Deodorization options and trends

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The methods and conditions governing the deodorization of fats and oils have been well known and discussed for many years. Commercial plant designs have evolved to a point where today, relatively few basic differences remain between the systems in use. These differences, in turn, usually are due to specific adaptions to special processing or product conditions. This article is an attempt to present some typical design options for a deodorization system and to point out a few of the strong and weak points of each. For obvious reasons, many of the designs discussed will bear some resemblance to various brand systems. All evaluations and performance indications, however, are based on the author's personal experience, and conclusions on what is possible and practical are intended only as a basis for discussion.

Semi-continuous or continuous processing

Semi-continuous deodorization is characterized by the intermittent movement of a relatively small batch of product through consecutive heating, deodorizing and cooling stages (trays) in the system. Semi-continuous systems generally are associated with the fact that they are considered easy to stock-change and usually have the lowest contamination of one product into another.

This is partly due to the relatively smaller wet surface of a "batch" tray versus a "labyrinth" continuous flow tray, but more so because true semi-continuous systems have less external (outside deodorizer) heat exchangers and piping. Heating and cooling are done in the deodorizer (in trays) or in vacuum vessels that can be drained by gravity, while external equipment located below the deodorizer inlet or a downstream component must be purged into the deodorizer.

The intermittent flow pattern and tray cycling sequence also provides natural "break points" in the product flow, making the stock-change simpler and often faster. A semi-continuous system, for example, can have a tray cycle-time of 15 minutes, which allows for a 15-minute stock-change period and feed interruption with about 13 minutes for each individual tray to "drip" dry when equally sized. The residual amount of product in a 30,000 pounds per hour (pph) plant (Fig. 1) with no external heat exchangers and gravity transfer of the product through the deodorizer should be about 300 pounds.

The drawback of a true semi-continuous system is that it is complicated and costly to achieve more than 50% heat recovery due to the intermittent flow pattern.

Continuous systems, on the other hand, may have a heat recovery of up to 85% due to the ease of countercurrent heat exchange. They can be designed to have a relatively short stock-change feed interruption (depending on the tray sizes), but the "drip-time" after the tray has drained then will be considerably shorter. Furthermore, the wet surface area outside the deodorizer may be quite large when attempting optimal heat recovery. Much of the external equipment and piping must be drained by purging.

Proper design and installation of heat exchangers, pumps and piping will more or less eliminate pockets of product that otherwise are likely to form in various places. For example, spiral-type heat exchangers should have cross channel drain slots. Also, piping should be sloped and, when vertical towards the deodorizer, reduced in size. Even so, the residual amount of product in a traditional continuous system may be as high as double that of a semi-continuous system when maintaining a reasonably short feed interruption. Therefore, it is difficult to justify continuous operation for plants with seven to eight stock-changes or more per 24 hours when product contamination is an important factor.

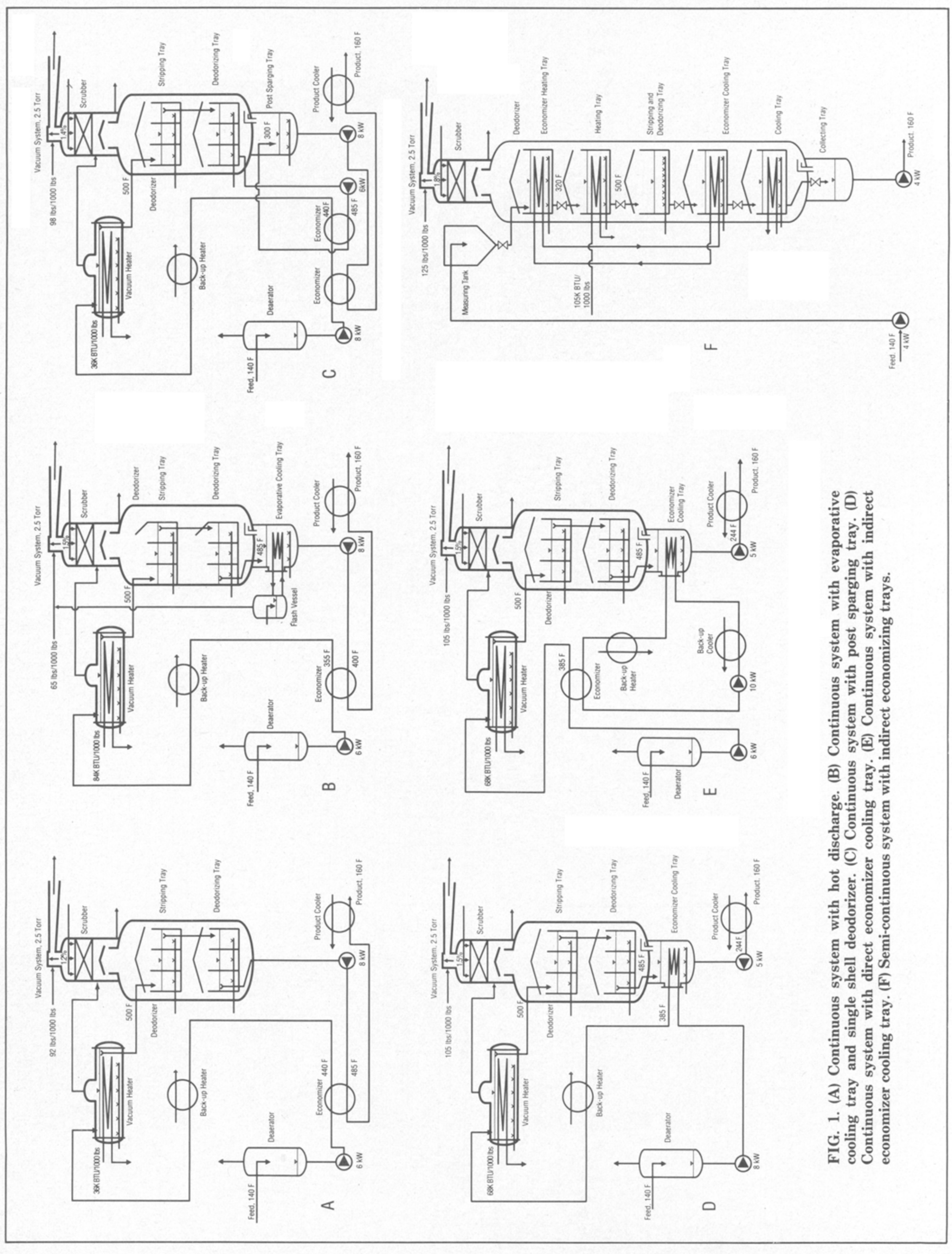

FIG. 1. (A) Continuous system with hot discharge. (B) Continuous system with evaporative cooling tray and single shell deodorizer. (C) Continuous system with post sparging tray. (D) Continuous system with direct economizer cooling tray. (E) Continuous system with indirect economizer cooling tray. (F) Semi-continuous system with indirect economizer cooling trays.

Pre-heating product under vaccum or pressure

Product heating can take place in pressurized external heat exchangers as partly done in most continuous systems or inside a sparged vacuum vessel as most often is done in semi-continuous systems. Besides the degree of heat recovery and the amount of residual oil associated with these practices, other aspects should be considered.

Generally, heat transfer surfaces operating at higher temperatures in steam-agitated (sparged) trays or vessels under vacuum have a more predictable and longer period of operation between scheduled cleaning breaks than external heat exchangers. This, at least, is the case when processing soybean oil, which has a tendency to precipitate polymerized materials when heated above 350 F, especially if the feedstock quality is poor or the upstream processing is inadequate.

The precipitated materials may stick to heating surfaces to restrict the flow or heating capacity. In a heated tray, this happens more slowly and does not present sudden production disturbances. On the other hand, cleaning and maintenance of heated trays inside a deodorizer usually take much more time and effort than cleaning external equipment. In most cases, heat exchangers can be cleaned in place by cleaning solutions. A stand-by unit then can be utilized to ensure uninterrupted production. Heat exchangers operating with seed oils at high temperatures, however, tend to require more frequent cleaning due to the narrow flow passages and lack of agitating steam. If not cleaned regularly, they also may clog rather suddenly and cause production problems. Some claim that fouling also may be more noticeable in the deodorizer itself since the product has not been as thoroughly deaerated as when it is under vacuum during the entire heating process.

A possible compromise for continuous systems with external economizers, therefore, is to deaerate the oil at 200–250 F before further heating and to do the final heating to process temperature under vacuum. This minimizes the risk of fouling in the heat exchangers and inside the deodorizer while maintaining high heat recovery and easier maintenance.

In connection with heating, an important difference in the processing temperature for soybean oil and similar oils should be noted. U.S. processors, for instance, commonly deodorize the oil at temperatures as high as 500 F. This enables up to 20% tocopherol in the recovered distillate and reduces the necessary deodorization time to as low as 15 minutes. Other processors prefer to leave more tocopherol, a natural antioxidant, in the oil and minimize the risk of unwanted high temperature-related chemical changes in the oil. Therefore, they deodorize the oil at temperatures between 440–465 F, which increases the necessary retention time and amount of stripping steam.

Pre-cooling product under vacuum or pressure

The heat recovery and cleaning and maintenance aspects mentioned for heating partly apply also to cooling conditions. The key issue in cooling, however, is the flavor of the product. Many oils, especially soybean oil, will develop an off-flavor when discharged at process temperature from the deodorizer. Traditionally, it has been considered necessary to cool the oil to 300 F under vacuum in a sparged vessel before discharge.

However, this is difficult and expensive if a high heat recovery is required. For this reason, the necessary degree of cooling should be more closely adjusted for various products. Among the most sensitive products are salad and cooking oils based on soybean oil. In these cases, the system should be designed to allow cooling to at least 400 F to ensure an acceptable flavor.

Several top-quality liquid oil brands in the U.S. market are based on soybean oils deodorized in this fashion, and they compete successfully with oils cooled to 300 F and lower. Other seed oils are not as sensitive and can be discharged at even higher temperatures. Hydrogenated products, palm and lauric-type oils and fats may not require cooling under vacuum at all, especially when they serve as shortening base stocks.

Heat recovery systems

Figures 1 and 2 show different systems for achieving

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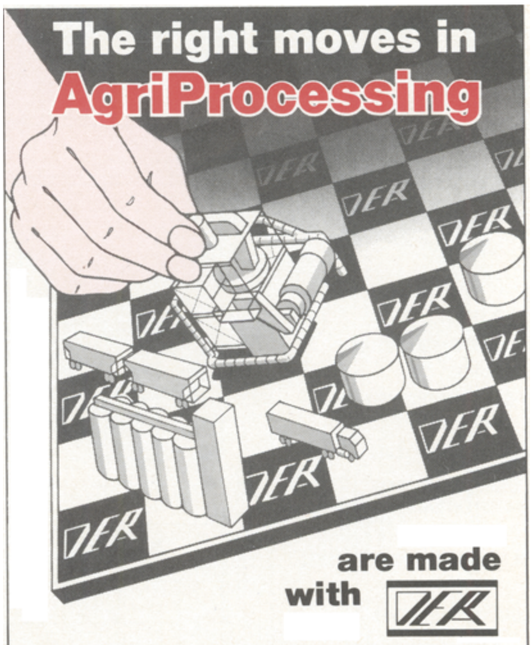

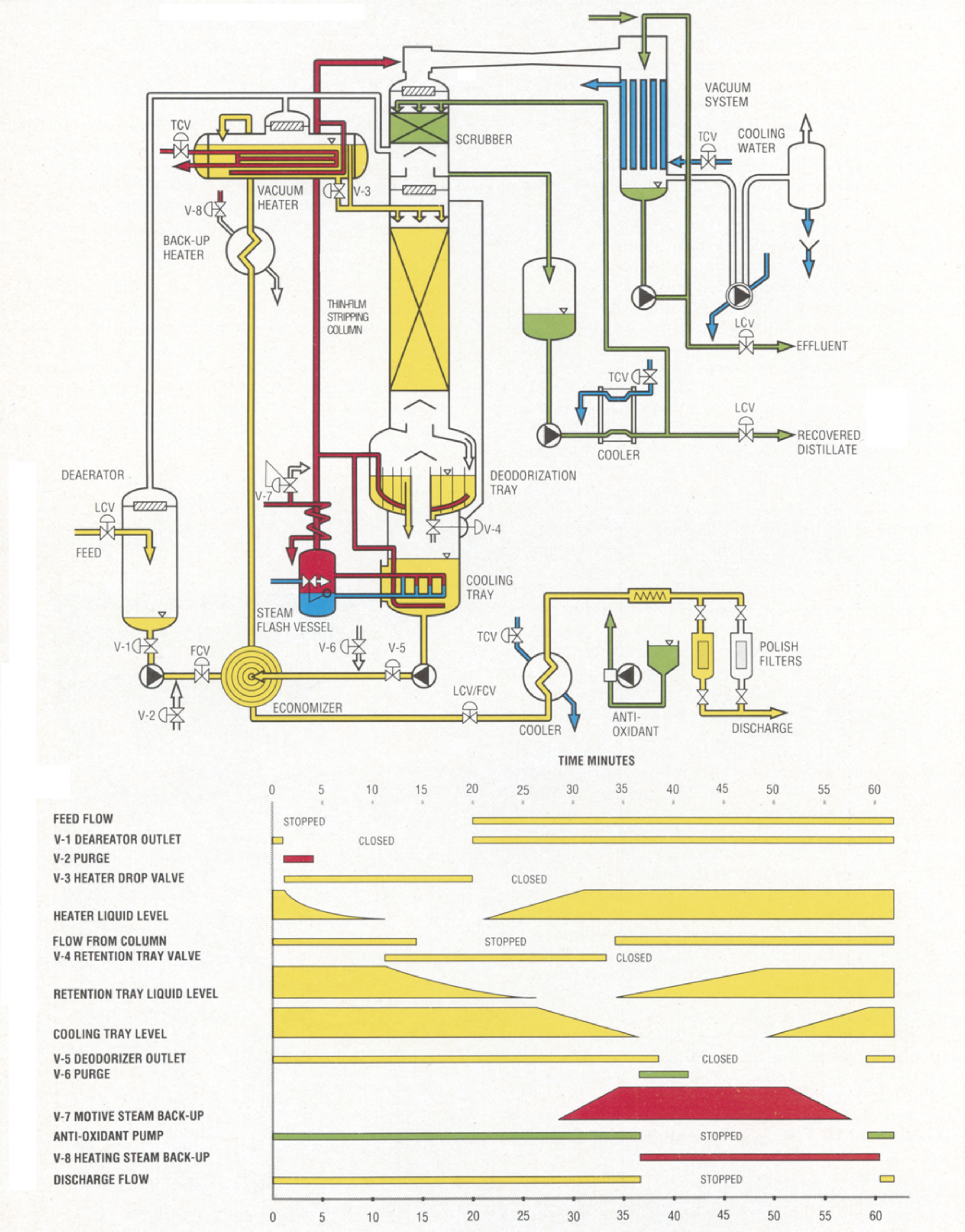

FIG. 2. Continuous thin-film deodorizing plant with evaporating cooling.

TABLE 1

Summary of Performance of Different Design Options in Deodorizing Systems (as illustrated in Fig. 1 and Fig. 2)

Note: K=1,000.

Item	1A	1B	1C	1D	1E	1F	2
Heat recovery (%)	80	58	80	67	67	46	58
Heating energy (BTUs/1000 lb)[a]	36 K	84 K	36 K	68 K	68 K	105 K	84 K
Steam generating energy (BTUs/1000 lb)[b]	117 K	72 K	125 K	134 K	134 K	154 K	0
Pumping energy (BTUs/1000 lb)[c]	1.6 K	1.6 K	2.5 K	1.5 K	2.4 K	0.9 K	0.3 K
Total energy (BTUs/1000 lb)	155 K	158 K	164 K	203 K	204 K	260 K	87 K
Deodorization time (min)[d]	20	20	20	20	20	15	15
Vacuum time above 400 F (min)[e]	30	36	30	32	32	30	35
Stock-change time (min)[f]	15	15	15	15	15	15	15
Drip time per tray (min)[g]	5	5	5	5	5	13	7
Residual product ext. (lb)[h]	361	310	474	291	175	33	310
Residual product int. (lb)[i]	156	236	163	318	318	273	1496
Total residual product (lb)[j]	517	546	167	609	493	306	1806
Vacuum discharge temp. (°F)	485	400	485/300	244	244	160	400

[a] Based on SBO sp.ht. 0.57–0.60.

[b] Based on vacuum & strip stream at 1,115 BTUs/lb.

[c] Based on 3,414 BTUs/kwh.

[d] At 485–500 F.

[e] While in sparged vacuum vessels.

[f] Feed interruption time (empty tray for "semi").

[g] After bulk of liquid has been drained.

[h] Piping, valves, heat exchangers and pumps.

[i] All vacuum vessels.

[j] Transferred from one stock to another.

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heat recovery in a deodorization plant and the effect each has on the energy consumption and residual oil in the system.

The designs are all based on a capacity of 30,000 pph, 2.5 Torr vacuum, 1.3%-1.8% stripping steam, final heating under vacuum for 15-20 minutes, deodorization time at 500 F and 30 minutes above 400 F, and a heat loss of about 15 F.

Such factors as process conditions and calculated heat recovery, energy consumption and product contamination are presented in Table 1. Many conclusions can be drawn from this table. However, it should be remembered that energy costs, feedstock quality, finished product quality requirements, labor costs and quality vary widely, especially when comparing systems operating in different countries. Consequently, the data should be considered only as a basis for discussion.

Double- or single-shell deodorizer

The first deodorizers were open iron tanks in which batches of oil were heated and agitated with steam. The tanks evolved into pressure vessels subjected to vacuum. Today's "batch" deodorizers used in small refineries or for specialty products have not changed much in basic design except for the choice of stainless materials of construction. These deodorizers can be referred to as single shell since the outside shell surfaces are exposed to atmosphere.

In semi-continuous and continuous deodorizers, it is common to "hang" multiple open trays inside a pressure shell and subject the entire assembly to an even vacuum. The main advantages of this are a lower risk of exposing the hot oil directly to air should a leak in the shell occur, lower heat losses or insulation requirements and the economics of constructing the trays of expensive high-grade stainless materials while making the shell of carbon steel.

The main disadvantage of the double-shell design is that it is difficult to observe, inspect and service the internals compared with a single-shell design. Also, when stainless is required for the shell as for high free fatty acid (FFA) feedstocks, the system will have a higher cost relative to a single-shell system.

Furthermore, modern insulation materials compensate for the higher surface temperature of the vessel. Today's improved welding techniques essentially eliminate the risk of oxidation leaks through a single shell, especially if all passages through the shell are located above the liquid level or are vacuum-insulated, as illustrated in Figure 2. The main advantage of the single-shell design is its serviceability. It is easy to mount sight glasses in strategic places to observe what is going on during start-up, operation and stock-changes. It also will be easier to see and decide when cleaning is required and to observe the results. Furthermore, single-shell deodorizers can be designed more economically to provide sufficient crawl space and elbow room for cleaning and maintenance.

A good compromise between the two designs, perhaps, is to house high-maintenance heating and cooling coils in single-shell containments while the basic deodorization takes place in a double-shell vessel. Some typical single and double shell designs are illustrated in Figures 1 and 2.

Stripping in thin-film columns or sparged trays

The theory of deodorization supports designs that provide uniform partial vapor pressure in the oil throughout the process. Thin-film technology has been successfully used in various process applications (for example, in the petroleum industry) for a very long time. In fats and oils deodorization, however, with the exception of a major refiner in the U.S., it was not until the mid-1980s that thin-film systems started to appear in force in full production plants. This happened in Southeast Asia, where there was a need for very large and energy-efficient plants for stripping and deodorizing palm and lauric-type oils.

Thin-film deodorization has the basic advantage of lowering energy requirements for driving the vacuum system. It also reduces the total retention time of the system. Compared with traditional cross-flow tray deodorizers (Fig. 1), the stripping (sparging) steam requirements in a thin-film system are less than half. Enthusiasm for this clear advantage, however, has been dampened by fears of polymerization and clogging problems, especially for seed oil processing. The "clogging risk" has been shown to be greatly exaggerated, as evidenced by the long, trouble-free operation of several commercial plants operating on seed oils. It is obvious that should a thin-film packed column be exposed to a substantial air leak at high temperatures while processing sensitive oils, severe polymerization and clogging could force complete shutdown and removal of the packing material, a not-so-pleasant thought for a busy refiner.

One drawback of a thin-film system is the higher amount of residual oil in stock-change when processing multiple feedstocks. Due to the large thin-film surface, the amount of residual oil in a 30,000 pph plant may be up to 1,800 pounds, or almost six times as much as in a traditional semi-continuous system.

Thin-film systems, thus, are more likely to become popular in larger refineries with few product changes. Figure 2 shows a typical thin-film system where the oil is precooled to 400 F by evaporating boiler condensate, which covers the total steam requirement for stripping and the vacuum system. The time chart shows a typical stock change procedure.

Vacuum systems

In many ways, a vacuum system truly is an integrated part of the deodorizing plant. For instance, this is the case in which indirect condensers are used to eliminate the build-up of fat in cooling towers and the associated odors carried over from the scrubber. One design for this is shown in Figure 2. The fat that precipitates on the cooling surfaces is continuously reacted and removed by a circulating caustic solution. A drawback of this system is a small increase in the motive steam consumption due to the higher relative cooling temperature.

One of the key elements when designing vacuum systems is the temperature of the cooling water. When higher than 86 F, for instance, it usually is necessary to use "double boosters" to economically reach 2.5 mm of mercury, a common suction pressure. It also becomes necessary to have special, lower temperature cooling water for mechanical vacuum pumps if these are to be used. Another aspect of the cooling water is the effect of seasonal changes in air temperature for cooling towers. By reducing the amount of booster motive steam when the temperature drops, it is possible to save considerable amounts on an annual basis.

In cases where low-cost electric power is available, it may be advantageous, based on overall energy consumption, to refrigerate the coolant, which then lowers the motive steam consumption accordingly.

Conclusions

The key factors in the design of a deodorization system are energy consumption, product quality, performance reliability and investment cost.

The relative importance of these varies greatly for different applications and locations. In practice, plant designs are a compromise between different design options, some of which have been discussed. When evaluating the overall performance of a working deodorizing plant, it often is apparent that the conditions governing the design of the plant have changed since it went into production.

Therefore, it is essential when planning a new project to evaluate design and process options in relation to utility costs, product quality and production demands that will govern the facility long-term.