic groups, for vegetable-based additives over animal additives in many foodstuffs. To the extent it can, the baking industry (bread, rolls and cake) has responded to this trend. Vegetable products generally are preferred consistent with economics, but their exclusive use can hardly be sustained when the price of edible tallow-derived product, expressed as a (90%) monoglyceride, is lower than that of the vegetable additive by more than 6¢/lb. The bulk price of edible tallow is frequently 6-8¢/lb lower than that of soybean oil. Soybean monoglyceride products enjoyed a brief boom in 1980 when crude soybean oil was 20-22¢/lb, but currently higher oil prices suggest that product growths will likely follow the population growth rate.

Consumption of total animal and vegetable monoglyceride products in the U.S. in 1981 is estimated at 226.5 million lb (unpublished, Sonntag). About three-quarters of this production is prepared by batch glycerolysis technology, although two producers employ continuous processing for large-volume products. The remaining quarter of this production is by direct esterification technology and appears to be more suited for industrial uses. Production of monoglycerides from soybean oil is difficult to estimate, but probably less than 10% of the entire volume in 1981 was produced from this oil.

Both glycerolysis and direct esterification methods of monoglyceride production are highly heat-dependent (17). Trends in recent years have stressed energy conservation and a lower processing temperature by superemulsification and other techniques, but these improvements have not resulted in any price reductions. Significant developments in American monoglyceride production can be expected in the next decade. Low temperature enzyme-catalyzed interesterification of glycerol with fatty acids are the anticipated contributions to oleochemical growth from biotechnology. The magnitude of changes such technology could initiate is hard to contemplate. A 20-24¢/lb price reduction is conceivable, which would spur introduction of fatty vegetable monoglycerides into industrial applications on a large scale and be spearheaded by products from soybean oil. Derivatives of monoglycerides from soybean oil are included in the right column of Table III. These derivatives offer a variety of food emulsification advantages over monoglycerides, but at a slightly higher price than 40% or 60% monoglycerides. The ethoxylated derivatives, promoted by Ashland Oil and Refining Co. (18-20), now Sherex Chemical Co., are the cheapest and function primarily as dough strengtheners but not as bread softeners (21). They are blended with monoglycerides for most of their uses in

baking. Succinylated monoglycerides were developed by National Dairy Products Corporation in 1966 (22,23), and presently are produced and marketed by Eastman. The diacetyl tartaric acid esters, called Data or Datem esters, were an American development (TEM line-Hachmeister, 1959; Myyatem-Eastman, 1973). They were never commercialized in the U.S. to any extent, but did receive some development in Europe (Panodan, Grindsted Products, Inc.). Presently, Hercules is marketing Datem Lamegin ES in an attempt to reintroduce this product here (24). Lactylated monoglycerides (Drew, Eastman, P&G, Lever Bros.), stearyl monoglyceride citrate (Pfizer) and sodium stearyl fumarate (Pfizer) were never seriously commercialized in the U.S. as baking additives.

The most significant characterization of monoglycerides and their derivatives as baking additives appears to be the amylose complexing index, as defined by Krog (24). For comparison, the relationships are given below (the higher the index the better the performance):

Hydrogenated soybean monoglyceride (90%)	87
Soybean monoglyceride (55)	28
Hydrogenated soybean monoglyceride (50)	42
Lactylated monoglyceride	22
Succinylated monoglyceride	63
Data esters	49
Sodium stearyl-2-lactylate	72
Calcium stearyl-2-lactylate	65

The 1983 U.S. production of sodium and calcium stearyl-2-lactylates is estimated at 22.5 million lb. Small amounts of products reportedly are imported from Brazil and Japan. These are premium, higher cost food emulsifiers whose development has been limited by the present price of the raw material (\$0.97-1.01 per lb), so-called 88% food-grade synthetic lactic acid obtained from lactonitrile by hydrolysis (Monsanto Chemical Co.). These derivatives are FDA-approved as 2-lactylates. The starting material, lactic acid, although already partially polymerized, must be further internally esterified by water removal before it is esterified. No large expansion for these lactylate derivatives is expected unless there is a concurrent development of fermentation grade food-approved lactic acid, selling in the \$0.65-0.75/lb range, together with some processing developments through interchange esterification. However, a 10-15¢/lb drop in price could easily result in a doubling of the sales volume (a non-Kosher powdered sodium salt sold for \$0.87/lb in 1982).

The general preference for vegetable- over animal-based food additives should be noted for 2-lactylate salts, where apparently better overall performance is exhibited by 90% stearate derivatives from soybean oil than for 70-80% stearate derivatives obtained from edible tallow. This is perhaps the first in a series of 90% stearate oleochemicals where a distinct performance (or quality) advantage can be cited for soybean-derived derivatives.

A small, developing use of soybean oil as a shortening in bread baking along with monoglycerides and polysorbates (25) has been observed. Soybean oil may be used similarly in rolls and cakes (26).

Brominated soybean oil is a specialty product that finds use in essential oil dispersion in citrus fruit beverages. The product has a high specific gravity and retards or prevents the separation of essential oils from bottled lemon, lime or orange drinks. The annual volume is relatively steady at 2 million lb.

The non-food applications of fatty monoglycerides have a history of predicted substantial growth, but to date, no significant large development has occurred. Price is the primary restriction.

One soy oil product for which early potential was ex-

TABLE V

Industrial Applications for Soy Fatty Acids and Soapstock Fatty Acids

Soy oil fatty acids	Soy soapstock fatty acids
Alkyd resins	Animal feed products
Dimer acids	Medium grade soap products
Coatings	Toilet soap
Surfactants	Low cost oleochemicals for petroleum and rubber industries
Fatty amines, other nitrogen derivatives	
Nylon-9	
90% Stearate oleochemicals	
Vegetable oleic acid	
Acylated polylactate resins	

pected was a detergent additive, sulfated hydrogenated acylated monoglyceride surfactant. This market need was satisfied by derivatives made directly from coconut oil (Arctic Syntex M) (27), and the high C-18 product from soybean oil proved to be unacceptable.

Fatty monoglycerides have good oil dispersion properties and usually have been mentioned whenever emulsions or oil recovery operations are discussed. If cheap, low temperature, direct enzymatic esterification or interesterification technology could be developed to produce 90% alpha monoglycerides without large energy costs and the need for molecular distillation, then certain large scale oil emulsification applications would be feasible on the basis of a projected 20¢/lb reduction of monoglyceride prices.

Soybean Oil per se

Uses of soybean oil as pesticide dispersant and in grain dust control continue to grow at a good rate. The background, advantages, potential and expressed concerns in the use of soybean oil in dust control in grain elevators has been covered adequately by The American Soybean Association in 1982 (28). The use of soybean oil as a carrier for the application of pesticides to agricultural and forest lands also has been reviewed by ASA (29). Present and estimated volume for these two developing markets are: grain dust control—1983, 7 million lb, 1990, 250 million lb; pesticide dispersion—1983, 25 million lb, 1990, 500 million lb (30).

Epoxydized soybean oil plasticizer/stabilizers (ESO) have been produced and marketed for over 30 years [1965, 49.5 million lb; 1975, 70.1 million lb; 1982, 85.1 million lb (average price \$0.48/lb); 1984, (est'd) 82-85 million lb]. This material is a cheap, serviceable plasticizer extender for polyvinyl chloride, but it lacks low temperature performance compared to epoxy esters like isooctyl epoxystearate (IES), from isooctyl oleate, and *n*-octyl epoxystearate (OES), from *n*-octyl soyate," [Clash and Berg T, °C are ESO -13, IES -53, OES -46 (31)]. Acrylated epoxydized soybean oil is a 1963 developed product (32) which may still prove to have advantageous properties on a commercial scale.

In 1984 ca 119 million lb of soybean oil of high iodine value was used in the manufacture of "oxidizing" alkyd resins, and another 6-8 million lb in epoxy resins and other coatings. The volume of oil used for these purposes had declined steadily since 1949 and cannot be expected to show future growth. Soy methyl ester usage in alkyd resin and other types of coatings has been quite small. Replacement of fatty acids with methyl esters in some uses occurred, although the extent prevailing among soy derivatives is difficult to estimate. These developments would not alter soybean oil prospects much because oil would be subjected to methanalyzer for ester production rather than split to fatty acids.

Soy Fatty Acids

In 1980 USDA data indicated that 21 million lb of crude soybean oil was used for the production of fatty acids other than in the production of paints, resins and coatings. We estimate the 1984 volume of soy fatty acids, both hydrogenated and unhydrogenated, to be 25 million lb. A double-distilled grade of soybean fatty acids was priced at \$0.48/lb (May, 1984, CMR). Most of this production was used for nitrogen derivatives (80%) (amines, amides and quaternary salts), but some was used for the preparation of esters, etc. (20%). Because new applications research shows a preference in some uses for 90% stearate derivatives, the use of soybean fatty acids should show a significant increase.

Dimer acids are produced in the U.S. largely by modifications of clay-catalyzed polymerization of tall oil fatty acids (TOFA). Soy fatty acids, when the price is right, are blended into the TOFA charge to extend the linoleic acid content and afford a faster reaction rate. The average linoleic/oleic ratio is 53/25 = 2.12 for soy fatty acids compared to 37/51 = 0.725 for TOFA. The additional 7-10% of linolenic acid serves to further increase the degree and rate of polymerization. American dimer acid production is sensitive to raw material prices; 2-3 million lb of soybean fatty acids used in the production of 50 million lb of dimer acid in 1980 was derived largely from soapstock rather than from crude soybean oil when the latter was priced in the range 21-26¢/lb. Applications for soybean fatty acids in alkyd resins and in other coatings are decreasing annually, with the estimated 1984 use level at only 35-40 million lb out of the total of 126 million lb oil used.

The difficulty in predicting anticipated growth in surfactant applications is in estimating the fraction attributable to soybean-based raw materials compared to that for generally cheaper inedible tallow. Logically, growth in soy derivatives depends on functional properties that contribute to quality and/or performance advantages in the surfactant. Thus, the "soy-alkyl" group (3% C-18, 10% C-16, 22% C-18:1, 54% C-18:2, 10% C-18:3 and others) might have some advantages compared to the "tallow-alkyl" (2% C-14, 3% C-14:1, 25% C-16, 11% C-16:1, 7% C-18, 46% C-18:1, 3% C-18:2 and others). And, "hydrogenated soy-alkyl" (90% C-18 and 10% C-16) might have advantages compared to "hydrogenated tallow-alkyl" (70% C-18, 30% C-16), but these usually are not obvious until revealed by applications research. Reassuringly, these differences exist, as evidenced by 1982 production of 1.27 million lb of soy-alkyl trimethylammonium chloride and the sale of 1.2 million lb of monosoy-alkyl amine (33). Aggressive applications research should reveal other examples.

We might expect oleochemicals with a higher saturated C-18 content to exhibit properties of so-called "hard hydrophobicity" and higher melting points. Water repellent properties also might be enhanced. Soybean oil is a superior, more economical raw material than tallow for production of such materials.

The production of Nylon-9 from soybean fatty acids has not been commercialized, presumably because of low yields. Soybean oil may not be the best raw material for this development, and we suggest that production of Nylon-9 be reevaluated using genetically-altered high-oleic sunflower oil when this oil becomes available.

Soy-based oleic acid has potential in the preparation of oleates for use in Kosher food additives, and for food wrappings where applicable. Before this can be achieved, homogeneously-catalyzed selective hydrogenation methods need to be developed which will permit the conversion of linolenate and linoleate to oleate without substantial buildup of stearate, isoleate or *trans*-isomers. Recent developments in selective hydrogenation of soybean oil

indicate some progress (34), but catalyst removal and recovery problems remain to be resolved. Moreover, this program would be in competition with newly developed high-oleic sunflower oil, which conceivably could provide up to 93% oleic acid in high yield and with low polyunsaturate content, obviating the need for selective hydrogenation.

Polyacrylate and acylated polyacrylates are colorless, transparent resins. Development has been retarded by the high price of synthetic lactic acid. If cheaper lactic acid could be made available by biotechnology, the stearyl component of hydrogenated soybean fatty acids could be used for oil-soluble stearylated polyacrylate resin formation. A price reduction for lactic acid of 30¢/lb probably would be required for this development to mature.

Fatty Acids Derived from Soybean Soapstocks

Refined fatty acids are not used in animal feed, and pet foods and cottonseed foots are prohibited in poultry feed, but soybean soapstocks compete with inedible tallows and yellow grease in the entire market. Estimated fat usage in animal and pet foods was 1.35 billion lb (for 70 billion lb of prepared feeds) in 1975; 1.535 billion lb in 1980, and is projected at 1.75 billion lb (2.6% projected annual growth rate for 1975-1985) (35) for 1985 and 2.345 billion lb (a 2.7-3.0% average annual growth rate for 1980-1990) for 1990 (36). Good growth for recovered fatty acids from soybean soapstocks can be expected, especially in chicken and turkey feeds where "energy" promotion is important, and in pet food products, where the trend to upgrade the fat content from 5-7% to desired nutritional level prevails. Pricing is highly determinative in both animal feed and pet food applications. Also, a moderating effect on soybean-derived fatty acid and other vegetable-derived soapstocks usage can be expected due to enforced FDA safety levels to prevent chick edema and chlorinated pesticide residues in these products. Nevertheless, due to availability, it is reasonable to expect a substantial use increase (30%) over a five-year period. In 1980, at least 75% of the "loss and foots" tabulation (360 million lb) represented 3.1% of the estimated 11.72 billion lb of crude soybean oil produced for that year (37).

Soybean soapstock fatty acids find application as medium-grade soaps for laundry and dry cleaning operations, building maintenance and industrial cleaners, car wash liquids, cutting oils and for food and dairy plant cleaners, but perhaps only 20% of the estimated total market of 250 million lb presently can be attributed to soy-based sources. A significant increase in soy products for this market requires quality improvements such as lower oil content of the fatty acids and removal of color bodies and certain other objectionable contaminants.

At 14-15¢/lb, acidulated soybean soapstocks could be the source of the stearate component of toilet soap (usually about 20% coconut oil-derived and 80% inedible tallow-derived). Methyl esters provide an efficient route for the upgrading process and, in fact, could be the basis for the overall soap production (38). Economic evaluation of this development shows that the cost of the upgrading process should be restricted to about one-quarter of the price differential between acidulated soybean soapstocks and the long range price of soap-grade inedible tallow.

Low-cost oleochemicals provide the best potential for increased use of soybean soapstocks, because strict demands

upon certain quality specifications like color, odor and homolog distribution are generally unnecessary and usually dispensed with. An increased effort to develop less costly methods for converting triglycerides of soapstocks to fatty acids is noted. Increasing applications for these products in petroleum, rubber, in flotation and other areas are most likely.

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