Liquid Waste Treatment in the Vegetable Oil Processing Industry – U.S. Practices

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ABSTRACT

Wastewaters from vegetable oil processing in the U.S. are in many cases discharged to publicly owned wastewater systems for treatment with community wastewaters. Nine plants provide treatment for direct discharge to rivers or streams. The major treatment process utilized in either case is biological treatment. Both research studies and full-scale treatment have demonstrated the effectiveness of biological treatment in degradation of vegetable oil to an extent equal to or superior to removal of organic material from domestic sewage. Limitations of the concentration of oil accepted in discharges to publicly owned treatment works were prevalent in earlier years; however, during the last few years, the compatibility of vegetable oil in municipal wastewater treatment systems has been acknowledged. Real problems with oil are more likely from petroleum type oil which can be associated with process and effluent quality problems. The train of treatment processes for direct discharge typically includes pH adjustment to acidic state, gravity separation, pH adjustment to near neutral, chemical coagulation plus dissolved air flotation, biological treatment, and in some cases filtration through granular media. Effluent qualities as good as 7.5 mg/l of biochemical oxygen demand and 1 mg/l of oil have been reported.

INTRODUCTION

Wastewater treatment currently being employed by edible oil refining plants in the U.S. is outlined in this paper. The article is intended primarily for technical people in the industry who are not environmental control specialists. Therefore, simplified explanations of terms and treatment processes are offered. The information should enable a technical manager to understand the work of treatment process consultants and designers. The scope is generally limited to plants receiving raw or degummed oil and which carry out refining, deodorizing, and bleaching processes.

TREATMENT APPROACH

Two basic ways of providing wastewater treatment are employed by industries in the U.S. One way is for the industry to provide treatment at the manufacturing plant site satisfactory for discharge directly to rivers or other public waters. The second is to discharge the untreated or partially treated wastewaters to the sewers of a local government agency providing wastewater conveyance and treatment services. The latter practice is generally termed "joint treatment." The industry practicing joint treatment is required to provide control and "pretreatment" to various degrees in order to use the publicly owned facility. Such requirements are discussed subsequently in detail.

The main element of the treatment provided is biological treatment regardless of whether it is provided by industry or by a public agency. Therefore, a basic description of biological treatment is provided in this discussion, and later the specific biological treatment processes used by the industries treating their own wastes are described.

The several variations in biological treatment all depend on maintaining a culture of bacteria in facilities for contacting the wastewater and the bacterial mass. The process consists of providing conditions such that a great population of bacteria will feed on the organic matter in the wastewaters. The bacteria convert the organic matter to carbon dioxide, water, and other simple, innocuous products, and, of course, a certain mass of bacteria are created. The bacteria in some treatment processes are maintained in suspended form in the wastewaters. In others, the bacteria are attached to fixed surfaces and the wastewaters are passed over these surfaces.

The bacteria, in bringing about this conversion, use oxygen which is present in solution in the wastewaters. Therefore, a major part of the treatment equipment for those processes using bacteria suspended in the wastewaters is for transferring oxygen from the air into the wastewaters to supply the needed oxygen. This is generally accomplished by violently agitating the water surface by rotating blades or by bubbling air into the liquid.

Biological treatment produces organic matter itself in the form of masses of bacteria. This material, together with solid matter settled from wastewater, is called sludge. At many plants, sludge is treated by yet another biological treatment process, called digestion, which destroys part of the sludge and renders the residual more easily dewatered. In this case, however, the sludge is held in closed tanks excluding the air. The organic matter in the sludge is largely converted to methane gas in the digestion process. The final sludge product is a relatively stable residue which can be disposed of in several ways, including use as a soil conditioner.

JOINT TREATMENT IN MUNICIPAL SYSTEMS

All but nine edible oil refineries in the U.S. discharge their manufacturing wastewaters to municipal systems for treatment with the residential, commercial, and other industrial wastewaters of the community. The main reason for such joint treatment practice is that it costs less than the alternative. A large plant serving both industry and residences simply costs less to construct and operate than several separate treatment plants serving each industry and the residents. Where the costs are fairly shared among the users and beneficiaries of the system, all participants in the community system share in the economies of scale; so it is a saving to both the industrial and residential members of the community. Another advantage is the minimizing of space used for treatment. This saving of space is especially important for crowded industrial plants. The joint plant would be expected to operate to achieve better efficiency for comparable processes because of operation by a specialized, full-time staff. A small industrial plant would be subject to lapses in performance because of part-time attention by operators without as much training or specialist supervision. Joint treatment also avoids the need for an industrial plant to dispose of solid residues from a wastewater treatment plant located at the industry site. An edible oil plant treating its own wastewaters could have a costly problem in storing and disposal of residues of solid or semisolid material generated in treatment. The hauling of such waste treatment residues from an industry treatment plant would be wasteful of energy and would contribute to transportation congestion problems in the industrial area.

One reason some plants in the U.S. are treating their wastewaters for direct discharge to public waters is the unavailability of the opportunity to discharge to a minicipal or publicly owned wastewater transport and treatment system. The plants are located in rural areas so remote from collecting systems that joint treatment is not practical.

HISTORICAL RESTRICTIONS ON JOINT TREATMENT

The acceptance of edible oil industry wastewaters containing high concentrations of oil into municipal wastewater transport and treatment systems has not been without controversy. Objections to oil-bearing wastewaters could have arisen from a number of real or hypothetical problems. Blockage of sewers likely did occur during early experience when floatable fat in significant quantities was discharged by some industries to smaller municipal sewers. When the sewers are of large diameter and domestic sewage and other wastewaters are a major portion of the flow, plugging from even floatable fat is unlikely. The removal of floatable oil from the wastewaters prior to discharge to the municipal system will even in the extreme situation limit or eliminate sewer blockages from congealed oil. A recent examination of a municipal sewer, which had received the wastewaters from an edible oil refinery for over 30 years, revealed no coatings of oil interfering with flow (1).

A second important early influence toward objecting to oil in wastewaters was undoubtedly the problem with a layer of congealed oil that accumulated in the sludge digesters of the early-day treatment plants. Sludge is the term used for slurries of solid matter removed from the wastewaters in treatment. These slurries are commonly held in closed tanks (digesters) for about 30 days for stabilization before final disposal. In early designs, the sludge digestion tanks were not provided with means for adequately mixing the tank contents. In such unmixed digesters, the oil did accumulate in a solid layer at the surface. In this solid form, the surfaces of the oil layer exposed to bacteria were limited, and degradation took place very slowly. These accumulations of oil or grease had to be removed manually at great expense. Physical damage to digester appurtenances also occurred frequently from this mass of solid material. The provision of mechanical mixers in the digesters, which practice began in the 1950s, has eliminated serious problems caused by oil scum in digesters.

A third reason for objecting to the oil-bearing wastewaters was another treatment plant problem, namely, the plugging of lines used to transfer the scum from settling tanks to the sludge and skimmings processing equipment. Oil, which reached its congealing temperature in these lines, would coat the sides of the pipe and restrict the flow. Complete blockages would finally occur. The lines had to be steamed out, rodded, or reamed to restore their use. These sludge line plugging problems are eliminated or minimized by design changes such as larger size pipe and steam heating of pipe walls. Modern municipal plants incorporate such features. Oil and grease are present in significant concentration in household wastewaters so that the plant must be designed to handle the oil and grease separating in the treatment system without difficulty. Such design is now standard practice.

Another objection to oil-bearing wastewaters in earlier periods was related to occurrences of excessive foam in the aeration portion of treatment plants. Foam generated from domestic sewage contains, in many circumstances, much oily material. When the foam collapses, the residue contains oil and grease. The foam occasionally covered walkways and drained down walls; when collapsed, the foam commonly left a slick and troublesome greasy layer. Incidents of troublesome quantities of foam being generated in sludge digesters also occur. Again, the collapsed foam contains considerable oil or grease.

The oil or grease is not a causative agent of the foam but tends to accumulate at water-air interfaces, and, therefore, the air bubbles carry oil to the water surface with the foam. With the substitution of biodegradable detergents, foaming at treatment plants has been greatly reduced. Foam incidents occasionally do occur. More information is being discovered on causes of foaming. One recent finding is that a population of certain organisms in the activated sludge leads to a persistent froth. No evidence has been developed showing oil as a cause of foaming. On the contrary, triglycerides and fatty acids are foam suppressants.

Still another reason for concern with oil-bearing wastewaters in early years likely arose because many publicly owned treatment works provided only primary treatment, i.e., sedimentation. The soluble and emulsified oil would not be removed in primary treatment. Legislation of the early 1970s has or soon will result in all municipal wastewaters receiving biological treatment. Biological treatment is effective for these wastewaters and eliminates the concern over the material passing through the treatment plant.

Those plants which practice drying or incineration of wastewater treatment sludges have a special problem with oil in the sludge. During the drying process, some oil is volatilized. To meet air emission standards, the driers and incinerators had to be equipped with afterburners to maintain destructive temperatures for combustion of the volatile matter. This problem is not unique to municipal systems handling wastewaters from the edible oil industry. Household wastewaters contain animal/vegetable oil in significant concentrations. Therefore, the volatilization problem is present and must be controlled even in the absence of industrial wastewaters. If appropriate and worth the trouble, the costs of the operation to control volatiles can be shared among industrial and residential users as a special element of the service charges in proportion to their contribution of the materials involved.

Finally and most importantly, the concern and restriction on use of publicly owned treatment systems for oil-bearing industrial wastewaters arose because of failure to distinguish between kinds of oil. For wastewater treatment purposes, the two kinds of oil with distinctly different response to treatment are animal/vegetable oils and petroleum oil. The animal/vegetable oils are of triglyceride and fatty acid structure, while the petroleum oils are aliphatic and cyclic hydrocarbons. Both are included in the measurement of oil in water by standard analytical methods. These two types of oil respond quite differently in biological degradation and removal in wastewater treatment processes. The animal/vegetable oil in dispersed form is oxidized and degraded in aerobic (oxygen present) biological treatment systems at rates comparable to those prevailing in degradation of the organic matter of domestic sewage as a whole. In the well-mixed anaerobic (oxygen absent) sludge digestion process, dispersed animal/vegetable oil is rapidly degraded to the useful gas, methane.

Petroleum oil, on the other hand, is less subject to bacterial oxidation under aerobic conditions. The particular circumstances of bacterial acclimation and other factors limit the positiveness of statements about the biological degradation of petroleum oil. Petroleum oil as well as other oil can be removed in the biological treatment process by virtue of its becoming physically associated with the solid material removed. In this way, it is removed as part of the sludge and not by bacterial oxidation to CO_2 and H_2O. Distinguishing between removal by degradation and physical removal is difficult and complicates observations for biodegradability. Under anaerobic (no oxygen) conditions differences in biodegradability of the two types of oil are pronounced. Petroleum oil is not significantly biologically degraded under the anaerobic conditions of sludge digestion. This constitutes one of the reasons for severe restrictions on petroleum oil concentrations in municipal systems.

The matter of entrapment or entrainment or absorption of oil on the biological floc, which was mentioned in the previous paragraph, is another reason for limiting petroleum oil concentrations. A sludge floc, if it includes sufficient oil, will have lower than normal specific gravity. Therefore, if the oil content of the agglomerated particle is low enough, the settling velocity may be insufficient for its separation in the settling process; and it will remain in the water effluent rather than settle in the sludge. Such oil-bearing sludge can be of such specific gravity that the floc is buoyed to the surface; this has been observed in biological systems treating petroleum oil-bearing wastewaters. The phenomenon has not been observed in the case of animal/vegetable oil in such systems where the loading of the treatment system is within the standard design range. Since the animal/vegetable oil is biodegradable, there is no reason at normal loadings to expect it to accumulate in the biological floc to an abnormal extent. The waste treatment literature includes remarks alluding to "coating" of sludge with fat and oil. No researcher has recorded such coating in photographs or otherwise, and consequently its existence is questionable. The alleged "coating" of bacterial floc is mentioned because such allegation is the basis of another objection to oil in wastewaters, specifically that such coatings interfere with the transfer of oxygen to the wastewater and from the wastewater to the organisms. These allegations at the levels of oil found in practical municipal situations were shown to be untrue by actual observations of oxygen transfer rates. The transfer rates observed in wastewaters containing moderate concentrations of oil-bearing industrial wastewaters were equal to those observed for domestic sewage alone (2).

Unfortunately, misinformation, unsubstantiated fear, and partial knowledge, plus abuses from discharge of excesses of floatable oil, led municipalities to adopt limitations on the concentration of oil in wastewaters admitted to the municipal sewers. A number often adopted was a limitation of 100 mg/l of total oil. The reason this particular number was selected is obscure; but it can be rationalized by the thought that strictly domestic wastewaters, although averaging in 24-hr composite samples ca. 35-50 mg/l of oil, occasionally could possibly contain up to nearly 100 mg/l. Therefore, the limit on oil-bearing industrial wastewaters was, by this reasoning, set at about the maximum a domestic sewage sample might have.

Other cities adopted limits of 300 mg/l and up to 600 mg/l. Some municipalities attached specifications to the limitation, saying that exceptions would be given if it was shown that the oil was biodegradable and did not obstruct sewers or otherwise interfere with treatment. Fortunately, limitations have been enforced on edible oil-bearing wastewaters in only a relatively small number of communities.

Such concentration limits on materials which are compatible with joint treatment are undesirable. The principle reason concentration limits are objectionable is that they discourage water conservation and waste volume reduction practices. Volume or discharge rate is the most costly element of transport and treatment of wastewaters. Concentrated wastes are less costly to treat. A treatment plant can be tailored to accomplish excellent treatment for any concentration of the domestic and industrial waste mix. Separate biological treatment of the two would be much more expensive. The volume of wastewaters from an edible oil plant compared to the volume of wastewaters from the residences of a community of significant population is such that the industrial wastes will increase the oil concentration of the combined flow only a few milligrams per liter. Household wastewaters average ca. 35-50 mg/l of oil.

Fortunately, the thinking that concentration of animal/vegetable oil in wastewaters must be limited is dying out, and more enlightened reasoning is prevailing. The rationale for such limits has proven to be based on inadequate information or circumstances no longer applicable.

ENLIGHTENED JOINT TREATMENT CONTROL

The rules and regulations for use of municipal wastewater collection and treatment systems by industrial and commercial members of the community are embodied in local documents referred to as sewer use ordinances. Recently, the term *pretreatment* has come into general usage for the limitations placed on industrial use of publicly owned works. The term *pretreatment* is particularly used with regard to the Federal Environmental Protection Agency regulations. The EPA, since 1972, has had authority to dictate certain minimum pretreatment requirements specific to each industry category. Also, the EPA has issued general pretreatment requirements for all industries practicing joint treatment.

The Federal EPA pretreatment standards and limitation for the edible oil industry have not been issued at this writing (January 1976). Documents of EPA sponsorship, which will be used as a basis for developing the edible oil industry's wastewater control standards, indicate that the general pretreatment requirements are all that are needed for the edible oil industry. In other words, the documents state that no special pretreatment requirements are needed for the industry's wastewaters.

The general pretreatment requirements mentioned above protect the system from corrosive materials, explosive materials, or materials that tend to form deposits or coatings on the sewer surfaces and obstruct flow. The general pretreatment regulations limit the pH to > 5.0. The language concerning material that obstructs sewers has been interpreted as prohibiting oil in the physical form that will come to the surface in the pipes and pump stations. Such oil is considered to potentially be a cause or contributor to obstruction of flow and is therefore, according to a common interpretation, prohibited by the national or general treatment standards for industrial wastewaters. Floatable oil may be defined as that which is removed by a gravity separation facility of approved design. The engineers of the local wastewater agency must make the decision on the design of such gravity separation facilities which are acceptable.

The General Pretreatment Standards of the Federal EPA for industrial users of publicly owned treatment works currently in force were those promulgated on November 8, 1973. The regulation recognized that animal/vegetable oils are compatible with publicly owned treatment works, and no limitation on concentration of dispersed forms is advocated. The biodegradability of animal/vegetable oil was also recognized by the Environmental Protection Agency in a publication issued in May of 1975 (3).

The Water Pollution Control Federation, which is the major trade association of water pollution control technologists in the world, has recently revised its manuals to reflect the compatibility of animal/vegetable oil-bearing wastewaters in joint treatment. Their *Manual on Sewer Use Regulations* suggests that industries practicing joint treatment remove floatable oil prior to discharge to municipal systems. Floatable oil is defined in the suggested ordinance in the *Manual* as follows:

> Floatable oil is oil, fat, or grease in a physical state such that it will separate by gravity from wastewater by treatment in an approved pretreatment facility. A wastewater shall be considered free of floatable fat if it is properly pretreated and the wastewater does not interfere with the collection system.

Of importance here is that no analytical procedure for floatable oil is needed. The provision of the pretreatment facility constitutes compliance. The suggested ordinance recommends the following language for controlling oil concentrations:

TABLE I

Performance of Southern California Plants

Plant name	Loading	Size plant (million gallons per day)	BOD[a] removal (%)	Oil removal (%)
Pomona	Normal to overloaded	8	97	98
Los Coyotes	Normal	12	96	98
San Jose Creek	Normal	24	98	99
District 26	Normal	3	98	99
Whittier Narrows	Normal	15	99	99

[a]BOD = biochemical oxygen demand.

TABLE II

Performance of Northern California and Pacific Northwest Plants

Plant name	Loading	Size plant (million gallons per day)	BOD[a] removal (%)	Oil removal (%)
Sacramento County Control	Normal	25	96.1	96.4
Sacramento City, Northeast	Normal	14	92.0	93.0
West Sacramento	Normal	3	89.4	94.2
San Jose/Santa Clara	Normal	90	87.9	95.6
RWQCP Palo Alto	Normal	30	92.9	93.3
Richmond	Normal	5	86.8	89.5
Pure oxygen pilot plant	Normal	0.02	93.2	94.1
Air pilot plant	Normal	0.02	85.9	96.0
Renton, WA	Overloaded	28	98.1	82.6
Portland, OR Col. Pt.	Normal	70	77.5	73.7
Beaverton, OR Fanno Pt.	Overloaded	8	67.5	47.9

[a]BOD = biochemical oxygen demand.

> The limitation or restrictions on materials or characteristics of waste or wastewaters discharged to the sanitary sewer which shall not be violated without approval of the superintendent are as follows: .... (c) wastewaters from industrial plants containing floatable oils, fat, or grease.

The municipal engineers, in application of this ordinance, need to make a decision as to whether or not each industrial user has sufficient floatable oil to warrant a requirement of pretreatment in gravity oil separation facilities. A simple test simulating such treatment by settling samples in the laboratory may be useful in decisions on other plants.

EFFECTIVENESS OF JOINT TREATMENT IN OIL REMOVAL

The effectiveness of joint treatment for oil-bearing wastewaters is best attested to by observations of the performance of municipal plants in oil removal. Relatively few municipalities measure oil content of their wastewaters on a routine basis, so the data available is not extensive. In 1975, consulting engineering firms were employed to compile existing oil removal information from plant records, control agency files, and their own records. Data were obtained from 59 municipal plants ranging from small to 180 million gallons per day in capacity. The data were for total oil as measured for the most part by the soxhlet extraction procedure with hexane as the solvent. One criterion for judging performance of these plants in oil removal is comparison of efficiency in removing oil to their performance in removing biodegradable organic matter. The latter is measured by a test procedure termed *biochemical oxygen demand*, generally referred to as BOD. The plant loadings of BOD were generally on the high side of the range suggested in design manuals. Data for the activated sludge plants for which oil data were located are summarized in Tables I-IV. The data are presented for four groups of plants according to geographic location.

Data for the first group of plants (Table I) are for plants located in Southern California. All of these activated sludge plants performed very well in BOD removal, 96-99%, and even better in oil removal, 99%. Plant loadings were in the normal range.

Data for the second group of plants (Table II) are for plants in Northern California and the Pacific Northwest. Again, eight of these eleven plants, the first eight in the table, achieved oil removal. Two overloaded plants achieved poorer oil removal than BOD removal, and one plant, even though normally loaded, did poorly in both.

Data for the third group (Table III) are for plants in New York and Connecticut. Data from 21 activated sludge plants were obtained. Only one to four results were available for each plant. Sixteen of these 21 plants achieved greater reduction of oil than BOD. The oil removal percentages for these 16 plants are underlined in the last column of the table.

Data for the fourth group (Table IV) are for two activated sludge plants in Texas and two in Wisconsin. The averages reported for Austin and Ft. Worth represent many samples. Wisconsin data represent results of special studies, two days' results in Beloit and six in Milwaukee. Results of the Ft. Worth plant show low removal of oil. No explanation was found for this.

The incoming wastes at all of these plants contained appreciable concentrations of oil. Attempt was made to note cases of significant wasteloads of oil from industry in

TABLE III

Performance of New York and Connecticut Plants

Plant name	Loading	Size plant (million gallons per day)	BOD[a] removal (%)	Oil removal (%)
Buchanan	Low	0.23	95	99
Stony Point	Normal	1.0	88	90
Rockland	Low to normal	17	41	42
Haverstraw	Low	2.5	67	90
Bay Park	Normal	70	91	92
Northport	Low	0.3	80	98
Hunts Point	Low	120	76	70
Wards Island	Low	170	76	72
Newtown Cr.	Normal	150	94	95
Bowery Bay	Normal	120	59	70
Jamaica	Normal	110	70	93
Owls Head	Low	110	51	80
Coney Island	Normal	100	77	90
Tallman Island	Normal	64	42	40
26th Ward	Low	60	65	84
Bridgeport E.	Low	7	72	72
Bridgeport W.	Low	30	64	80
Fairfield	Low	8	90	86
Greenwich, C.	Low	12	61	83
Milford-Beaver	Low	0.2-1.0	91	95
Milford-Town	Low to normal	2.5	66	77

[a]BOD = biochemical oxygen demand.

TABLE IV

Performance of Texas and Wisconsin Plants

Plant name	Loading	Size plant (million gallons per day)	BOD[a] removal (%)	Oil removal (%)
Austin	Overloaded	20	79	82
Ft. Worth	Normal	45	89	48
Beloit	Normal	8	94	89
Milwaukee, Jones Is.	Normal	200	96	86

[a]BOD = biochemical oxygen demand.

these plants. The plant exhibiting the highest oil concentration was the Sacramento County Control Plant. At this plant, industries with appreciable concentrations of animal/vegetable oil in their effluents were significant. During June and July, 1975, 31 sets of daily samples were analyzed for the common parameters, including oil. The oil content of the inflow was over 100 mg/l on 19 of the 31 days involved. The reductions achieved were excellent: 99% of the oil was removed, 96% of the BOD, and 97% of the suspended solids.

In summary, these data on municipal plant performance indicate that a predominance of the plants do remove oil to about the same or greater extent than they do biodegradable organic matter as measured by the BOD test. Certainly these data show that no restriction on animal/vegetable oil is justified as a general regulation on the basis that the oil will not be satisfactorily removed by a biological treatment plant of the activated sludge type.

Further evidence of the biodegradability of animal/vegetable oil is established by application of biological treatment to the industrial wastewaters alone. The biological treatment is described in detail later. At this point, it suffices to relate that oil reductions on the order of 95-99% are achieved. The loadings of the industrial plants in terms of pounds of BOD per day per pound of bacteria or biological matrix in the system (measured as volatile suspended solids) are within the generally accepted design range for plants treating domestic sewage.

Residence time of the wastewaters in these industry-owned treatment systems is much longer than in municipal plants. People have interpreted this as indicative of less biodegradability. This is an erroneous conclusion because the residence time for treatment is a function of the concentration of BOD in the wastewater. Design principles for the activated sludge process are such that, if the BOD of domestic wastes were to be increased by removal of water to reach the same concentration as these industry wastes, the residence times in treatment would be the same as for the industrial wastes. Residence time is not a factor in modern activated sludge plant design; the residence time is established by BOD:bacteria ratios and an economic balance between the concentration of bacteria in the system and the tanks and pump sizes.

EQUALIZATION FOR JOINT TREATMENT

Occasionally, municipal officials will advocate equalization of the wastewaters of an industrial user so that high short-duration flows or organic loads, referred to as slug loads, will not upset the municipal plant. The gravity separator does function to even out slugs. Slug loads such as from rapidly discharging the wastewater from batch acidulation or from a recirculated cooling water system with high fat content may be avoided by slow discharge. The volume and quantity of pollutants in the edible oil plant wastewaters compared to the community wastes is generally such that the impact of peaks on total flows and loads received at the treatment plant is of no importance.

NEUTRALIZATION

The General Pretreatment Requirements of EPA prohibit the discharge of wastewaters with pH <5.0 to publicly owned sewer systems. The local agency in their sewer use ordinances frequently specify 5.0, 5.5, or 6.0. The reason for these regulations is to avoid corrosion of the sewers or interference with treatment processes. An upper limit of pH is also usually provided in local sewer use ordinances: typically an upper pH of 10.5 or 10 or 9.5 is specified. This upper limit is not a matter of corrosion control but is to protect the treatment process.

The dilution effect of domestic sewage would take care of modest losses of alkaline materials. However, there is little buffering capacity for such in domestic sewage, and in some systems a loss of as little as 100 lb of an alkali hydroxide could have damaging effects. As a practical matter, this problem is controlled by placing an upper limit on pH.

The major wastewater source which must be controlled for meeting pH limits is the wastewaters from acidulation. These wastewaters are released from the process at a pH of ca. 2-2.5 or even lower. Where acidulation is carried out by batches, neutralization may also be accomplished batchwise. The wastewaters from continuous acidulation may also be neutralized continuously. The control system for accomplishing continuous neutralization is complex and difficult to design. Of course, where a large equalization tank is provided, neutralization is made easier. Sensing and delivering the proper quantity of neutralizing chemical is fraught with difficulties because a small quantity of neutralizing agent in excess of that needed will result in out-of-limits high pH values. A system at one plant which has been reported to be functioning satisfactorily is a dominant bath neutralizing system. The dominant bath neutralizing tank holds 20-30 min of normal flows at about mid-depth, which is the operating level maintained. The additional capacity of about equal volume is used for surges and short-time storage. The dominant bath is continuously mixed by pump recirculation. A sensor in the system signals the caustic feed control. The neutralized wastes are released from the neutralizing tank by a valve in the recirculation line. The discharge valve is controlled by a low level shutoff which maintains the minimum bath volume. The valve also has a control which does not allow the discharge valve to open unless the pH is within limits. A high level alarm completes the scheme. This neutralizing system receives floor drainage from the caustic and acid pump areas as well as the acidulation wastes.

Some oil refining plants acidulate only the caustic extract. The water rinse following caustic extraction (soapy water) is not processed in the acidulation system. Soapy water must be neutralized before discharge. This stream can be added to the acidulation wastes for partial neutralization. Caustic cleanouts, particularly of the deodorizer, create heavy loads of alkaline wastes which can also be used for neutralization of acidulation process wastes.

The recovery of oil from process wastewaters by gravity separation is improved by maintaining a low pH. This is practiced where materials of construction or acid-proofing of pipes and tanks makes such practice feasible. The acidulation process wastewaters can be used to maintain a low pH of all plant wastewaters in the gravity oil separation tank. The effluent from the oil separation tank must be brought within the desired pH range before discharge to the municipal system. Attempts to obtain satisfactory neutralization in the discharge pipes or manholes have proven difficult because of the need for very close control of the addition of neutralizing agent. A dominant bath system such as previously described for acidulation wastes would be expected to be the most satisfactory. Neutralization in transit in a pressurized pipe is practiced in one system known to the author. An in-line baffled mixer is used downstream from the neutralizing chemical injection point.

DISSOLVED AIR FLOTATION

Dispersed and emulsified oil may be reduced to relatively low levels by chemical-coagulation followed by dissolved air flotation. The dissolved air flotation process consists of pressurizing all or part of the wastewater and contacting the pressurized wastewater and air so that up to ca. 50 ppm of air is dissolved in the flow. This usually requires ca. 50-75 psi pressure and a few seconds of air-

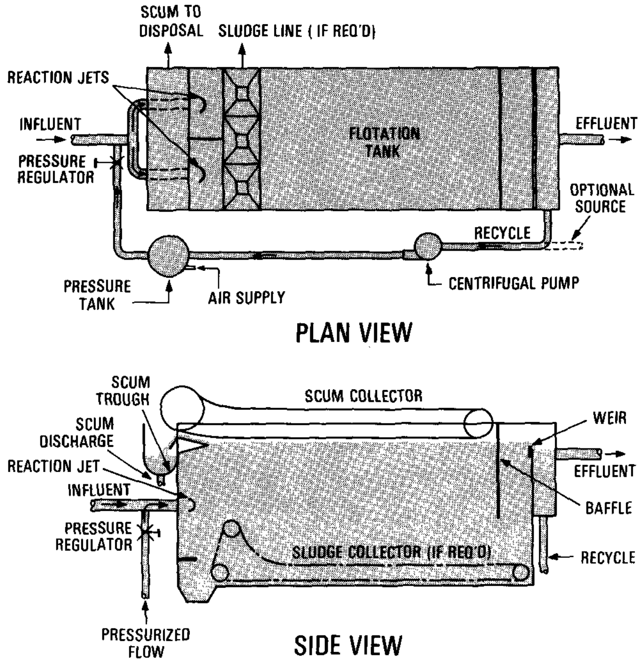

FIG. 1. Dissolved air flotation process equipment. This model utilizes rectangular tanks and pressurization of a recycle stream.

water contact. Coagulating chemicals are added to the flow, and it is released into a tank at atmospheric pressure. At the reduced pressure in the tank, the air is no longer soluble and comes out of solution in the form of minute bubbles. Gases tend to come out of solution at interfaces between the water and solid surfaces. Thus, bubbles of air coming out of solution become attached to the particulate matter present in the waste flow. In this case, the particulate matter consists of agglomerates of oil and the coagulating chemical. The agglomerate of oil-coagulate-air now has a specific gravity such that it rapidly moves upward to the water surface.

The chemical coagulant plays an important role in the dissolved air flotation process. The chemical neutralizes the surface charges on the colloidal or dispersed oil particles and bridges them together. Dissolved air flotation is not effective for edible oil wastewaters in the absence of coagulating agents. The original coagulating agents were the trivalent and divalent mineral coagulants–aluminum sulfate, ferric chloride, ferrous salts, and calcium hydroxide. About 20 years ago organic flocculants were developed; hundreds of proprietary organic flocculants are now marketed. A number of organic flocculants were evaluated in an investigation of application of the dissolved air flotation to edible oil refining wastewaters (4). The most promising application appeared to be as supplements to the mineral coagulants.

In the early 1970s, a proprietary process was marketed which employed a low level electric current for coagulating the oil in wastewaters. The imposing of a small electric direct current between a central electrode and the tank walls is claimed to improve the efficiency of dissolved air flotation. The process is used to enhance chemical coagulation, and its use alone is not advocated by the developers.

Either circular or rectangular tanks may be employed for the dissolved air flotation process. With rectangular tanks, the flow is introduced in a distribution section at one end, passes into and through a quiescent central section, under a baffle, and exits via an overflow weir (Fig. 1).

The float or scum on the surface is removed by flight type scrapers which extend through the froth layer to just below the water surface. The flights are slowly moved along the tank, pushing the froth up a beach at the end to an elevation above the water surface. The float drops from the beach to a trough. This scum is not in the form of an oil layer but is typically a viscous froth high in moisture content.

With circular tanks, the flow is admitted near the center, well below the surface. The flow moves radially, under a baffle, and exits over a weir. The float is moved by a rotating arm up a beach near the periphery of one point and into a trough.

The processing of the float at one plant consists of acidulating it much in the same manner as the process of continuous acidulation of caustic extract of oil. Following the mixing of acid and float in a small reactor, the oil is separated by continuous centrifugation. The acid stream is reused for neutralization of other streams. At another plant, the float is returned to the inlet stream of the gravity oil separation facility handling the total plant wastes. The oil froth is broken by dilution in the waste stream. The coagulating chemical is washed from the oil particles. The oil becomes part of the oil recovered in the gravity separator and is marketed for animal feed. Apparently there is no problem with remnants of the coagulating chemical in the recovered oil where either of these processes are employed. The recovered float is not useful as produced but must be further processed to reduce the water content and remove the flocculant. The fate of an organic flocculant in the process is unknown. Undoubtedly some would remain with the recovered oil. Some of such flocculants are approved for use in coagulation of drinking water supplies. These would likely be acceptable in oil for animal feed.

The most recent development in equipment used for the dissolved air flotation process is vertical baffles oriented with the flow, which in effect divide the tank into a series of narrow, parallel basins. These units are used in the paper industry. No installations are known in the edible oil industry. Another recent development is the use of relatively shallow tanks in the order of 3 ft. Earlier practice utilized tanks 6-10 ft deep.

The principal design factor for the process is the size of the tank. The most useful design parameter is termed the surface overflow rate expressed as gallons per day per square foot. Values ranging about the figure of 3,000 gal/D/ft^2 are generally used.

There are differences in ways of routing the flow to secure the air in solution. The simplest is to pressurize the entire flow, pass the flow over some contact media in a pressure vessel containing air, and on into the flotation tank. Some designs pressurize only ca. 25% of the flow and mix this flow with the remainder in the inlet section of the flotation tanks. This avoids the expense of pressurizing the whole flow and also enables the chemical dosing and floc formation in the unpressurized stream. Thus, the pressurization, air contact, and release of the coagulated materials through valves are avoided. This is claimed to obtain superior removals because the chemical agglomerates are not broken up so much. A variation is the pressurization of a portion of the flotation unit effluent in a recycle arrangement. The untreated waste in the recycle system reaches the flotation tank without pressurization. This avoids obstruction of the media in the air contact tank with material in the untreated wastewaters.

The creation of air bubbles by forcing air through porous diffusers is not effective in flotation of dispersed and emulsified oil. However, in the petroleum industry the addition of fine air bubbles by paddle or rotor aerators on the water surface is practiced. These aerators create air bubbles, and oil is subsequently removed in a similar manner to dissolved air flotation. No installations of this type in the edible oil industry are known.

Separation of dispersed oil by chemical coagulation and gravity separation, without air, is not normally practical. The mineral coagulant forms a particulate which by itself is of greater specific gravity than water. Entrainment or inclusion of oil in the particles tends to lower the specific gravity, and if enough oil is present the particle will float. The problem is that particles are likely to be generated with a specific gravity about the same as water, and these will not be separated in the gravity separation system. Such treatment is reported to be practiced by a small baking plant with oil-bearing wastes. Here, however, a very long settling time, ca. 4 hr, is used, and apparently the chemical dosage is high, creating a settleable floc.

An important part of the dissolved air flotation process is the chemical coagulation which agglomerates the oil into removable-sized particulates. Unfortunately, chemical coagulation is a phenomena sensitive to optimum conditions. The pH of the incoming wastes is one important factor. Each coagulant has its most effective range, which can be quite narrow. Also, the concentration of the material being removed will affect the chemical dose needed for maximum effectiveness. Extraneous materials such as emulsifying agents and dispersing agents in sufficient concentration can completely negate chemical coagulation and in effect render the coagulation and the dissolved air flotation process ineffective. For these reasons, the dissolved air flotation process is most reliable and consistent when applied to wastewater of consistent characteristics. Consistency of wastewater characteristics is usually not a trait of the industry. Batch acidulation is one reason. Washout of tanks and lines is another. For this reason equalization facilities and good neutralization (pH control) are important when dissolved air flotation is practiced. One industrial plant has an equalization tank of sufficient capacity for 24 hr of normal flow, whereas another plant utilizes only in-line pH control, with no equalization beyond that incidental to gravity oil separation.

Dissolved air flotation in one installation reduced the concentration of oil in wastewaters of the industry from an average of ca. 600 mg/l down to ca. 100 mg/l. According to a report on this installation, the effluent concentration attained will be as high as 150 mg/l quite often. A consulting firm employed to study wastewater treatment practices of the industry reported that in an exemplary plant the dissolved air flotation reduces the wastewater oil concentration from 3,500 to 1,050 mg/l (5).

The dissolved air flotation process is employed in two situations. One or two plants employ the process because of oil concentration limitations placed on discharges to municipal systems. Several plants treating for discharge directly to public waters employ the process prior to biological treatment. For those plants employing the process to meet municipal sewer use regulations, an important factor is the reliability of the process. One edible oil plant reports difficulty in consistently meeting a limit of 100 mg/l. Instead of dissolved air flotation, one plant manufacturing chemicals from animal fats chose to rely entirely on its own biological treatment. When treating wastewaters of the edible oil industry for direct discharge, the small scale involved in biological treatment compared to a municipal system appears to make economics favor dissolved air flotation preceding biological treatment. In consideration of employing the flotation process, the sensitivity of the coagulation step must be appreciated. Coagulation of dispersions with chemical flocculants is an art or is empirical. The importance of pH control has been stressed. In addition, the presence of dispersants and surface active agents will change the needed coagulant dose. In fact, high concentrations of phosphates or surfactants can make coagulation practically impossible. Since cleanup operations using such materials are frequently carried out, particularly where margarine or salad oil production is involved, some interruptions in performance may be expected.

The particular and peculiar conditions at each plant will affect the economics and reliability of the dissolved air flotation process so that no generalizations about its applicability, effectiveness, and economics appear to be warranted.

SURFACE ADSORPTION

One plant meets an imposed limit of 100 mg/l on industrial users of its publicly owned treatment works by means of a granular media filter. The adsorption unit, though structured similar to a rapid sand filter as used in water treatment, acts by adsorption of the oil on the surface of the filter media. The medium is fine silica sand. The media is cleaned of its oil load by contact with hot caustic. The caustic containing the oil removed is used in the oil refining process. The treatment system at this plant consists of holding the wastewaters at low pH in a gravity oil separator large enough for ca. a 24 hr residence time. The effluent is then neutralized and pumped through the adsorption unit. The unit works satisfactorily on wastewaters with oil contents under, say, 300 mg/l. At high concentrations, it reaches its oil-holding capacity rapidly, and time spent in regeneration is excessive. This treatment scheme is being employed at a plant which will be shut down and dismantled as soon as new facilities are completed at another location.

This filter system had its origin in a proprietary device developed in the early 1970s. The developer claimed two unique principles in such adsorption removal on the granular media. The filter medium was stated to have the property of attracting oil and not attracting water. Second, a high velocity was recommended in order to produce an intergranular turbulence leading to effective contact of particulate oil and the surfaces of the media. The inventor recommends backwashing the media with hot water. Oil is recovered from the hot water by gravity sedimentation.

BIOLOGICAL TREATMENT

Edible oil refining plants at nine locations employ biological treatment prior to discharge of process wastewaters to rivers or other public waters. Each plant employs a train of processes. A typical sequence of processes in the treatment train is gravity separation of floatable oils, flow equalization, pH adjustment, dissolved air flotation, and biological treatment. The edible oil industry in the U.S. makes use of one form of biological treatment almost exclusively. The form used is termed *aerated lagoon treatment.*

The facilities for aerated lagoon treatment are unlined earthen basins with a water depth of ca. 12 ft. Spaced out on the water surface are a number of aeration devices, perhaps as many as 20. These devices are electric motors driving blades placed at the water surface which whip the surface violently, thereby throwing water drops into the air and creating fine air bubbles in the water. The aerator also serves to cause strong currents in the water radiating out from the blades along the surface and returning near the bottom. Bacteria will naturally develop in the basin, and, since the entire basin is well stirred, they will be dispersed throughout. The incoming waste is mixed with the bacteria-bearing basin contents. The bacteria act to degrade the organics. The dispersed bacteria carry out in the effluent of the stirred basin. Thus, a balance between bacteria growth in the basin and bacteria leaving the basin in the effluent will develop. The concentration of bacterial mass will be ca. 100 mg/l or less. The basin must be sized to contain sufficient bacteria to degrade the organics in the waste. The residence time in the basin will range from 5 to 20 or more days in such faciltities handling industrial wastes. The loading in terms of pounds of BOD per day per pound of bacterial mass in the basin will range around 0.2.

The effluent is usually passed through a quiescent part of the basin or a separate basin where solid matter settles out and accumulates. The effluent would typically contain suspended solids at a level of ca. 30-50 mg/l and BODs of ca. 40 mg/l.

One plant in the industry treats the effluent from the aerated lagoon in another biological treatment system called activated sludge. The two forms of biological treatment thus are applied in series in this instance. In the activated sludge process, the bacteria develop in the form of minute clumps or agglomerates ca. 200 μm in size. These clumps will settle readily from the waste in quiescent flow. Thus, the fundamental basis of this process is the settling out and return of the bacterial mass for reuse on new incoming wastes. The facilities of the one plant where this treatment is applied consist of a circular steel tank with a water depth of ca. 20 ft. Oxygen is supplied by discharging compressed air through a bubble distributor near the bottom of the tank. The air is whipped into small bubbles by a rotating blade shortly above the air release.

A fundamental difference between the aerated lagoon and the activated sludge treatment processes is that in the lagoon process there is no attempt to recycle the bacteria mass from the effluent back to the incoming wastes. This has an importance in design because with the aerated lagoon there is little control over the concentration of microorganisms in the lagoon. To attain greater numbers of organisms, the lagoon would have to be made larger. A major factor in aerated lagoon design is, therefore, residence time—10 or more days' residence is common. On the other hand, the concentration of microorganisms in the activated sludge plant can be controlled within limits; concentrations up to ca. 5,000 mg/l may be used. Thus, residence times are usually a fraction of a day.

In the activated sludge system, there is a production of bacteria amounting in mass to ca. 25% of the organics stabilized. This is produced as a slurry of ca. 2% solids called sludge. The disposal of this material is costly. In the aerated lagoon, the bacteria produced are carried out in the effluent, and their residence time in the system is long enough that the dead bacteria are themselves stabilized. There is no solids disposal involved of any significance.

The microorganisms involved require nitrogen and phosphorus in their life processes. A ratio of 1 mg/l of phosphorus per 100 mg/l of BOD is a normal requirement and ca. 16-20 mg/l of nitrogen per 100 mg/l of BOD. Some of these materials will be naturally present in the process wastewaters and in the sanitary wastes from employees if they are added. Some nitrogen may need to be added to fill the requirement; usually the nitrogen is added in the form of ammonia. Phosphorus is generally present in adequate concentrations in edible oil refining wastewaters.

These biological processes may be designed to achieve BOD removal up to a maximum effectiveness of ca. 95%. Much of the BOD present in the wastewaters is from the oil. The oil removal effectiveness typically exceeds that for BOD.

There are other systems of biological treatment which undoubtedly would function satisfactorily in treating edible oil wastewaters. However, in the U.S. only two systems as described are used, the aerated lagoon and activated sludge.

FILTRATION

Two of the plants practicing aerated lagoon treatment subject the lagoon effluent to an additional process before discharge. The process is termed filtration. The filter in this case is a bed of granular material ranging from coarse grains of ca. 1/8 in. diameter down to fine sand. The bed is ca. 36 in. in depth and is made of several materials in more or less stratified form. The bottom layer is typically a very fine sand of a dense stone, the next layer is of common sand, and the top layer is grains of hard coal called anthracite.

The effluent passes down through the filter. The filter is designed to obtain a deposit of material throughout the bed depth—the coarse material being removed in the upper layer and the smaller material in the fine sand near the bottom. By such distribution, a great amount of water can be

TABLE V

Existing Treatment Train and Major Design Factors of a Plant for the Biological Treatment of Edible Oil Refinery Wastes

Number	Treatment unit	Significant design features
1	First pH mix tank	8.2 l/sec (130 gpm) capacity. Adjust the raw waste pH to 1.5-3 to ensure adequate separation of oil and water for gravity separation.
2	Flow equalization tank	851.6 m^3 (225,000 gal) capacity.
3	Skimming tank	1,135.5 m^3 (300,000 gal) capacity operation at a fixed level for continuous mechanical skimming. Recovered oil is pumped to an oil holding tank, 37.8 m^3 (10,000 gal) capacity. Here steam and gravity are used to separate oil and water, with the water being sent back to the flow equalization tank.
4	Second pH mix tank	Anhydrous ammonia addition with automatic pH control and alarm equipment to raise the pH to 7.
5	Dissolved air flotation (2 units) with chemical addition	Retention times, along with the ratios of lime, alum, and polyelectrolytes, are varied to produce the maximum amount of pollutant reduction. 68.1 m^3 (18,000 gal) capacity each.
6	Aerated lagoon (2 units operated in series)	4,542 m^3 (1.2 million gal) capacity, with five 14.9 kW (20 HP) floating surface aerators and a 5-6 day retention time per lagoon.
7	Stabilization lagoon	Same design as above but without surface aerators. Overall retention time in the three basins is 15-18 days.
8	Dual media filter with chlorination before and after	Suspended solids and bacteria removal. No data on retention time dosages or design.
9	Final effluent	BOD, 40 mg/l; SS, 50 mg/l; oil and grease, 1.0 mg/l; total phosphorus, 9 mg/l; nickel, 0.02 mg/l; pH, 7-8.

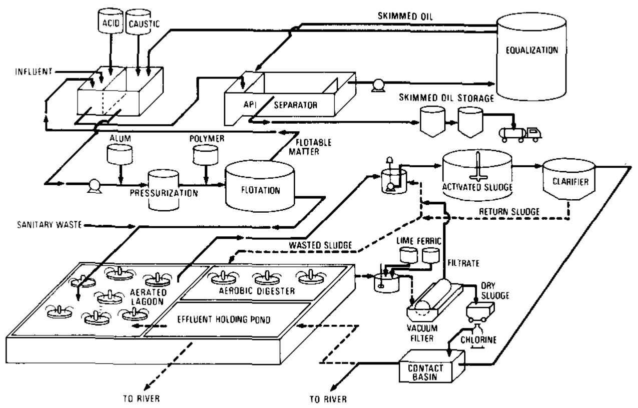

FIG. 2. Treatment train.

filtered before there is much interference with the flow rate from deposited material. Filtration rates are ca. 2-4 gal/min/ft^2.

Suspended solids in lagoon effluent are predominantly microorganisms. Effectiveness of this type of filter is very low unless the suspended matter is pulled together in larger particles by a coagulating agent. Such a coagulant is used prior to filtration at a dose rate of a few milligrams per liter.

Material removed in the filter is flushed out periodically when the flow rate is significantly reduced by reversing the direction of water flow. Water is forced upwards through the filter at sufficient rate to lift the particles apart and cause them to tumble about in turbulent flow. This wash water is pumped back to the lagoon. The different sizes of the filter media settle back into their layered pattern because of differences in specific gravity.

Reduction in solids level accomplished by the filter is sporadic–some samples show a reduction of 50% while others show little removal.

TREATMENT TRAIN FOR DISCHARGE TO PUBLIC WATERS

Assemblage of the various treatment processes in two plants of a U.S. edible oil refiner serves as a summary of the subject. Two identical treatment systems for edible oil refineries in the south central U.S. provide the train of treatment described in Table V in the sequences shown. Wastewater flow and size of the units of one plant are generally spelled out in the table. This information was assembled by a consulting engineer for the Federal EPA in 1975 (5).

Finally, the edible oil processing plant treating its wastewaters by a combination of aerated lagoon and activated sludge has a total treatment train illustrated in Figure 2. In this treatment train, the incoming wastewaters are first made acidic, pH 4-5, upstream from a gravity oil separator. The wastewater then goes to an equalizing tank providing ca. 24 hr residence time. From the equalizing tank, the wastes go to a mix tank, where the pH is brought to about neutral. Coagulating agents, alum, and polymer are added. The flow is pressurized and discharged to the dissolved air flotation unit. The effluent from the flotation unit is discharged to an aerated lagoon biological treating unit. Residence time in this unit is ca. 10 days. The lagoon effluent is discharged to an activated sludge plant providing 40 hr residence time. After settling in a clarifier, the effluent is chlorinated, passes through a contact basin, and finally the chlorinated effluent enters a holding pond. The holding pond discharges to the river. The system is reported to reduce the BOD from an initial 4,960 mg/l to 7.5 mg/l (6).

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