RENDERING PLANTS

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Rendering plants process or "recycle" animal and poultry by-product materials in order to produce tallow, grease, and protein meals. The rendering industry is divided into two basic groups: integrated and independent. The integrated rendering plants are operated in conjunction with animal slaughterhouses or poultry processing plants. This type of plant is an integral part of the animal slaughterhouse or meat packing operation and processes all of the residual material from these operations. This also applies to those rendering plants that process the offal and feathers from poultry processing plants.

Independent rendering plants collect their raw materials from a variety of sources that are off-site or separate from the plant itself. These renderers send out special-body route trucks to collect discarded fat and bone trimmings, meat scraps, restaurant grease, blood, feathers, offal, and entire animal carcasses from a variety of sources: butcher shops, supermarkets, restaurants, fast-food chains, poultry processors, slaughterhouses, farms, ranches, feedlots, and animal shelters. Independent renderers collect raw materials primarily in metropolitan areas. However, a number of these renderers collect raw material from a variety of regional areas and require the use of a transfer station, which receives the collected material for further transport to a rendering plant.

Animal rendering systems are divided into two classes: edible rendering of animal fatty tissue into edible fats and proteins for human consumption, and inedible rendering of animal by-product materials into fats and proteins for animal feed and nonedible applications. Edible rendering plants are normally operated in conjunction with meat packing plants under the inspection and processing standards established by the U.S. Department of Agriculture, Food Safety and Inspection Service (USDA/FSIS). Edible tallow or lard is produced from beef or swine fatty tissue.

Inedible rendering plants are operated by independent renderers to produce inedible tallow and grease. These are used in the feed rations for livestock and poultry, for soap production, and for fatty-acid manufacture. A number of different grades of inedible tallow and grease are produced for these different categories of use. For example, "yellow grease" or feed-grade animal fat is produced from waste cooking fats received from restaurants and deep fat fryers. This product is used as an ingredient in animal and poultry feeds. Protein meal includes animal and poultry meals that are used as feed supplements for livestock and poultry. Rendering plants also produce blood meal and feather meal. These products usually have their protein content specified.

The meat packing industry during the past 15 years has converted its meat production facilities almost totally from an animal carcass to a "boxed beef and boxed pork" operation.[1] This has resulted in more fat and bone being trimmed at the slaughterhouse and less raw material being available to the independent renderer. Also, there has been a recent downward trend in tallow and grease prices.

During the past 10 years or more, the number of independent rendering plants has been reduced significantly. Currently, an estimated 150 independent rendering plants are operating in the United States.[2] This consolidation also applies to integrated rendering, with an estimated 75 meat packing plants and 25 poultry processing plants also including rendering operations.

PROCESS DESCRIPTION

Current edible and inedible rendering systems are described in detail by Prokop.[3] These include the batch cooker, Duke continuous and Stord waste heat dewatering systems for inedible rendering. The Sharples Trim-R process is described for edible rendering.

Edible Rendering

The current edible rendering process is continuous and consists of two stages of centrifugal separation. A typical feedstock of beef fat trimmings from USDA inspected meat processing plants consists of 14–16% fat, 60–64% moisture, and 22–24% protein solids.

The Sharples Trim-R Edible Fat Process is shown in Figure 1. Fat trimmings are ground through a Weiler grinder and belt conveyed to a melt tank equipped with an agitator and steam-heated jacket. The melted fatty tissue at 110°F is pumped to a Reitz disintegrator to rupture the fat cells. A Sharples Super-D-Canter Centrifuge separates the proteinaceous solids from the melted fat and moisture containing a small percentage of solids or fines.

A second-stage centrifuge is required to "polish" the edible fat, which is first heated to 200°F by a shell-and-tube heat exchanger with steam. The Westfalia De-Sludging Separator makes a two-phase separation where the polished edible fat discharges from the top and the water fraction containing the protein fines is discharged as sludge from the bottom. The edible fat is pumped to storage, whereas the sludge from the centrifuge is either transported to an inedible rendering plant or passed through a primary treatment system for wastewater.

Since no cooking vapors are emitted from current edible rendering processes and heat contact with the edible fat is minimal, odor emissions from these rendering plants are perceived as having little impact. This also is due to the freshness of the raw material being processed and the plant sanitation and housekeeping practices that have been established by the USDA/FSIS. As a result, the remainder of this section is devoted to inedible rendering processes and the control of their odor emissions.

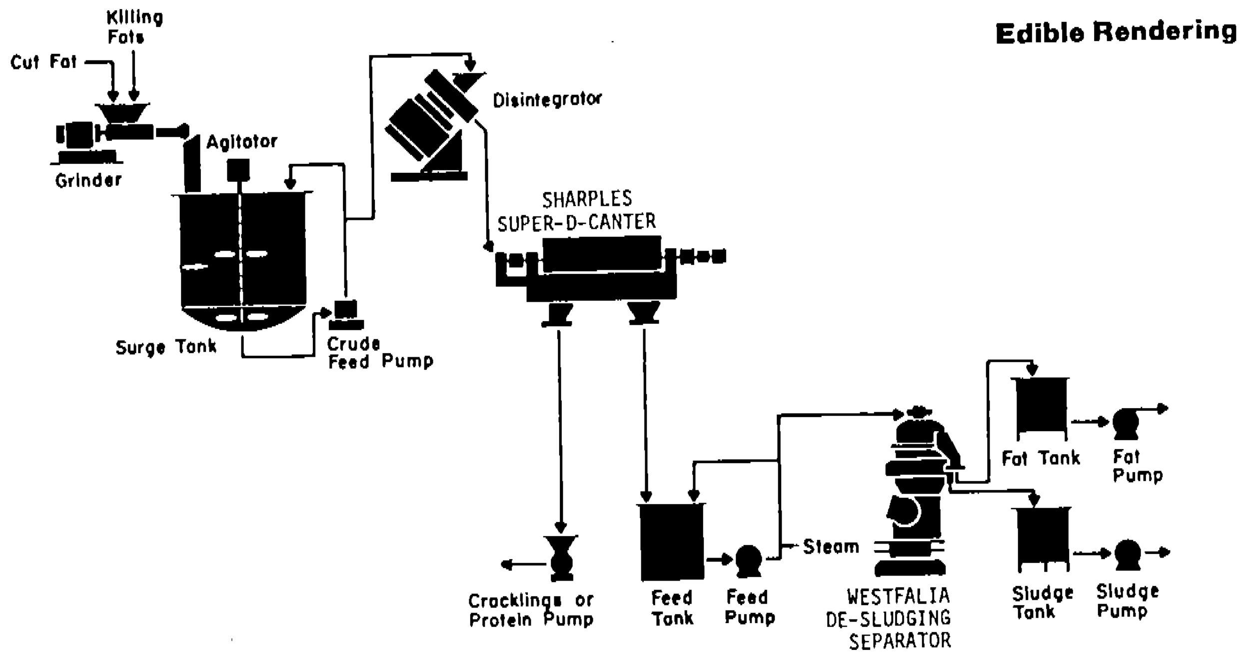

FIGURE 1. Edible Rendering System (From Reference 3)

Wet Rendering Versus Dry Rendering

Wet rendering is defined as a process of separating fat from raw material by boiling with water. This is normally accomplished by boiling the raw material in a tank of water. The products of wet rendering are fat, stick water containing glue, and wet tankage (protein solids). The wet rendering process involves the addition of water to the raw material and the use of live steam to cook the raw material and accomplish separation of the fat.

The wet rendering process no longer is used in the United States because of the high costs of energy and of an adverse effect on fat quality. The water added to the raw material must be evaporated, which increases fuel costs to generate additional steam for moisture removal. Also, contact of the fat with excess water under a boiling temperature tends to increase the free fatty acid content of the fat.

The wet rendering process has been exclusively replaced by dry rendering, which is defined as a process for releasing fat by dehydrating raw material in a batch or continuous cooker. After moisture removal in the cooker, the melted fat is separated from the protein solids. No excess water or live steam is added to the raw material in this process.

Raw Materials for Rendering

The integrated rendering plant for an animal slaughterhouse or poultry processor normally receives only one type of raw material. This simplifies the control of the processing conditions, which usually require only minor adjustments. Also, the raw material is relatively fresh, undergoing little or no noticeable deterioration. Conversely, the independent renderer often handles a variety of raw materials that require either the operation of multiple rendering systems in parallel or significant changes in the operating conditions for a single system to process variable raw material.

Table 1 provides specific raw-material yield data and the split between the fat and protein solids content of various categories of raw materials for inedible rendering.[1]

In comparing Table 1 with a similar table (Table 221) in the previous edition of this manual, we see that the fat content of steers and hogs has increased significantly as a result of improved breeding and the nutritional feeding of fat to livestock. However, the fat content of butcher shop fat and bone has decreased due to the production of "boxed beef/pork," since more of the available fat is trimmed at the packing house.

Basic Rendering Process—Batch Cooker System

Figure 2 from reference 3 illustrates the basic rendering process where batch cookers are used. These are multiple units arranged in a row or series of rows, depending on the size and arrangement of the rendering plant. Each cooker consists of a horizontal, steam-jacketed cylindrical vessel equipped with an agitator. This vessel is known as a batch cooker because it follows a repetitive cycle: the cooker is charged with the proper amount of raw material, the cook is made under controlled conditions, and, finally, the cooked material is discharged.

The raw material from the receiving bin is screw conveyed to a crusher or similar device for size reduction. For batch cookers, the raw material is reduced in size to 1 or 2 inches to provide efficient cooking, which normally re-

TABLE 1. Composition of Raw Materials for Inedible Rendering

Source	Tallow/Grease, Wt %	Protein Solids, Wt %	Moisture, Wt %
Packing house offal and bone			
Steers	30–35	15–20	45–55
Cows	10–20	20–30	50–70
Calves	10–15	15–20	65–75
Sheep	25–30	20–25	45–55
Hogs	25–30	10–15	55–65
Dead stock (whole animals)			
Cattle	12	25	63
Calves	10	22	68
Sheep	22	25	53
Hogs	30	28	42
Butcher shop fat and bone	31	32	37
Blood	None	16–18	82–84
Restaurant grease	65	10	25
Poultry offal	10	25	65
Poultry feathers	None	33	67

Source: Reference 1.

quires 1½ to 2½ hours. The raw material is quite variable, depending on the source, and adjustments in the cooking time and temperature may be required to process it. The final temperature of the cooked material ranges from 250°F to 275°F, depending on the type of raw material.

After the cooking process is completed, the cooked material is discharged to the percolator drain pan, which contains a perforated screen that allows the free-run fat to drain and be separated from the protein solids, which are known as "tankage." After one or two hours of drainage, the protein solids still contain about 25% fat and are conveyed to the screw press, which completes the separation of

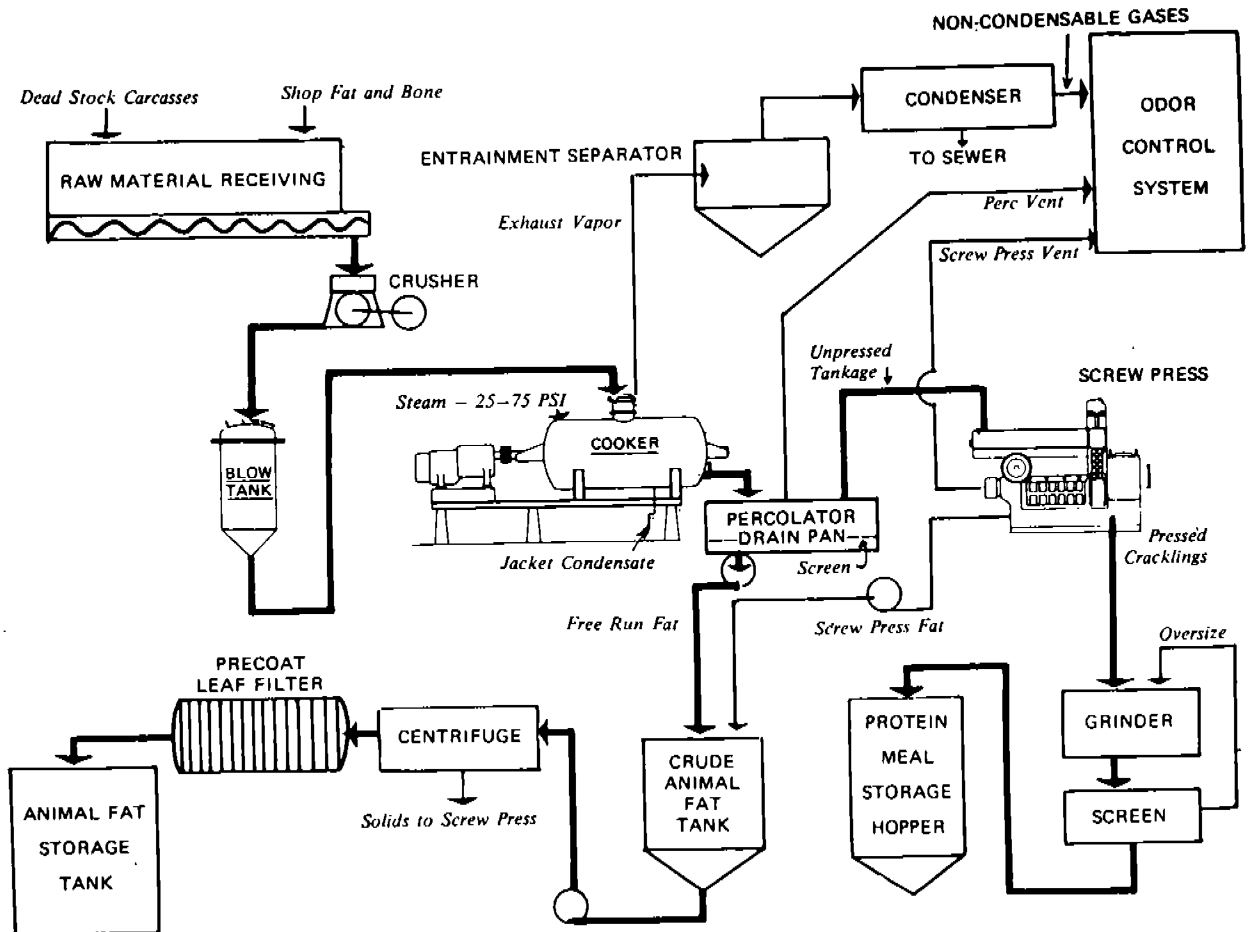

FIGURE 2. Batch Cooker Rendering Process

fat from solids. The final protein solids have a residual fat content of 10%.

The solid protein material discharged from the screw press is known as "cracklings." It is normally screened and ground with a hammer mill to produce protein meal that essentially passes a 12-mesh screen. The fat discharged from the screw press usually contains fine solid particles that are removed by either centrifuging or filtration.

Continuous Rendering Systems

Since the 1960s, a variety of continuous rendering systems have been installed to replace the batch cooker systems. Continuous rendering is synonymous with continuous cooking. The raw material is fed continuously to the cooker, and the cooked material is likewise discharged at a constant rate.

A continuous rendering system normally consists of a single continuous cooker, whereas the batch cooker system consists of multiple cooker units. A continuous system usually has a higher capacity than the batch cooker system it replaces. This increased capacity provides for more efficient processing of the raw material by processing more material in less time.

Continuous rendering also has a number of other inherent advantages over the batch system. Since a continuous process requires less cooking time or exposure to heat, improved product quality normally results. Further, the continuous system occupies considerably less space than a batch cooker system with equivalent capacity, thus saving building construction costs. Finally, a single-cooker unit is inherently more efficient than multiple-cooker units in terms of steam consumption and achieves a significant savings in fuel usage by the boilers. Likewise, less electric power is consumed for agitation in the single continuous cooker unit.

The Duke continuous rendering system is manufactured by the Dupps Co., Germantown, Ohio. This rendering system is shown in Figure 3.[3] The Duke system is designed to provide a method of cooker operation similar to that of the batch cooker. The Equacooker is a horizontal steam-jacketed cylindrical vessel equipped with a rotating shaft to which are attached paddles that lift and move the material horizontally through the cooker. Steam also is injected into the hollow shaft to provide increased heat transfer.

The feed rate to the Equacooker is controlled by adjusting the speed of the variable-speed drive for the feed screw, which establishes the production rate for the system. The discharge rate for the Equacooker is controlled by the speed at which the control wheel rotates. The control wheel contains buckets, similar to those used in a bucket elevator, that pick up the cooked material from the Equacooker and discharge it to the drainer.

The drainer performs the same function as the percolator drain pan in the batch cooker process. It is an enclosed screw conveyor that contains a section of perforated trough

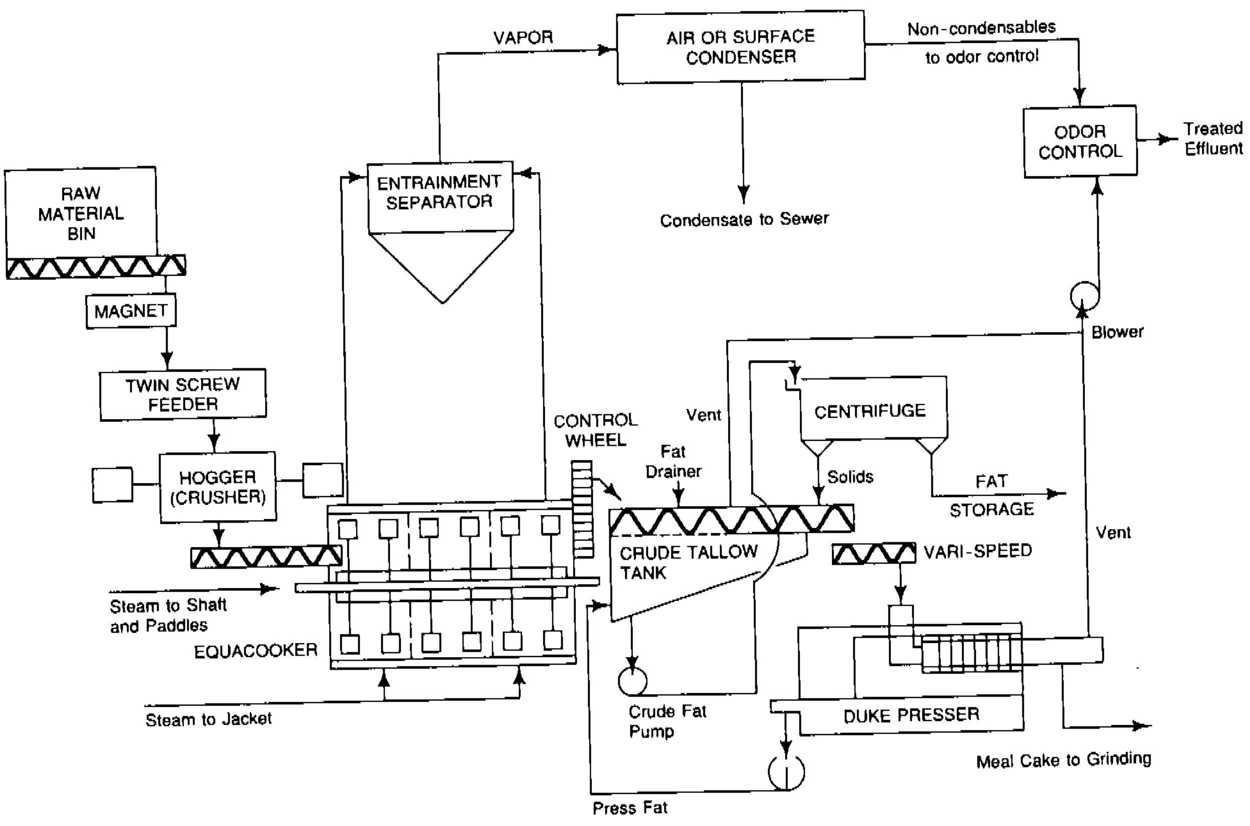

FIGURE 3. Duke Continuous Rendering System

for the free melted fat to drain through to the crude tallow tank. The protein solids containing residual fat are then conveyed to the pressers for the additional separation of fat. The pressers and other components of the Duke continuous system are similar to those used for the batch cooker system. A central control panel is provided for the operator to consolidate the instruments required for process control of these continuous systems.

New Continuous Systems with Reduced Energy Usage

During the early 1980s, considerable effort was spent on developing new rendering systems that utilize the cooking vapors from either a batch cooker system or a continuous rendering system to obtain further moisture removal. Most of this new rendering technology has evolved in Europe, where energy costs have been significantly higher than in the United States.

The Stord waste-heat dewatering (WHD) system, for example, is manufactured by Stord, Inc., in Bergen, Norway. It is illustrated by Figure 4 from reference 3. The Stord WHD system consists of a preheater, twin-screw press, and evaporating system. It usually is installed in conjunction with an existing rendering system.

In this system, raw material is screw conveyed as usual from the raw material bin over an electromagnet and fed to a prebreaker for coarse grinding. This ground material passes through the preheater, which is a horizontal, steam-jacketed, cylindrical vessel with a rotating shaft and agitator to move the material through the vessel continuously and to improve heat transfer. The temperature of the raw material in the preheater is controlled and ranges from 65°C to 85°C (150°F to 190°F), depending on the type of raw material

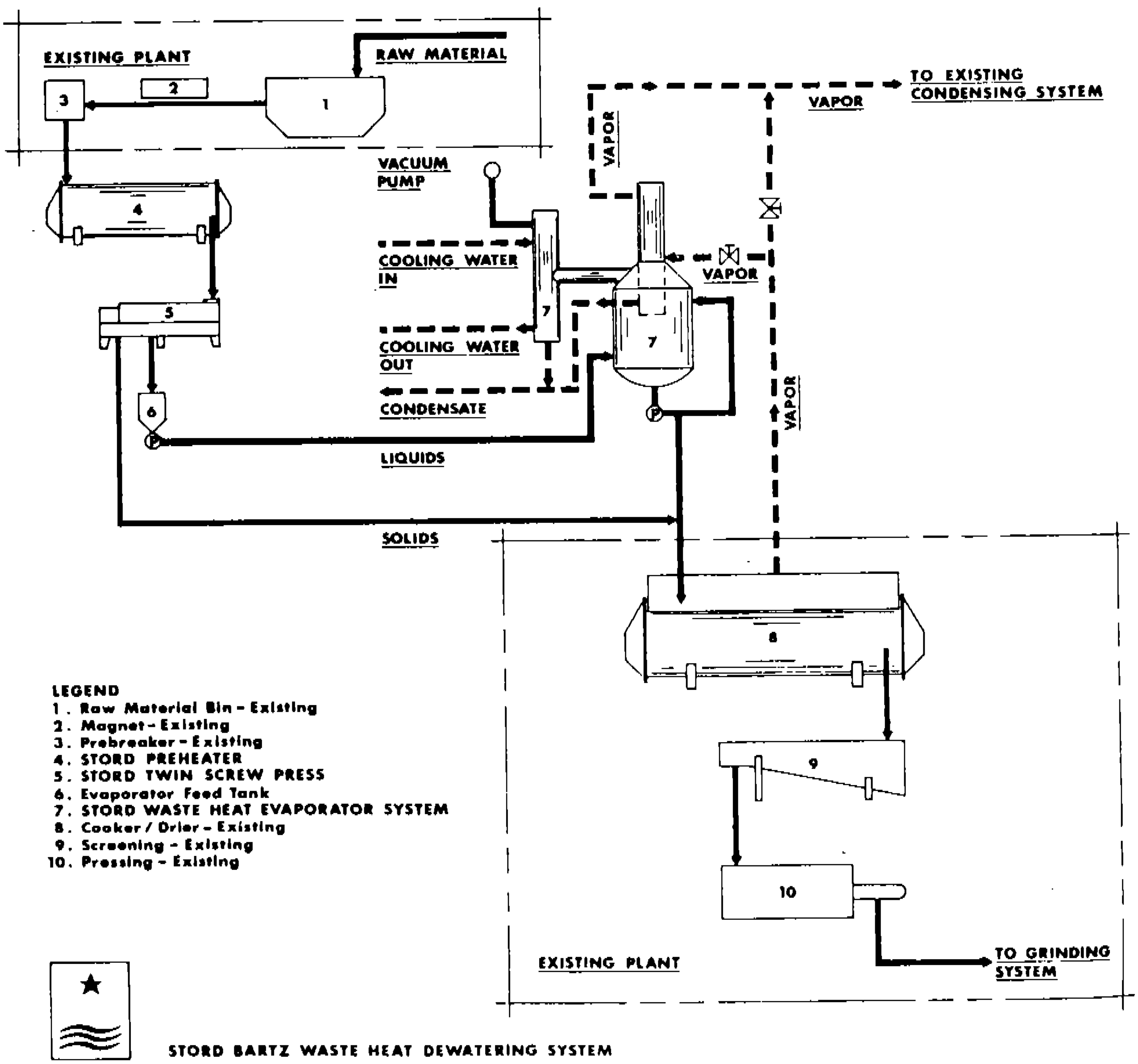

FIGURE 4. Stord Waste-Heat Dewatering System

being processed. This heating step is necessary to melt the fat and condition the animal fibrous tissue properly for the subsequent pressing operation.

The twin-screw press consists of intermeshing, counter-rotating, twin screws moving inside a press cage assembly. It includes a perforated screen through which the liquid is pressed and a series of vertical support plates to secure the perforated screen in place. The perforated screen with heavy backing plate is constructed to follow the contour of the rotating flights of the twin screws. The feed material fills the free space between the screws and the press cage. At the feed end, the twin screws are constructed with a lower-diameter shaft and deeper flights to provide a larger volume of space. As the press screws rotate, this space decreases and the material is subjected to a steadily increasing pressure to squeeze out the liquid through the perforated screen.

The twin-screw press separates the heated and ground raw material into two phases, a press cake of solids containing fat and moisture and a liquid containing mostly the melted fat and water. The solids are screw conveyed to the existing cooker or dryer, which is steam heated to remove the moisture. Final separation of the fat from the solids is completed with a screw press.

Liquid from the twin-screw press is pumped from the feed tank to the evaporator, which consists of a tubular heat exchanger mounted vertically and integrally with the vapor chamber. The vapors from the existing cooker or dryer provide the heating medium for evaporation. The liquid pumped to the evaporator enters at the top of the heat exchanger and flows by gravity downward through the tubes discharging into the vapor chamber, which is maintained under a vacuum of 24 to 26 in. Hg provided by a vacuum pump. The temperature of the liquid ranges from 70°C to 90°C (160°F to 200°F) at which point the moisture is evaporated. The water vapor from the vapor chamber is condensed with a shell-and-tube condenser through which cooling water is circulated.

The basic concept of the Stord WHD system is to use the waste heat in the vapors from the existing cooker to evaporate the moisture from the liquid removed by pressing the raw material, thus converting the existing plant into a two-stage evaporation system. It is essential to balance the operation of this system so that sufficient vapors are available from the existing cooker to evaporate the moisture from the pressed liquid. Operation of the preheater and twin-screw press requires adjustment for different types of raw material with varying moisture content in order to achieve proper balance of this system.

In addition to reducing fuel costs by 30–40%, the operation of the Stord WHD system, in conjunction with the existing cooker system, is capable of increasing production throughput by 75%.

These new systems[4] incorporate the use of microcomputer control concepts that are capable of performing essentially all start–stop sequences, monitoring specific process elements and recording process data to provide trend or deviation outputs. If a particular malfunction occurs, the control system automatically shuts down key operating elements that otherwise could cause serious damage or loss of production.

Blood Processing and Drying

Whole blood received from animal slaughterhouses contains 16–18% total protein solids. Of this amount, approximately 70% of the total protein is recovered as blood meal after steam coagulation and drying. The soluble protein fraction remains in the serum water.

In the past, batch cookers were used to coagulate and dry the blood. However, the dried blood becomes quite dusty and is easily entrained in the exit gases from the cooker. The batch cookers have been replaced by continuous drying processes that are more energy efficient and provide a product with improved quality. Blood meal is highly valued as an animal feed ingredient because of its relatively high lysine (amino acid) content. The continuous drying processes maintain the lysine content of blood nearly at the maximum available, whereas the batch process reduces this lysine availability by 30–50%.[5]

In the continuous blood process, whole blood passes through an inclined tubular vessel into which steam is injected to coagulate the blood solids. This slurry is pumped to a horizontal, solid bowl centrifuge, which separates the blood solids from the blood serum water. The blood solids at 50–55% moisture are fed into a continuous drying system: either a gas-fired, direct-contact ring dryer or steam tube, rotary dryer.

The Dupps Ring Dryer is manufactured by the Dupps Co. in Germantown, Ohio. The coagulated blood solids enter the dryer through a hammer-type mill and are air conveyed through the "ring" duct at a temperature of 200°F to the manifold. At this point, the moist product is separated from the dried product and is recirculated back to the ring duct for further drying. Heated air at 600°F from the direct-fired furnace passes through the hammer mill and provides the heat necessary to dry the moist product. This heated air consists of 60% recycled exhaust air and 40% makeup air. The dried product is separated from the exhaust air by twin cyclone collectors with rotary valves. The exhaust air normally passes through a venturi scrubber and packed tower scrubber in series before discharging to atmosphere. This dryer is furnished in four different models with varying evaporative capacities, ranging from 1000 to 4000 pounds of water evaporated per hour.

The Anderson 72 Tube Rotary Steam Dryer is manufactured by Anderson International Corp. in Cleveland, Ohio. The moist feed material cascades over the rotating, steam-heated tubes. Fresh air passes through the dryer across the steam-heated tubes and exits from the dryer with the moisture released from the solids. The 72-tube unit is the only model available and has an evaporative capacity estimated to be 650 pounds of water evaporated per hour.

Poultry Feathers and Hog Hair Processing and Drying

The feathers and hog hair consist mostly of keratin, which is a long-chain, highly cross-linked, relatively indigestible protein. The rendering process converts the keratin by chemical hydrolysis, combining with water at elevated temperatures (280–300°F), into shorter-chain, more digestible amino acids. This hydrolyzation is accomplished by processing the feathers or hair in a batch cooker with an internal cooker pressure of 40–50 psig maintained for 30 to 45 minutes. The moisture content after hydrolyzation is approximately 50%. The feather hydrolysis process is discussed,[6] including the effect of the processing conditions on the quality of the feather meal product. The feathers or hair may be dried in the batch cooker. However, the drying operation normally is conducted with either the Dupps Ring Dryer or Anderson Rotary Steam Tube Dryer, both of which were described under "Blood Processing and Drying."

Grease Processing

The recent growth of the restaurant business, and of fast-food chains in particular, has made the recycling of restaurant grease an important part of the rendering industry. In the past, 55-gallon drums of grease were picked up at restaurants and unloaded manually by plant employees for processing at the grease plant. Currently, much of this grease is bulk loaded into specially designed and constructed vehicles, which transport and discharge it directly to the grease processing system without any manual labor.

The melted grease is screened to remove coarse solids, then heated to 200°F in vertical processing tanks, and stored for 36–48 hours to separate the grease from the water and fine solids by gravity. Four phases of separation normally occur: (1) solids, (2) water, (3) emulsion layer, and (4) grease product. The solids settle to the bottom of the processing tank and are separated from the water layer above. The emulsion is processed through two stages of centrifuges: a horizontal, solid bowl type to remove solids and a vertical disk type to remove water and fines. The grease product is skimmed off the top. No air is introduced into the processing tanks for "blowing" or drying of the grease.

AIR EMISSIONS CHARACTERIZATION

Odor is the primary air pollutant emitted from the rendering process. There is a potential dust problem in a few instances, such as the exhaust from the Dupps Ring Dryer when processing blood or feathers. However, the provision of proper control equipment, such as cyclones and venturi scrubbers, is normally adequate to abate this type of emission.

Points of Emission

For the batch cooker rendering process, the primary sources of high intensity odors include the noncondensibles from the cooker exhaust and emissions from the screw press, since the material in both cases is heated to temperatures of about 220°F. The processing of blood or poultry feathers normally results in high odor levels. Other sources of high intensity odors include dryers, centrifuges, tallow processing tanks, and the perc pans that are open to the plant atmosphere and receive the discharge from the batch cookers. The hot, cooked material from the batch cooker not only releases odor, but also fat particles, which tend to become airborne and are deposited on equipment and building surfaces within the plant.

The raw material is another source of odor, but it normally is not significant when processed without delay.

TABLE 2. Odor Concentration of Emissions from Inedible Batch Cookers during Discharge to Perc Pan

Type of Raw Material Cooked	Emission During Cooker Discharge odor units/cf[a]	Emission Five Minutes After Discharge odor units/cf[a]
Poultry feathers	200	20
Poultry and turkey offal	2,000	500
Slaughterhouse viscera and bones	150	150
Fresh meat and bone trimmings from beef slaughterhouse	100	70
Meat & bone trimmings with	25,000	3,000
high percent rancid restaurant grease	40,000	200
Mixture of dead cats and dogs, fish scrap, poultry offal, etc.	1,000	1,500

[a]Odor units per cubic foot by ASTM syringe method.

Source: Reference 7.

However, the age of the raw material is important because older material that has deteriorated will result in substantially higher odors being generated during the cooking and pressing operations. Also, the type of raw material being cooked is a significant factor. For example, dead stock will tend to result in the emission of higher-intensity odors during the rendering process.

Table 2 illustrates the effect of raw material on the odor emission from an inedible batch cooker when discharged to the perc pan.[7]

An important trend during the 1970s and 1980s involved the replacement of batch cooker systems with continuous rendering systems that are essentially enclosed and are capable of confining the odors and fat aerosol particles within the equipment. By providing proper equipment seals and locating suction pickup vents at strategic points, a major percentage of the odor generated from the continuous rendering process can be confined and treated by a low-volume scrubber system or by boiler incineration.

Odor control measures have been applied successfully to the Duke continuous rendering system because of its ability to confine the process odors within the system. Recent innovations in rendering equipment technology have resulted in the replacement of screw conveyors delivering raw material to and cooked material from the Equacooker with specially designed pumping systems. This has provided a better seal at the Equacooker, preventing the leakage of high-intensity odors into the plant operating area.

The primary sources of high-intensity odors from the Duke continuous process are similar to those for batch cooker systems: the cooker exhaust noncondensibles and the press vents. In the past, only these two odor emissions from a Duke system were normally vented to an afterburner to incinerate them. However, experience has proven that additional pickup vents are required at the drainer and at the centrifuge to prevent leakage of high-intensity odor to the plant atmosphere. Depending on the leakage occurring at the feed end of the Equacooker, an odor pickup may be located at the inlet chute.

The degree of tightness of an enclosure at each pickup point is an important factor to consider in designing an exhaust duct system. A definite but regulated excess of air is needed at each pickup point to minimize leakage of odor from the rendering process. Often in the past, the exhaust system for an afterburner was undersized because it was desired to incinerate the least volume of air and so minimize fuel costs. A damper is provided at each pickup point to adjust and maintain each flow at the desired rate and also to balance the exhaust duct system.

Composition of Rendering Odors

Odor emissions from rendering plants are relatively complex mixtures of organic compounds. Samples of rendering plant odors have been analyzed by a combination of gas chromatograph and mass spectrometric methods. A total of 30 or more odorous compounds were identified.[8]

Further research work identified the odorous compounds present in rendering plant emissions. Improved analytical techniques provided a more complete list of components. The major compounds included organic sulfides, disulfides, C-4 to C-7 aldehydes, trimethylamine, and various C-4 amines, quinoline, dimethyl pyrazine and other pyrazines, C-3 to C-6 organic acids. Compounds of lesser significance included C-4 to C-7 alcohols, ketones, aliphatic hydrocarbons and aromatic compounds. Odor panel tests were also conducted to relate odor intensity with the various important peaks identified by gas chromatography.[9]

Table 3 lists odor-detection and recognition threshold values for certain odorous compounds known to be present in emissions from rendering plants. Some of the compounds have extremely low odor threshold values and can be detected at concentrations as low as 1 ppb or less.

Odor Emission Data

It is essential that accurate odor emission data be available in order to design an odor control system that successfully abates the emission. If such data are not available, it may be necessary to conduct appropriate odor sensory measurements and obtain accurate gas-flow data. In this section, odor dilution to threshold values are provided for various high-intensity odor emissions from the rendering processes, together with their corresponding volumetric emission rates expressed in cubic feet per minute.

Odor emissions from batch rendering cookers are discussed in detail.[7] In a batch cooker, the rate of moisture removal rises initially, reaching a peak usually within one hour, then decreases rapidly until the end of the cooking cycle. The cooking time for a batch cycle normally ranges from 1½ to 2½ hours, depending on the initial moisture content and type of raw material being processed.

The average steam rate during the batch cooking cycle will normally vary from 450 to 900 ft^3/min. Shell-and-tube condensers through which cooling water is circulated or air-cooled, finned-tube condensers are used to condense the steam vapors and cool the condensate to normally below 120°F. The batch cooker noncondensibles range in odor intensity from 5000 to 1 million odor units/standard cubic feet by the ASTM syringe method, depending on the age and type of raw material. The volumetric emission rate of the noncondensibles may vary from 25 to 75 ft^3/min, depending on the tightness of the batch cooker top cover/discharge door openings and shaft seals.

Table 4 shows odor sensory data obtained[13] during a batch cooker cycle, with polyethylene bag samples being collected at half-hour intervals during the cook cycle. These samples were evaluated using the IITRI dynamic olfactometer. Readings were also obtained with an instrument measuring the concentration of total organic compounds (as methane) in parts per million.

TABLE 3. Odorous Compounds in Rendering Plant Emissions

Compound Name	Formula	Molecular Weight	Detection[a] Threshold (ppm, v/v)	Recognition Threshold (ppm, v/v)
Acetaldehyde	CH_3CHO	44	0.067	0.21
Ammonia	NH_3	17	17	37
Butyric acid	C_3H_7COOH	88	0.0005	0.001
Dimethyl amine	$(CH_3)_2NH$	45	0.34	—
Dimethyl sulfide	$(CH_3)_2S$	62	0.001	0.001
Dimethyl disulfide	CH_3SSCH_3	94	0.008	0.008
Ethyl amine	$C_2H_5NH_2$	45	0.27	1.7
Ethyl mercaptan	C_2H_5SH	62	0.0003	0.001
Hydrogen sulfide	H_2S	34	0.0005	0.0047
Indole	$C_6H_4(CH)_2NH$	117	0.0001	—
Methyl amine	CH_3NH_2	31	4.7	—
Methyl mercaptan	CH_3SH	48	0.0005	0.0010
Skatole	C_9H_9N	131	0.001	0.050
Trimethyl amine	$(CH_3)_3N$	59	0.0004	—

Source: References 7, 10, 11, and 12.

TABLE 4. Batch Cooker Noncondensible Odor Emissions

Cook Cycle, hours	Cooker Temperature, °F	Total Organics, ppm	Odor Dilution[a] to Threshold
¼	150		
½	220	180	40,000
1	245	1,000	45,000
1½	245	700	97,000
2	245	400	75,000
2½	245	260	93,000
3	245	200	127,000

[a]IITRI dynamic olfactometer

Source: Reference 13.

Another series of six samples were taken simultaneously on a different day approximately three hours after the batch cooker cycle began. The cooker temperature was recorded at 265°F and the noncondensibles temperature at 90°F, and the total organics varied from 230 to 330 ppm during the sampling. The odor dilution to threshold values (IITRI dynamic olfactometer) varied from 184,000 to 276,000. The batch rendering plant was known to process raw material such as dead stock, which emits unusually high-intensity odors during the cooking process.

The steam vapor emission rate from continuous rendering processes is relatively constant and can be calculated for a specific moisture content and tonnage rate of raw material being processed. The capacity of cookers and dryers usually is expressed in terms of evaporative capacity as pounds of water evaporated. For example, the Series 1800 Duke Equacooker with regular shaft has a rated evaporative capacity of 12,000 pounds of water evaporated per hour based on a steam pressure of 100 psig.

During the past five years, a number of Duke Series 1800 continuous systems have been evaluated to quantify the high-intensity odors emitted from the process. These emissions include the noncondensibles from the Equacooker, the drainer, centrifuge, and other sources of odor. Samples were taken of the noncondensibles alone and also of the total odor emissions from the Duke system or other rendering plant operations. All samples were taken during the late spring or summer months and were evaluated using the IITRI dynamic olfactometer. Also, these evaluations were conducted with varying types of raw material, including that from beef slaughterhouse, shop fat and bone, and restaurant grease and fish. Table 5 from reference 14 summarizes the data, which include the volumetric emission rates.

There has been a tendency in the past to have inadequate odor pickup flow rates for certain emissions from Duke continuous systems. Table 6 provides a guide for establishing the volumetric rate of pickup for various odor emissions from a Series 1800 Duke continuous system. These should not be considered as rigid requirements, but instead as guidelines.

No odor sensory data are available for the new con-

TABLE 5. Odor Emissions From Continuous Rendering Processes

Plant	Category of Renderer and Material	Rendering Process and Type of Emission	Odor Dilution[a] to Threshold	Emission Rate ft³/min
A	Integrated beef slaughterhouse	Duke—noncond.	20,000–50,000	450
		Duke—total[b]	39,100–43,200	1,500
		Blood ring dryer[c]	300– 1,000	2,000
B	Independent beef slaughterhouse and restaurant grease	Duke—noncond.	24,400– 62,700	—
		Duke—total[d]	56,000–138,000	—
B	Shop fat and bone	Duke—noncond.	11,000– 16,000	665
		Duke—total[d]	7,600– 13,200	1,200
C	Independent beef slaughterhouse and restaurant grease	Duke—noncond.	36,100– 39,800	800
		Duke—total[e]	21,600– 73,700	1,700
D	Independent herring (fish)	Duke—noncond.	39,500	600
		Duke—total[f]	23,800	2,600
D	Meat scraps and beef slaughterhouse	Duke—noncond.	59,400–93,800	600
		Duke—total[f]	28,100–59,200	2,600

[a]IIRTI dynamic olfactometer
[b]Includes noncondensibles, two presses, drainer, centrifuge, and blood coagulator and centrifuge. Tests conducted in mid-April in Texas.
[c]Venturi scrubber discharge after dryer exhaust.
[d]Both tests include noncondensibles, presses, drainer, and centrifuge. First test conducted during late July and second test conducted during late September in New England.
[e]Includes two presses, two tallow tanks, two centrifuges, drainer, and grease vapor noncondensibles. Test conducted in mid-August in New York.
[f]Includes two presses, centrifuge, drainer, meal product conveyor, and storage bins. Tests conducted in late May on West Coast.

Source: Reference 14.

tinuous systems with reduced energy usage. However, it has been observed in these plants that the odor emissions from the rendering process are definitely lower in intensity. This no doubt can be attributed to the lower processing temperatures that are used, particularly in the evaporator where the liquid from the twin-screw press is under vacuum for moisture removal.

AIR POLLUTION CONTROL MEASURES

Rendering plant operation and maintenance considerations are of basic importance in developing odor control measures to abate plant emissions. Raw material received at the plant should be processed with a minimum of delay. Cooking and pressing operations should be conducted to prevent overheating and burning of the processed material. As an example, a Duke Equacooker normally operated at a temperature of 270°F experienced a process upset, causing an increase to 320°F. This resulted in a corresponding increase from 14,000 to 102,000 odor units per standard cubic foot (ASTM syringe method).[15]

Start-up and shutdown operating procedures should ensure that all odor control equipment is operating properly while any raw material is being processed through the rendering system. Process equipment leaks to the floor or to the plant atmosphere should be corrected in a timely manner. Daily plant cleanup should normally follow shutdown of the rendering plant. Sanitation practices are crucial. A substantial amount of odor may be generated from within a plant building whose walls and ceiling have become permeated with fat aerosol odor emissions.

The basic purpose of providing odor control in a rendering plant is to reduce the odor emissions from the plant to a level that will result in the surrounding ambient air *not* containing odors that are a source of valid nuisance complaints. In designing a new control system or revising an old one, each individual plant situation must be evaluated separately based on a variety of factors, including proximity of neighbors to the plant, categories of neighbors present,

TABLE 6. Suggested Odor Pickup Flow Rates for Duke Process Emissions

Category of Odor Emission Pickup	Duct ϕ, inches	Flow Rate ft³/min
Equacooker inlet chute (if not sealed)	6	500
Equacooker noncondensibles	6	500
Drainer section	6	500
Equacooker unloading Elevator	4	250
Duke presser (10-inch or 12-inch)	6	500
Centrifuge (24 inches × 60 or 24 inches × 38 inches)	4	250
Tallow processing tank	4	250

surrounding topography, prevailing winds, plant building features, ability of rendering process to confine odors, residual plant odors, type of raw material, and seasonal climatic conditions.

The fundamental question often to be resolved is whether to treat the high-intensity odors only or also to treat a large volume of air that would be used to ventilate the operating area within the plant. A decision to treat only the high-intensity odors is usually predicated on the ability of the rendering process to confine these odors within the equipment. As discussed before, continuous rendering systems usually have this capability. Boiler incineration or multistage, low-volume scrubbing of the high-intensity odors is particularly compatible with this type of system.

Boiler Incineration of Process Odors

The installation and operation of afterburners or incinerators solely for pollution control is relatively uncommon due to the capital investment and fuel costs required. Currently, boiler incineration of the high-tensity process odors is a regular practice throughout the United States since all rendering plants require the generation of steam for the cooking and drying processes.

Two basic choices are available for the odorous air to be introduced into the boiler: primary combustion air (that mixed with fuel before ignition) or secondary combustion air (that mixed with the burner flame to complete combustion). The following factors should be considered for boiler incineration of high intensity odors.

1. The volume of odorous air to be handled should be minimized. Ensure that odor pickup points in the rendering process are not pulling excessive quantities of air.
2. Maximum fuel economy is achieved by using the odorous stream as primary combustion air, whereas its use as secondary combustion air probably requires additional fuel. When used as primary combustion air, particular care must be taken to see that the air stream is essentially free of moisture and particulate, which can interfere with the operation of the burner and controls.
3. Cooker noncondensibles can be successfully used as primary combustion air for incineration, provided that proper precautions are taken to "clean" it up. This is accomplished with a combination scrubber and entrainment separator of proper design. A water spray is provided to cool the odorous air and condense out the moisture. Likewise, the solid and fat aerosol particles should be removed.
4. Any high-intensity odors used as secondary combustion air should also be "cleaned up" in a manner similar to that described. When used as secondary combustion air, it is essential that the odorous stream come into intimate contact with the burner flame to accomplish efficient odor removal by incineration. Merely ducting the odorous air to the firebox without achieving contact with the flame may result in unsatisfactory odor removal.
5. The boiler size and burner capacity should be compatible with the amount of odorous air to be incinerated. If multiple boilers are used, the odorous air can be split among the various boilers or a smaller single unit can be used to incinerate the odors. The boiler should be equipped with suitable burner controls to ensure that the minimum firing rate is sufficient to incinerate the volume of odorous air passing through the firebox, regardless of the steam demand. A temperature of 1200°F or more is usually obtained in the firebox at the minimum firing rate. The residence time in the boiler firebox at maximum fuel rate is normally more than one second.
6. If an existing boiler is to be used, a thorough analysis should be made to establish that the combustion, control and safety requirements are satisfied for incinerating odors. The boiler manufacturer should be consulted regarding any details to modify the unit. Likewise, the insurance company should be contacted to receive their approval of any such revisions.

Figure 5 illustrates the boiler incineration of process odors used as primary combustion air. A two-stage spray scrubber with tangential inlet and entrainment separator is shown.

Previously, Table 5 summarized odor emission data for high-intensity odors from the Duke continuous process for Plants B, C, and D. Table 7 illustrates the odor removal efficiency achieved by boiler incineration for these same plants. The odor dilution to threshold values shown in this table were obtained with the IITRI dynamic olfactometer.

These results clearly show that boiler incineration is a very efficient method of odor control for treating the high-intensity odors from the rendering process. Two different incineration conditions are shown for Plant B to illustrate the higher stack exhaust odor levels resulting from the use of high-sulfur No. 6 fuel (2% sulfur) oil compared with those for natural gas. A strong, pungent, sulfur dioxide smell was observed in the exhaust stack emission. When natural gas or low-sulfur fuel oil is used as boiler fuel, the odor character of the stack exhaust is that of combustion gases only. In both cases, a rendering odor was not detected.

Wet Scrubbing of Process Odors

Multistage scrubber systems for treating the high-intensity odors provide an alternative to boiler incineration when the latter approach may not be feasible because of the boiler plant's being remotely located or for other reasons. These multistage systems have been successfully applied to rendering plant emissions since the early 1970s.

An evaluation[9] was made of various scrubbing agents to determine their comparative effectiveness to absorb and

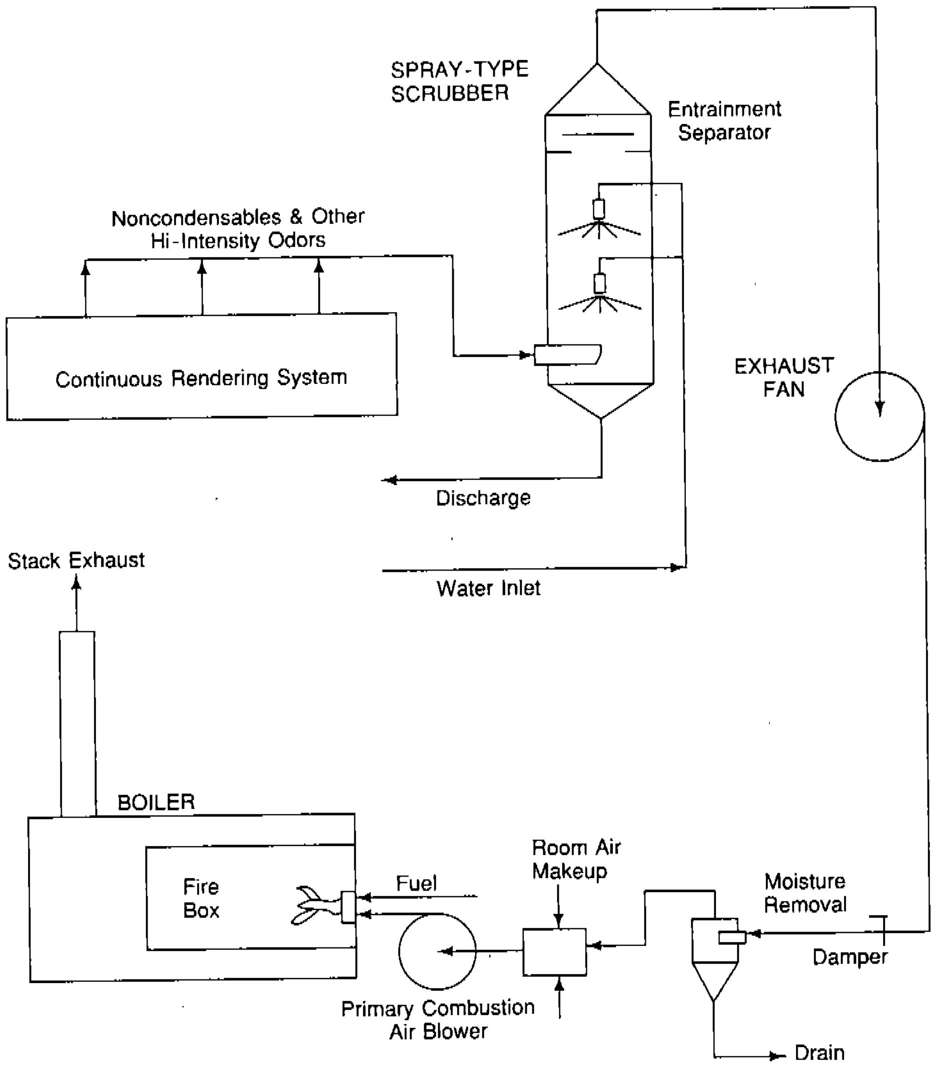

FIGURE 5. Boiler Incineration of Rendering Process Odors

neutralize selected odorous compounds in an experimental packed column. These odorous compounds were synthetically generated in the laboratory. Their selection included two sulfides, two amines, an organic acid, a ketone, an aldehyde, and an alcohol. Included among the various chemicals studied as scrubbing agents were water, soda ash, caustic soda, hydrochloric acid, sodium bisulfite, hydrogen peroxide, potassium permanganate, and sodium hypochlorite. The chemical oxidizing agents were found to be the most effective. From an overall viewpoint of treating a variety of odorants present in rendering plant emissions, sodium hypochlorite was considered to be the most effective agent.

Sodium hypochlorite or the addition of chlorine gas to a

TABLE 7. Boiler Incineration of Rendering Process Odors

Plant	Fuel Used	Fire Box Temperature, °F	Odor Dilution to Threshold Values[a] Boiler Inlet	Odor Dilution to Threshold Values[a] Stack Exhaust	Odor Removal %
B	No. 6 oil	—	56,000–138,000	234–650	99.5
B	Natural gas	—	7,600– 13,200	88–128	99.0
C	No. 6 oil	1,400	21,600– 73,000	76–157	99.6
D	Natural gas	1,250	28,100– 59,200	202–356	99.3

[a]IITRI dynamic olfactometer

Source: Reference 14.

caustic soda solution has been used since the early 1970s. More recently, chlorine dioxide generated on-site by the addition of chlorine gas to sodium chlorite solution has been used in a number of these scrubber systems. Chlorine dioxide is known to have a higher oxidizing potential than sodium hypochlorite.[16]

It is important to establish the design and operational criteria for a wet scrubbing system that uses a chemical oxidant solution, not only to obtain effective odor control, but also to achieve practical operation that is economical. This subject is discussed by Lundgren and others.[17]

The chemical oxidant solutions used in wet scrubbers normally are recirculated to conserve water and minimize chemical and wastewater treatment costs. The concept of balancing the oxidant chemical addition rate with the chemical use rate is important to achieve optimum usage and minimum cost. It is advisable to treat gas streams containing solid and fat aerosol particles with a preconditioning device, such as a low- to medium-pressure-drop venturi scrubber, to remove this particulate before passing to the chemical scrubber. Since the mass of the particulate matter suspended in the gas stream may exceed significantly that of the gaseous odor components, the rate of chemical oxidant consumption could rise quickly because the presence of the particles in the recirculating solution will tend to use up most of the oxidizing agent.

A two-stage scrubber system consisting of a venturi and a packed tower is described by Prokop.[18] This scrubber system treats high-intensity odors, including those from the screw press vents, blood dryer exhaust, raw feather receiving, feather noncondensibles, feather cooker discharge, and feather dryer exhaust. The scrubber system capacity is 32,000 ft^3/min. The scrubbing solutions consist of water circulating through the venturi at 110 gpm and sodium hypochlorite solution circulating through the packed tower at 350 gpm. Chemical consumption consists of 2 gph of 12% NaOCl solution.

A three-stage scrubber system consisting of a venturi and two packed towers in series is described by Prokop.[15] This scrubber system treats high-intensity odors, including those from the Equacooker noncondensibles, drainer, presser vents, centrifuge, and the steaming of grease barrels. The scrubber system capacity is 7500 ft^3/min. The scrubbing solutions consist of a weak solution of trisodium phosphate for circulation through the venturi at 22 gpm, a solution of phosphoric acid at 2–3 pH and recirculated through the first packed tower at 80 gpm, and a sodium hypochlorite solution at 10 pH and recirculated through the second packed tower at 80 gpm. The NaOCl solution is generated by an electrolytic cell from sodium chloride. The NaOH solution is added to control the pH of the NaOCl solution.

Figure 6 illustrates the operation of this multistage scrubber system. The high-intensity odors enter the throat of the low-energy venturi scrubber, which removes the particulate matter and cools and saturates the air with water vapor. A demister removes entrained droplets from the air before it passes upward through the first-stage counterflow packed-bed scrubber. Acid solution is recirculated through this stage to remove the amine-type odors and NaOCl solution is recirculated throughout the second stage to remove the sulfide-type odors.

Table 8 summarizes the odor sensory data obtained for these two multiple-stage scrubber systems. The odor removal efficiency of these two systems is approximately 99%.

Wet Scrubbing of Plant Ventilating Air

This approach provides a more complete solution to an overall plant odor problem. Fugitive odors within the plant can be captured and treated in a uniform manner with this type of scrubber. It is particularly suited for rendering plants located near sensitive population areas, such as residential or commercial. For this application, it is essential to have adequate distribution and flow of air throughout the plant in order to pick up and capture in the ventilating air those fat

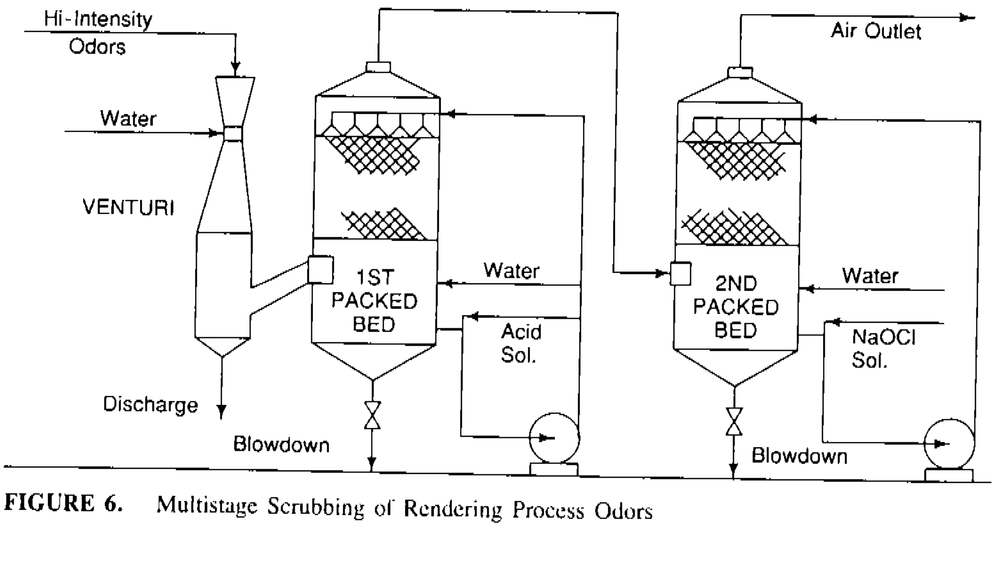

FIGURE 6. Multistage Scrubbing of Rendering Process Odors

TABLE 8. Multistage Scrubbing of Rendering Process Odors

Scrubber Category	Exhaust Flow, ft^3/min	Scrubber Solutions			Odors Units/scf[a]	
		First	Second	Third	Inlet	Outlet
Venturi and one packed tower	32,000	Water	NaOCl		5000–20,000	50–100
Venturi and two packed towers	7,500	Na_3PO_4	H_3PO_4	NaOCl	14,000	185

[a]ASTM syringe method.

Source: References 15, 18

aerosols and other particles that are emitted from the rendering process.

In addition to accomplishing effective odor control, these scrubbers provide proper ventilation of the plant operating areas, thereby maintaining satisfactory working conditions for the employees and improved compliance with the Occupational Safety and Health Administration standards. It is important to recognize that sufficient ventilating air must pass through the operating area during the summer months. Otherwise, doors and windows will be opened excessively, allowing the plant odors to escape from the building instead of being treated by the scrubber system. Ideally, a slight negative pressure should be maintained within the rendering plant.

Certain factors should be considered for the installation of a plant ventilating air scrubber.[19] These include the following.

1. Different types of operations should be separated. For example, protein meal grinding and storage should be isolated from rendering processes and raw material receiving in order to prevent bacterial contamination of the protein meal.
2. Ventilation air should flow from low odor sources to high odor sources. Thus, air from the finished product storage area should flow *toward* the process operating area where the scrubber is normally located. This also applies to the raw material receiving area.
3. Building openings need to be controlled in some positive manner. The overhead truck doors need to be kept closed whenever possible. A building fitted with gravity intake louvers that automatically close when a door is opened may be able to maintain a constant air volume exhausted from the building.

An important consideration in designing a plant ventilating air scrubber system concerns the number of room changes per hour for various categories of rendering plant operations. Table 9 provides a listing of these ventilation rates. A range of values is provided to allow sufficient flexibility in selecting an appropriate ventilation rate that takes into consideration the presence of an operator(s), emission of vapors or odors into the room atmosphere, ambient temperature (summer conditions), and raw material being processed.

A typical plant ventilation air scrubber is shown in Figure 7 as a single packed tower through which NaOCl solution is circulated. These scrubbers have capacities normally ranging from 40,000 to 80,000 ft^3/min.

The addition of NaOCl and caustic soda is controlled by means of oxidation–reduction potential (ORP) and pH measurements. This type of scrubber is capable of achieving 95% or more of odor removal based on inlet values of 2000 to 5000 and exhaust values of 100 to 200 (IITRI dynamic olfactometer).

Other types of wet scrubbers that have been successfully applied to treating the plant ventilating air in rendering plants include the following.

1. Cross flow, packed-bed scrubber where the air flows horizontally and is contacted by the scrubbing solution as it flows downward by gravity through the packing. The capacity for this type of scrubber ranges above 100,000 cfm and the scrubbing solution is recirculated at a rate equivalent to 8 gallons per 1000 ft^3 of odorous air. This type of scrubber is described by Frega and Prokop.[20]
2. Cross-flow, coarse-spray scrubber where the air flows horizontally past a series of baffles countercurrent to the spray pattern. The capacity for this type of scrubber ranges from 38,000 to 150,000 cfm and the scrubber solution is recirculated through each stage of scrubbing at 7½ gallons per 1000 ft^3 of odorous air. Either one or two stages are furnished where different scrubbing solu-

TABLE 9. Ventilation Guidelines for Rendering Plant Processing Areas

Processing Area Category	Number of Room Changes per Hour
Batch rendering system operating area	20–40
Continuous rendering system (suitably enclosed)	10–20
Grease melting and processing	10–20
Raw-material storage and handling	5–15
Fat processing (filtering and bleaching)	5–10
Protein meal milling and conveying	5–10
Fat storage	3–5
Protein meal storage	3–5

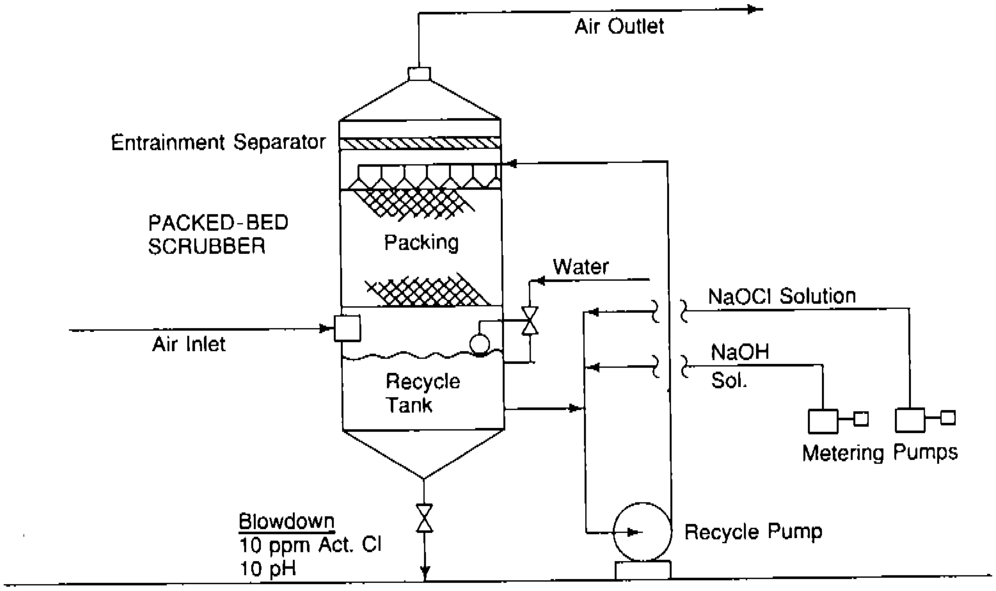

FIGURE 7. Packed-Bed Scrubbing of Plant Ventilating Air

tions are normally used in both stages. A two-stage scrubber of this type is described by Prokop.[18]

3. Mist spray, cocurrent flow scrubbers where very fine droplets are formed by atomizing nozzles normally supplied with compressed air. The mist spray at the top of the scrubber is directed downward in the same direction as the flow of odorous air. The capacity for this type of scrubber is available up to 75,000 cfm, with the once-through scrubbing solution delivered at one-half gallon per 10,000 ft^3 of odorous air.

Current practice for designing wet scrubbing systems to treat both the high-intensity process odor and plant ventilating air is to combine both types of scrubbers into a single system. A three-stage scrubber system is described[20] that consists of the following.

1. A venturi scrubber in series with a vertical countercurrent packed tower to treat the high-intensity odors, which include the Rotadisc noncondensibles, the drainer screw, and two Duke pressors. The scrubbing solutions consist of fresh water circulated through the venturi at 70 gpm and sulfuric acid solution at 2 pH recirculated through the packed tower at 75 gpm. This two-stage scrubber system treats 6300 cfm of odorous air.
2. A horizontal, cross-flow, packed-bed scrubber that receives the exhaust from the two-stage scrubber system described above and the plant ventilating air. Sodium hypochlorite solution at 9 pH is recirculated through this packed-bed scrubber at 575 gpm and its capacity is 70,000 cfm.

Table 10 summarizes the odor sensory data obtained with this three-stage scrubber system.

The overall reduction of the high-intensity odors by three stages of scrubbing (venturi, small packed tower, and large packed bed) exceeded 99%. The plant ventilating air scrubber had an odor removal efficiency ranging from 90% to 95%, depending on the inlet odor level.

Other Methods of Odor Control

Biofilter technology developed during the past 10 years in Europe and elsewhere has been applied to the treatment of rendering odors.[21,22] Biofilters consist of large beds of porous media that are capable of adsorbing odorous gaseous compounds and reducing these by aerobic microbial action to nonodorous components.

Two basic types of biofilter media influence flow rate. Compost, peat moss, heather, and other fibrous media, because of their greater porosity, allow high airflow rates ranging from 35 to 180 m^3/hm^2 (2 to 10 cfm/ft^2) of bed surface without excessive pressure drop resulting. This category of biofilter is analogous to the plant ventilating air wet scrubbers described earlier. Rendering plants currently

TABLE 10. Multiple-Stage Scrubbing of Process Odor and Plant Ventilating Air

	Odor Dilution to Threshold[a]	
	Average	Range
High-intensity odor scrubber		
Venturi scrubber inlet	112,000	42,900–175,000
Plant ventilating air scrubber		
Inlet	3,810	2,180–6,180
Outlet	332	165–628

[a]IITRI dynamic olfactometer.

Source: Reference 20.

TABLE 11. Soil-Bed Treatment of Cooker Noncondensibles

Date	4/11/84	4/12/84	6/26/85	6/27/85
Noncondensibles[a]	52,500	29,000	93,000	209,000
Soil-bed exhaust[a]	43	23	46	120
Odor removal, %	99.9	99.9	99.9	99.9

[a]Odor dilution to threshold values (IITRI dynamic olfactometer)

Source: Reference 23.

are operating such biofilters in Canada, Denmark, France, Holland, Germany, and New Zealand. Also, rendering plants in the United States are now installing these biofilters.

Soil-bed systems are another type of biofilter. Less porous media such as soil result in lower airflow rates, ranging from 2 to 10 $m^3/h/m^2$ (0.1 to 0.5 cfm/ft^2) of bed surface. Such a system is described[23] for a soil bed with a surface area of 4500 ft^2 that treats 650 cfm of Duke Equacooker noncondensibles. A bed depth of 60 cm (24 inches) was provided and the pressure drop across the bed was measured at 5 cm (2 inches) of water column. Two series of odor sensory tests were conducted approximately 14 months apart. Composite samples of soil-bed exhaust were evaluated, along with samples of the inlet noncondensibles. Table 11 summarizes the results, which are expressed as odor dilution to threshold (IITRI dynamic olfactometer). These odor sensory performance results clearly indicate the potential for soil-bed treatment of high-intensity process odors of relatively low volume. Compared with wet scrubbing systems, soil beds require considerably less initial investment and have lower operating costs.

Other odor control methods include activated-carbon adsorption and catalytic oxidation. No actual odor sensory performance tests related to rendering plant emissions have been reported for these methods since the publication of the second edition of this manual.

A very important part of the overall design of an odor control system is related to the emission from the control system into the surrounding atmosphere. Specific precautions should be taken to ensure that the stack design takes into account the height and exit velocity needed to provide the desired dispersion characteristics.

In performing atmospheric dispersion calculations to predict downwind ground-level concentrations, it should be recognized that estimates based on averaging times of 10 to 60 minutes typical of traditional models may be in error. Objectionable odors are detected in much shorter time intervals and peak concentrations for these short times can be much higher than the long-term concentrations for traditional models. Jann and Cha[24] discuss the importance of the odor dispersion averaging times being expressed in seconds in order to be able to predict the maximum odor concentration at ground level.

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NITRATE FERTILIZERS*

Horace C. Mann†

Ammonium nitrate (NH_4NO_3) is produced by neutralizing nitric acid with ammonia. The reaction can be carried out at atmospheric pressure or at pressures up to 410 kPa (45 psig) and at temperatures between 405K and 458K (270°–365°F). An 83 wt % solution of ammonium nitrate is produced when concentrated nitric acid (56–60 wt %) is combined with gaseous ammonia in a ratio of from 3.55 to 3.71 to 1, by weight. When solidified, ammonium nitrate is a hygroscopic white solid that contains 35% nitrogen.

In 1989, approximately 7,557,000 tons of ammonium nitrate solution were produced.[1] It is estimated that 15–20% of this amount was used for explosives and other purposes, while the balance was used as fertilizer. It is used either as a straight fertilizer material or in mixtures (with calcium carbonate, limestone, or dolomite) called calcium ammonium nitrate (CAN), ammonium nitrate-limestone (ANL), or various trade names, and in compound fertilizers, including nitrophosphates. It is also a principal ingredient of most nitrogen solutions.

Ammonium nitrate is used for blasting purposes in conjunction with fuel oil; relatively small amounts are consumed by the brewing and chemical industries. The earlier "grained" type of ammonium nitrate, made by rolling the semimolten salt in an open pan and coating with resins or waxes, has been largely superseded by prilled, granular, and crystalline end products.

The main disadvantages of ammonium nitrate are (1) it is quite hygroscopic, (2) there is some risk of fire or even explosion unless suitable precautions are taken, (3) it is reported to be less effective for flooded rice than urea or ammoniacal nitrogen fertilizers, and (4) it is more prone to leaching than ammoniacal products.

Some countries forbid the sale of straight ammonium nitrate as fertilizer because it can be used as an explosive when mixed with fuel oil or other synthesizers. In these countries, the mixture of ammonium nitrate with calcium carbonate (CAN) is permitted. Formerly, CAN contained 20.5% nitrogen (N), corresponding to about 60% ammonium nitrate (AN); at present, the most common grade is 26% N (75% AN).

Ammonium nitrate is generally regarded as posing no unacceptable hazard when suitable precautions are taken and is commonly used as a fertilizer with strict regulations. "Fertilizer-grade" ammonium nitrate cannot be exploded by impact. There are no records of explosions resulting from heat and fire alone.

Some compound fertilizers containing ammonium nitrate and chloride, such as potassium chloride, are subject to propagated decomposition or "cigar burning" when ignited. Once initiated, the decomposition propagates through the mass of material at a rate that usually ranges from 5 to 50 cm/h. The ignition temperature is about 200°C, and temperature in the decomposition zone is usually 300–500°C, but it may be lowered by certain sensitizing agents such as copper salts. As little as 4% potassium chloride (about 1.9% chlorine) is sufficient to make some mixtures susceptible to cigar burning. The reaction is inhibited by ammonium phosphate; therefore, many NPK compositions containing ammonium nitrate and potassium chloride are free from this hazard.

The exact nature of the reaction is not entirely clear, but it results in complete destruction of the ammonium nitrate and evolution of some of the chloride. Noxious red, white, yellow, or brown fumes are given off that contain NH_4Cl, HCl, Cl_2, NO_2, and other oxides of nitrogen, N_2, and H_2O. The fumes are toxic and have resulted in several fatalities in some incidents.

Because the reaction does not require oxygen, other than that present in ammonium nitrate, the fire cannot be extinguished by smothering. It can only be stopped by flooding with water. If a localized area of decomposition in a bin or pile is discovered early enough, the decomposing material may be removed from the building by a power shovel, for example, and extinguished by water, thereby saving the remainder of the material.

Perbal[2] concluded that compound fertilizers in general may be regarded as safe from explosion hazard if they contain less than 70% NH_4NO_3, unless there is a high

*Portions of this discussion were edited from AP-42, the U.S. Environmental Protection Agency's *Emission Factors Handbook*, Vol 1, Chapter 6.8, and *International Fertilizer Development Center Reference Manual*, IFDC-R.1, Chapter VIII.

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Air Pollution Engineering Manual

AIR & WASTE MANAGEMENT
ASSOCIATION

SINCE 1907

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