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CONTROL OF ODORS FROM INEDIBLES-RENDERING PLANTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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CONTROL OF ODORS FROM INEDIBLES-RENDERING PLANTS

1. INTRODUCTION

Although this document, describing the operation of rendering plants and placing emphasis on the effectiveness and cost of odor control technology, is directed primarily at the control of existing plants, the techniques presented are also applicable to new installations. Costs were developed only for rendering plants handling inedible animal matter because processing of inedible products is more prevalent and a much greater source of malodors than the processing of edible lard and tallow. Rendering of edibles is usually conducted as an adjunct to meat packing operations. Inedible rendering entails a much wider array of feedstocks including packinghouse and butchershop scrap, feathers, blood, and "dead stock" (whole animals that die by accident or through natural causes).

Air pollutants from rendering plants are significant only from the standpoint of malodors. The pollutants of concern--sulfides, mercaptans, organic nitrogen compounds, aldehydes, and organic acids--do not constitute a significant health hazard in the concentrations at which they are released to the atmosphere. For this reason, abatement techniques are aimed at reducing emissions to the extent that malodors are no longer noticeable at receptor points in the vicinity of the plants.

In developing this document, interest was focused on proven systems for controlling prominent odor sources in rendering plants. These sources include cookers, presses, driers, and other heated equipment that generates highly odorous gases. The most commonly applied control devices for these processes are condensers, afterburners, or both, but scrubbers are finding some usage. Although control techniques for other rendering operations such as grinding, handling, and storage are not fully developed, investigations into the most successful control systems, chemical scrubbers, were conducted and results are reported.

Consideration has been given to those maintenance and operating practices that affect the release of malodors. Control techniques for "housekeeping odors" are highly subjective, and this document does not purport to provide a clear-cut solution.

2. RENDERING INDUSTRY STATISTICS

2.1 EXISTING PLANTS

2.1.1 Introduction

The rendering industry has experienced a definite growth during the past two decades. The production of inedible tallow and greases has increased from 2.3 billions pounds worth $150 million in early 1950 to an estimated 5.4 billion pounds worth approximately $430 million for 1971.[1] This trend can be traced largely to increases in livestock production and meat consumption. Increased plant efficiency, which has resulted in the more complete recovery of fats, has also been a factor. The preceding production data for inedible tallow and grease reflect an average annual increase at the rate of 4 percent.

The United States is the world's leading producer, consumer, and exporter of tallow and greases. Since the early 1950's, the United States has accounted for 55 to 60 percent of the world tallow and grease output.[1] The export market has been the largest single outlet, consuming about 50 percent of the domestic output. Table 2-1 provides some information regarding the various markets for inedible tallow and greases.

Table 2-1. UTILIZATION OF INEDIBLE TALLOW AND GREASE, 1960 TO 1970[1]
(10^6 lb/yr)

Year beginning October	Soap	Animal feeds	Fatty acids	Lubricants and similar oils	Other	Exports	Total
1960	732	443	351	70	151	1,769	3,516
1961	702	732	402	79	177	1,710	3,802
1962	688	774	433	78	151	1,738	3,862
1963	660	861	478	91	230	2,338	4,658
1964	690	714	530	102	203	2,155	4,394
1965	649	855	575	107	208	1,962	4,356
1966	665	972	547	98	283	2,214	4,779
1967	631	990	576	89	291	2,212	4,789
1968	637	1,061	585	98	289	2,009	4,679
1969	601	1,093	610	97	320	2,051	4,772
1970[a]	615	1,140	568	89	214	2,591	5,217[b]

[a]Preliminary data based on census reports.
[b]4,877 actual; Reference 2.

2.1.2 Location and Size

Most rendering plants are located in or near cities and in proximity to poultry or meat packing facilities. Many small renderers are, however, located in small towns and rural areas. The larger concentrations of facilities are found in the midwestern parts of the country as shown by Figure 2-1, which provides a general idea of the distribution of rendering plants throughout the country; however, this information is only approximate because edible rendering and fish reduction plants are included in the state totals.

Data obtained from the 1967 Census of Manufacturers and summarized in Table 2-2 provide some information on the size of existing rendering plants. The distribution of plant sizes indicated in Table 2-2 should be considered approximate since only about 69 percent of the industry is reflected. Plants range in size from small operations with 1 to 4 employees and annual sales of about $100,000, to large operations with over 100 employees and sales of from $5 to $10 million. An average plant could be characterized as employing 23 workers and having annual sales of approximately $1 million.

2.1.3 Number of Facilities

As of 1968, there were 770 firms operating 850 facilities engaged in the rendering of inedible animal matter.[3] Of this number, about 460 were operated by independent renderers, 330 were controlled by the meat packing and poultry industries, and the remainder were owned by companies having manufacturing interests other than meat and poultry processing. It is estimated that approximately 275 of the plants controlled by the meat industry also are involved in edible rendering at separate locations of the same plant.[4]

2.1.4 Type of Process

It is estimated that from 75 to 80 percent of the inedible rendering industry consists of older batch-type facilities. New plants can be expected to use a continuous process, although this decision is somewhat dependent upon the size of the operation. A small operation might install new batch units.

2.2 FUTURE TRENDS

The growth pattern for the rendering industry has not been consistent because of the divergent trends of major markets. The displacement of soap by detergents has resulted in a considerable reduction in the demand for tallow by manufacturers of the former. The soap industry, once the major market for tallow, has reduced its demand by 56 percent since 1950.[1] The annual demand for tallow has stabilized at about 0.6 billion pounds in the past few years. This amount could increase if the use of phosphates declines because of concern with water pollution problems.

During the same period, the use of inedible tallow in animal feeds has emerged as a major outlet. The estimated consumption of tallow and greases by the animal feed industry was 1.1 billion pounds during 1970.[1]

The estimated production of meat meal and tankage for 1970 was 4.0 billion pounds. The production of these materials has shown an annual growth rate of 1.6 percent since 1963 compared to a growth of 1.9 percent for inedible tallow and greases during the same period.[6] The primary outlet for meat meal and tankage is as a high-quality protein product for the animal feed industry. Increasing demand for this purpose is tending to increase the value of meat meal and tankage.

The number of domestic rendering plants has decreased from about 850 plants in 1968 to 750 plants in 1972, and the slight decline is expected to continue. It is estimated that

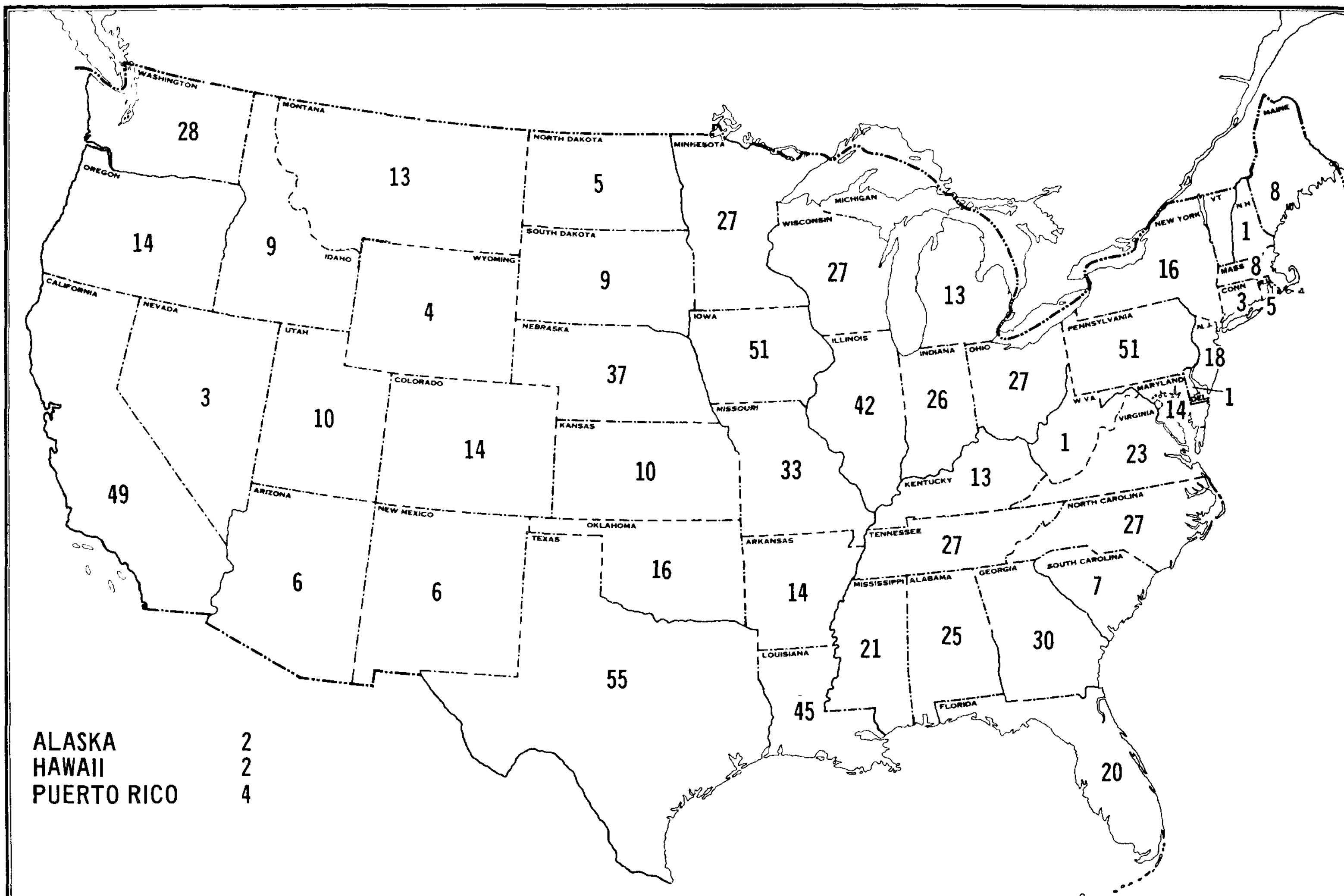

Figure 2-1. Rendering and fish-reduction plants, 1968.[4]

Table 2-2. STATISTICS FOR RENDERING PLANTS BASED ON NUMBER OF EMPLOYEES PER PLANT, 1967[5]

Establishment size, no. employees	Number of establishments	Number of employees	Value of shipments, $\$10^6$
1 to 4	132	300	12.0
5 to 9	103	700	27.9
10 to 19	127	1,800	62.2
20 to 49	157	4,800	207.1
50 to 99	51	3,500	117.1
100 to 249	18	2,600	131.0
Totals	588	13,700	557.9[a]

[a]Total value of shipments from all sources.

new construction will add from 20 to 40 plants per year. Most of these facilities are expected to be replacement plants employing a continuous process.

2.3 COST STATISTICS

2.3.1 Tallow and Meal Prices

Table 2-3 gives historical data on prices of inedible tallow and bulk meat and bone meal as derived from various issues of the trade journal of the meat packing industry.

Evidently, the products of inedible rendering are subject to severe price fluctuations. Prices in early 1973—the basis of the emission control costs—were high, as were prices for edible meats.

2.3.2 Selected Cost Statistics

Table 2-4 contains published cost data on the inedible rendering industry. The statistics in this table include those for the fish rendering industry. Table 2-5 is therefore presented to put fish rendering economics in its proper perspective.

Comparison of the two tables shows that the value of shipments of fish rendering products has usually not exceeded 10 percent of that for both industries and suggests that Table 2-4 approximates the performance of the animal inedible rendering industry.

In view of these facts, Table 2-4 indicates that costs of materials, measured as a percent of sales, have been fairly uniform at approximately 60 cents of every sales dollar, over the years 1960 to 1969. Also, over the entire time span, cash from operations available for depreciation, interest charges, debt retirement, dividends, taxes, and retained earnings has trended upward steadily. This performance was in spite of product price fluctuations over long ranges. Lastly, the total payroll has declined with respect to sales, over the time period tabulated.

Table 2-3. PRICES OF INEDIBLE TALLOW AND MEAL[7]

Quotation date	Tallow, ¢/lb	Meal, $/ton
January 18, 1969	4 1/2	92.50
June 14, 1969	5 3/4	92.50
December 27, 1969	6 1/8	105 - 107
March 7, 1970	6 3/4	115 - 120
June 27, 1970	7 1/4	95 - 100
December 26, 1970	6 1/4	105
February 6, 1971	7	95
July 10, 1971	6 5/8	90 - 95
December 11, 1971	5 5/8	90
January 22, 1972	5 1/2	100 - 102
May 5, 1973	11 3/4	295
June 23, 1973	15 1/2 - 16 1/4	375 - 400
July 14, 1973	15 5/8	225
September 22, 1973	11	160 - 170
November 24, 1973	11 1/2	225 - 240

Table 2-4. SELECTED COST STATISTICS FOR INEDIBLE RENDERING INDUSTRY, ANIMAL AND MARINE FATS AND OILS[9,10] ($\$10^6$)

Year	Value of shipments	Cost of materials	Total payroll	Cash from operations
1960	318.0	190.3	69.9	57.3
1961	376.3	219.0	69.9	88.3
1962	400.6	232.0	74.2	94.4
1963	474.0	280.4	78.3	115.3
1964	550.4	347.3	84.5	118.6
1965	669.2	425.8	90.2	153.2
1966	765.3	460.0	89.3	216.0
1967	557.9	349.1	91.8	117.0
1968	515.1	318.0	92.8	104.3
1969	608.7	373.8	99.5	135.4
1970	790.1	500.7	108.1	181.3
1971	865.9	580.4	111.9	173.6

Table 2-5. SELECTED STATISTICS FOR THE INEDIBLE FISH RENDERING INDUSTRY[8]

Year	Value of shipments, $\$10^6$		
	Fish scrap and meal	Fish oil	Total
1960	25	13	38
1967	40	6.1	46.1
1971	44	20.7	64.7

2.4 REFERENCES FOR SECTION 2

1. Kramer, G.W. U.S. Tallow and Grease Production and Marketing Trends. Reprinted from: The Fats and Oils Situation. Department of Agriculture, Economic Research Service. Washington, D.C. FOS - 260. November 1971. 9 p.

2. Current Industrial Reports, Department of Commerce, Bureau of Census. Washington, D. C. M20K Fats and Oils. September 1971.

3. Background Information for Proposed New-Source Performance Standards, Technical Report No. 10 - Rendering Plants. Environmental Protection Agency. Research Triangle Park, North Carolina. January 1973.

4. National Emission Standards Study. Department of Health, Education, and Welfare. Washington, D.C. Document No. 91-63. March 1970. p. F-367.

5. 1967 Census of Manufacturers. Department of Commerce, Bureau of Census, Washington, D.C. December 1969. p. 20H-12.

6. Current Industrial Reports. Department of Commerce, Bureau of Census. Washington, D.C. M20K. 1963-1970.

7. National Provisioner. National Provisioner, Inc. Chicago, Ill. June 1969-November 1973 issues.

8. Statistical Abstract of the United States Department of Commerce. Social and Economic Statistics Administration. Bureau of Census. Washington, D.C. 1972. p. 641, 642.

9. Annual Survey of Manufacturers for 1970. Industry Profiles M70(AS). Bureau of Census. U.S. Department of Commerce. Washington, D.C. June 1972.

10. Annual Survey of Manufacturers for 1971. General Statistics for Industry Groups and Industries M71(AS)-1. Bureau of Census. U.S. Department of Commerce. Washington, D.C. April 1973.

3. RENDERING PROCESSES

Animal matter not suitable as food for human consumption is converted into salable by-products through various reduction processes. Cows, horses, sheep, poultry, dogs, and cats that have died through natural or accidental causes, as well as the by-products from slaughterhouses, butcher shops, and poultry dressers, are processed into proteinaceous meal and tallow.

Many rendering operations are part of a meat packing or poultry processing plant and are designed to process blood, meat, offal, and feathers produced on the premises. These operations are referred to as captive plants. Off-site, or independent, rendering plants are operated independently and normally rely on a number of local sources for raw material. These sources may include hotels, restaurants, and miscellaneous processors of food and meats.

Although the rendering process is involved mainly with the heated reduction of fat-containing materials into tallow and proteinaceous solids, it can also include such operations as blood drying, feather drying, and grease reclaiming. Table 3-1 gives the tallow and solids yield of material processed by the rendering industry.

Table 3-1. COMPOSITION OF TYPICAL INEDIBLE RAW MATERIALS CHARGED TO REDUCTION PROCESSES[1]

(wt. %)

Source	Tallow or grease	Solids	Moisture
Packing house offal and bone			
Steers	15 to 20	30 to 35	45 to 55
Cows	10 to 20	20 to 30	50 to 70
Calves	8 to 12	20 to 25	60 to 70
Sheep	25 to 35	20 to 25	45 to 55
Hogs	15 to 20	18 to 25	55 to 67
Dead stock (whole animals)			
Cattle	12	25	63
Cows	8 to 10	23	67 to 69
Sheep	22	25	53
Hogs	30	25 to 30	40 to 45
Blood	--	12 to 13	87 to 88
Feathers (from poultry houses)	--	20 to 30	70 to 80
Butcher shop scrap	37	25	38

3.1 BATCH PROCESS RENDERING

The process raw material is placed in a dump pit (Figure 3-1) and conveyed to a hogger where the meat and bones are ground to facilitate mechanical handling and heat transfer. The ground material is then conveyed to the cookers for processing.

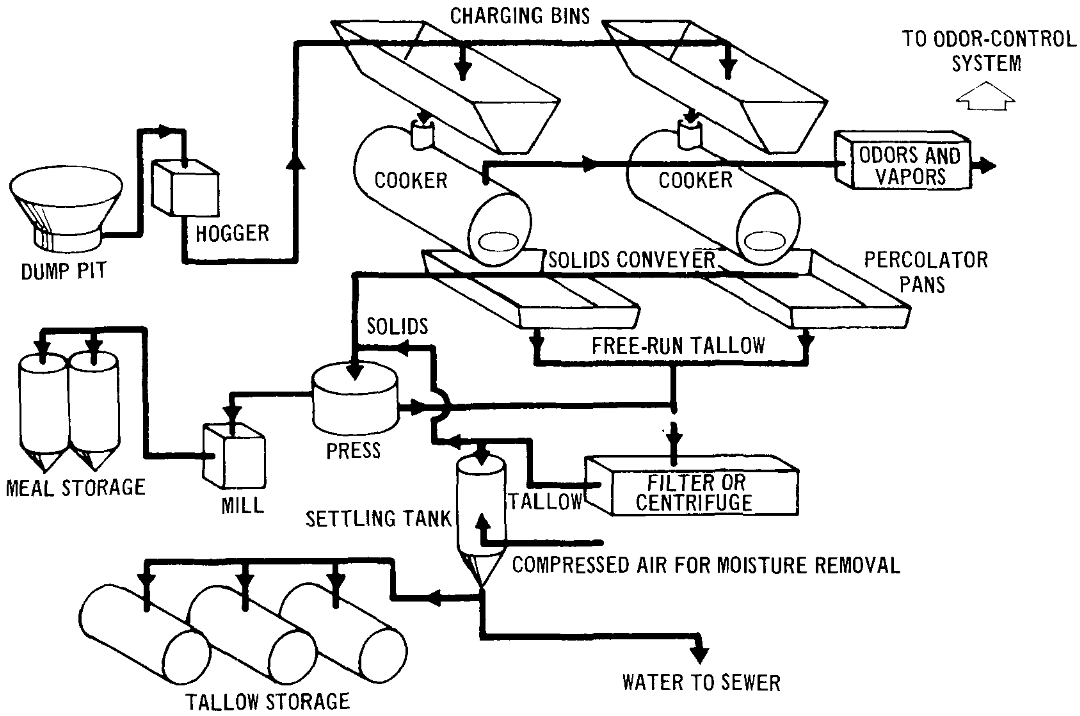

Figure 3-1. Batch rendering plant.

The cooking process, where the actual rendering takes place, may be either batch or continuous. Heat breaks down the flesh and bone structure, causing tallow to separate from solids and water. In the batch process, cookers are charged with 3,000 to 12,000 pounds of animal matter and heated for 1 to 4 hours.[1] Batch cookers may be operated either at pressures greater than 50 psig to digest bones, hooves, hides, and hair, or under a vacuum to produce high-quality tallow. The cookers are equipped with paddles to mix the charge during processing.

Dry rendering is used almost exclusively for inedible rendering and is carried out at atmospheric pressure or under partial vacuum. Operation can be either batch or continuous. Moderate-sized agitating vessels are used for batch operation; continuous operations are performed in agitating vessels designed for proper holdup time, or in multistage evaporators. The material is cooked until all of the free moisture in the tissue is driven off. Then the separated fat is screened to remove the solid proteinaceous residue.

Wet rendering is employed primarily for edible materials and is seldom used to process inedible material. However, it involves cooking under pressure by the direct addition of live steam. The fat and water are separated after cooking. The solids are screened out of the water, and the water is evaporated to a thick, protein-rich material that can be added to animal feeds.

3.2 CONTINUOUS PROCESS RENDERING

Continuous rendering is a highly mechanized dry rendering process. At least three process equipment arrangements are commonly used. Continuous processes usually consist of a series of grinders, steam-jacketed conveyor-cookers, and presses. In one process arrangement, animal matter is ground before it is fed to a precooker. After the initial cook, the material is again ground before its final processing in the second-stage cooker. Tallow and steam vapors are removed from solids at various points in the system.

In the continuous system shown in Figure 3-2, raw material is screw-conveyed to the hogger where it is ground and fed into the end of a multicompartment cooker. Reduction to water, tallow, and solids takes place in the multicompartment cooker as the raw material passes through the cooker compartments. On the other end of the cooker, processed material is removed by the control wheel and placed in a drainer to separate tallow and solids. The entrainment trap prevents solids from escaping the cooker and fouling the air pollution control system.

The scrubber-condenser handles vapors and noncondensables from the cooker. Condensation takes place in a fully enclosed tubular condensing section that is cooled with a

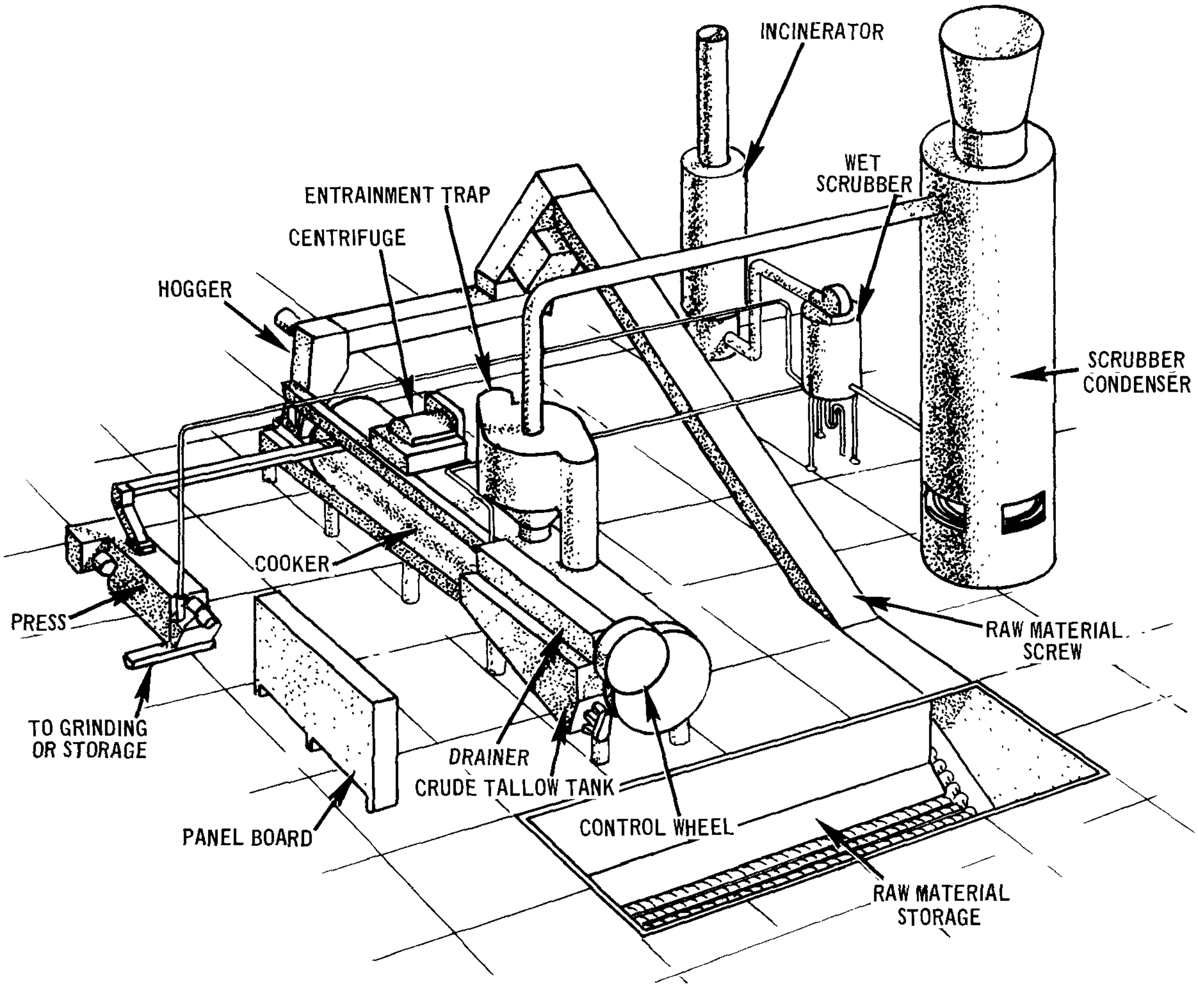

Figure 3-2. Continuous rendering plant. (Courtesy of The Dupps Company, Germantown, Ohio)

water spray. Condensed vapors flow off as waste, and noncondensables go to the small wet scrubber and incinerator. The same water spray also scrubs plant ventilating air, which is passed axially upward outside the tubes, also cooling the condenser water spray. The condensate and spray water are kept apart within the unit; the only mixing occurs on sewering. Because of evaporation and to avoid scaling, some spray water is bled off and some makeup is added.

The hours of operation for continuous and batch rendering plants vary and are not as dependent upon the process as they are upon the availability of raw material. Generally, plants pick up the raw material during the day and process it at night. If raw material is plentiful, the operation may run 24 hours a day and on weekends.

3.3 REFINING RENDERING PRODUCTS

Tallow and solids separated during cooking require further processing to obtain finished products. The solids, or cracklings, are pressed to remove residual tallow (Figures 3-1 and 3-2), and usually are ground to a meal before marketing.

Tallow is maintained at 200° F or above and is then processed in settling tanks, centrifuges, or filters (plate and frame presses or leaf filters) in order to remove the solids. If finely divided protein particles remain suspended in the tallow, the usual settling process of using cone-bottom tanks may be improved by washing the tallow with either trisodium phosphate or citric acid in order to coagulate these particles to aid separation. Moisture is removed from the tallow by flash drying, either at atmosphere or under vacuum, and also by blowing air through the tallow.

The tallow is further refined by adding caustic soda to neutralize the free fatty acids. The saponified free fatty acid settles out and is known as foots or soap stock. The tallow is usually filtered to remove all traces of the foots and other solids.

Tallow is further processed into a "bleachable fancy" grade, which commands a higher market price. Bleaching of the tallow is accomplished by the use of natural clays and also acid-activated clays, which have great absorptive power for fat pigments. This latter variety is replacing the use of natural clays because of its improved performance.

3.4 BLOOD AND FEATHER PROCESSING

Blood and feathers contain little fat and are processed only into meal. Blood is usually dried in a horizontal dry cooker. Sometimes a tubular evaporator is used to remove a portion of the water, and the blood is then transferred to a dry cooker for final evaporation. Steam-tube and ring driers are also used for finish drying of feathers and blood, respectively.

Feathers are initially pressure-cooked at about 50 psig in a dry cooker to hydrolyze the protein keratin, their principal constituent. Final moisture removal may be carried out in the cooker at ambient pressure or in separate air-drying equipment.

3.5 REFERENCE FOR SECTION 3

1. Air Pollution Engineering Manual. Danielson, J. A. (ed.). U. S. Department of Health, Education, and Welfare. Cincinnati, Ohio. Publication Number AP-40. 1967. p. 770 - 775.

4. EMISSIONS

Malodors are the principal air contaminants from rendering and companion processes. Although particulates are formed during the grinding and conveying of cracklings and during the air drying and conveying of meals, they are usually coarse in size and are not entrained in the ambient air.[1] Small amounts of tallow and solids, however, are entrained in the cooker exhaust gas. Particulates and tallow emissions contribute to the odor problem and can interfere with the operation of control equipment.

4.1 POINTS OF EMISSION

Cookers are a primary source of malodors in rendering plants.[2] When animal matter is heated, the cell structure breaks down, liberating gases and vapors. Further heating causes chemical decomposition, and the resulting products are often highly odorous.

Cooker streams contain 95 percent or more moisture by volume. The remainder of the stream, however, includes compounds that are highly malodorous.[3] Emission rates of odorous contaminants are a function of the rate of moisture evaporation. The maximum emissions from atmospheric cookers occur in the initial portion of the cook, whereas in pressure cookers the moisture evaporation rate and emissions proceed as the temperature builds up.

Processing tanks, in which tallow is dehydrated by boiling or air blowing, feather driers, tallow presses, and blood spray driers are lesser but significant sources of malodors. Driers can be a large source of malodors, particularly if feedstocks are putrified or not completely cooked beforehand, or where meal is overheated in the drier. Moisture content of drier streams is generally much lower than that of cooker streams. Feather drier streams, for instance, contain about 20 percent moisture.[2]

Odor concentrations from air blowing of tallow may be significant at high operating temperatures. Only small volumes of air are blown through the tallow for short periods, however. Percolator pans are also a source of significant odors for short periods. At the end of a cooking cycle, when tallow and solids are discharged into percolator pans, substantial quantities of steam and odors are released.[4] Percolator pan emissions are especially difficult to control because of the necessity to gather the vapors in suitable hoods, but at least one western plant has recently demonstrated a control by this method.

Storage areas, dump pits, and hoggers are a significant source of malodors if raw materials are not fresh. Ideally, raw materials should not be over 24 hours old when processed.

4.2 CHEMICAL NATURE OF EMISSIONS

Rendering-plant malodors have been attributed to a variety of organic compounds belonging to such classes as aldehydes, fatty acids, amines, mercaptans, and sulfides.[5-7] Aldehydes and fatty acids are the principal odorous breakdown products from fats; putrescine and cadaverine are two extremely malodorous organic nitrogen compounds associated with decaying flesh.[2] Keratins, the primary constituents of horny material (skin, hair, nails, feathers, etc.) are the principal source of sulfides and mercaptans.

Some specific compounds that have been identified in rendering-plant odors are trimethyl amine, quinoline, dimethyl pyrozine, skatole, ammonia, and hydrogen sulfide. Recent studies have identified such compounds as methyl and dimethyl sulfides; butylamine and trimethyl amine; the methyl pyrazines; aldehydes, ketones, and alcohols; and organic acids including butyric acid.[8] Odor threshold concentrations are extremely low for some of the malodorous compounds, and they can be detected in concentrations as low as 0.2 part per billion.[7] Many odorous compounds have not been identified, nor have their detectability limits been established.

Table 4-1 lists odor threshold concentrations for some odorous compounds. These data are based upon laboratory panel work done by trained members having professional scientific backgrounds, were compiled under ideal conditions with a minimum background odor, and probably represent relative differences in odor threshold levels and not necessarily absolute values.

Table 4-1. ODOR THRESHOLD LEVELS FOR SELECTED COMPOUNDS[2,7]

Compound	Chemical formula	Molecular weight	Odor threshold, ppb
Dimethyl amine	CH_3NHCH_3	45.08	4.7
Methyl amine	CH_3NH_2	31.06	21.0
Trimethyl amine	$(CH_3)_3N$	59.11	0.21
Ammonia	NH_3	17.03	46,800
Ethyl mercaptan	C_2H_5SH	62.13	1.0
Hydrogen sulfide	H_2S	34.08	4.7
Methyl mercaptan	CH_3SH	48.10	2.1
Dimethyl sulfide	CH_3SCH_3	62.13	2.5
Dimethyl disulfide	CH_3SSCH_3	94.23	7.6
Skatole	C_9H_8NH	131.18	220
Acrolein	$CH_2 = CHCHO$	56.06	210
Butyric acid	C_3H_7COOH	88.10	1.0

4.3 EMISSIONS IN TERMS OF ODOR UNITS

Terminology and test methods have been developed to quantify odor emissions. Almost all methods utilize the human olfactory system as the sensor.

The odor unit is defined as the quantity of any single or combination of odorous substances that, when completely dispersed in 1 cubic foot of odor-free air, is detectable by a median number of observers in a panel of at least eight persons.[3] It is desirable to specify the odor sensory method upon which an odor unit quote is based.

Table 4-2 lists odor concentrations and emission rates from various inedible rendering processes. These odor concentrations were determined by the Mills modification of the ASTM syringe method. The wide variation in odor concentrations for blood and rendering cookers reflects the different types and "ripeness" of raw materials.

Of the facilities listed in Table 4-2, the cookers are the predominant source of malodor emissions. Typical batch cookers release 250 to 750 scfm of exhaust gases over a 2- to 4-hour cooking cycle, and continuous cookers release 3000 to 4000 scfm. At an

Table 4-2. ODOR CONCENTRATIONS AND EMISSION RATES FROM INEDIBLE RENDERING PROCESSES[2]

Source	Odor concentration, o.u./scf		Odor emission rate, o.u./ton of feed	Exhaust products, scf/ton of feed	Typical moisture content of feeding stock, %
	Range	Typical average			
Rendering cooker, dry-batch type[a]	5,000 to 500,000	50,000	$1,000 \times 10^6$	20,000	50
Blood cooker, dry-batch type[a]	10,000 to 1,000,000	100,000	$3,800 \times 10^6$	38,000	90
Feather drier steam tube[b]	600 to 25,000	2,000	153×10^6	77,000	50
Blood spray drier[b,c]	600 to 1,000	800	80×10^6		60
Grease-drying tank, air blowing					
156°F		4,500			
170°F		15,000			
225°F		60,000			

[a]Noncondensable gases are neglected in determining emission rates.

[b]Exhaust gases are assumed to contain 25 percent moisture.

[c]Blood is handled in spray drier before any appreciable decomposition occurs.

average emission concentration of 50,000 odor units per scf, a batch cooker would release up to 37.5 million odor units per minute, and a continuous cooker would release 150 million odor units per minute. On the other hand, a 2000-pound-per-hour feather drier (1600 scfm exhaust volume) with an average emission concentration of 2000 odor units per scf would release 3.3 million odor units per minute.

The reliability of the ASTM[9] and other known odor sensory methods leaves something to be desired. Considerable effort is currently being expended to find more practical, simple, and reproducible methods. Results have been described recently for an alternate dynamic method for stack testing that uses a statistical approach.[10]

4.4 STATE AND LOCAL ODOR REGULATIONS

Several state and local jurisdictions have adopted odor control regulations that apply to rendering plants. Many are general prohibitions that apply to all odor sources; others are more specific to rendering operations.

The most common type of statute is a general-nuisance regulation. The enforcement of such regulations requires that a great deal of evidence be assembled to show that a given source causes nuisance or annoyance, endangers comfort, repose, health, or welfare of persons, or causes injury or damage to property or to business.

Many jurisdictions use odor regulations that are in the form of stack emission limits or fenceline allowances. These may be general or directed specifically at rendering plants, canneries, pulp mills, etc. Emission limits are usually based on dilution measurement procedures in which the human nose serves as the sensor. The use of dilution methods has given rise to the term "odor unit," in which allowable emissions are usually expressed. Regulation APC-9 of the State of Minnesota, as listed in Table 4-3, limits emissions from rendering plants to 1,000,000 o.u./minute.

Fenceline regulations stipulate maximum allowable odor limits at the rendering plant property line. These limits are not necessarily indicative of the level of emissions from the plant. The scentometer is normally used to enforce fenceline regulations. This instrument is essentially a clear plastic box containing two chambers of activated charcoal, two nasal ports for sniffing, and a series of odorous inlets that are directly connected with a mixing chamber and the nasal outlets. Air is drawn through the two charcoal beds (to make it odor free) and then mixed with the contaminated air to produce a threshold concentration. The unit of expression used for this work is the number of times that the odor is as strong as its threshold concentration, or the number of dilutions with pure air needed to dilute it to threshold concentration.[11] The allowable dilution limits for some states and localities are listed in Table 4-3.

The most common type of rendering plant odor regulation is an equipment standard that directs the operator to use specific incinerator parameters. Several such parameters are listed in Table 4-3; they usually apply to discrete processes within the plant, e.g., cookers, driers, and heated reduction processes, rather than to the entire facility. As noted in Table 4-3, required temperatures and residence times vary from 1200 to 1600° F and from 0.3 to 0.5 second. In jurisdictions where such equipment standards are in use, the operator usually has the option of using any other control system if he can show it provides equivalent odor abatement.

4.5 DISPERSION OF ODORS

No evidence exists that rendering-plant odors are harmful to health at dilute levels. Therefore, a reasonable objective is the prevention of detectable odors at ground level outside the plant. The regulations cited in Section 4.4 attempt to provide this assurance by limiting odor emissions or concentrations at the stack or fenceline or by requiring air pollution control equipment which will achieve these levels. Some typical installations--uncontrolled and controlled--will be examined to consider the effect of atmospheric dispersion.

Table 4-3. STATE AND LOCAL ODOR CONTROL REGULATIONS[12]

State or locality	Minimum odor control regulation			
	Incineration		Dilution[a]	
	Temperature, °F	Time, sec	Limit	Location
Pennsylvania	1,200	0.3	-	-
Minnesota	1,500	0.3	-	-
St. Louis, Mo.	1,200	0.3	-	-
Colorado	-	-	7	Residential, commercial
	-	-	15	All other land use
Cincinnati	-	-	7	Residential, light industry
	-	-	15	Heavy industry
Los Angeles County	1,200	0.3	-	-
Pittsburgh-Allegheny County	1,600	0.5	-	-
Arizona	1,200	0.3	-	-
Montana	1,200	0.3	-	-

[a]The dilution limit is the number of dilutions with pure air needed to dilute an odor to threshold concentration. The measurements are taken with a scentometer at the plant property line.

4.5.1 Odors from Uncontrolled Plants

Calculations have been made to estimate ground-level odor concentrations for an uncontrolled rendering plant. The plant assumed is approximately equal to Model C of Table 6-3, with a stack-gas flow rate of 6000 cfm. This plant uses a shell-and-tube condenser for cooker off-gases and, for simplicity, all plant odors are assumed to exit from the stack. Because Model C emits about 670 cfm from the condenser, there must be a large amount of dilution air to make up 6000 cfm; also, the stack temperature is assumed to be 90° F, along with a stack velocity of 10 ft/sec. The stack-gas odor concentration is taken as 100,000 o.u./ft^3, which is derived from the dilution and the usual range of exit concentrations from rendering plant shell-and-tube condensers. The stack is assumed to be 75 feet high, and the atmospheric stability is taken as D, with a wind speed of 1 m/sec.

Under the preceding conditions, the maximum ground-level concentration was estimated to lie 1600 feet downwind from the stack and to be about 1400 o.u./ft^3.[13] There would still be 170 o.u./ft^3 at ground level 2.5 miles from the stack, and a distance of about 30 miles* would be required for complete dissipation of odor. Although these figures are rough estimates, they are given here to illustrate the odor problem when rendering plants are uncontrolled. The following two sections, involving similar assumptions and calculations, illustrate the great improvment in the ground-level odor situation when reasonable controls are used.

4.5.2 Residual Odors from Chemical Scrubber

The maximum ground-level odor concentration was estimated[14] for a rendering plant controlled by a hypochlorite water scrubber (Section 6.4). The plant was assumed to be well kept, with negligible odor sources other than the scrubber exit gas. The plant was assumed to be approximately equal to Model C of Table 6-3. A stack gas flow rate of 6000 cfm at 90° F was assumed, along with an odor concentration of 200 o.u./ft^3. The plume rise was found to be negligible because the gas temperature was so close to ambient. With such a small plume rise, the maximum ground-level concentration will occur at low wind speeds. Assuming a wind speed of 1 m/sec, it was initially determined that a stack height of 30 feet would be required to prevent the ground-level concentration from exceeding 1.0 o.u./ft^3.[13] The actual odor source, however, will have a building under it and may have other buildings near it. When air flows past a building at any velocity, the air streamlines are bent. This bending is small at 1 m/sec, but increases with velocity, finally resulting in turbulent eddies just downwind of the building. Therefore, odorous air passing over the roof may be deflected groundward, or may be pushed downward in turbulent eddies. This phenomenon is called downwash. With a 30-foot stack, the occurrence of downwash is likely and will occasionally cause ground-level concentrations to exceed 1 o.u./ft^3 up to several hundred feet downwind. A rule of thumb is that the stack height--or stack plus building height if the stack is atop the building--should be 2.5 times the building height. Downwash effects from a building will extend 5 to 10 building heights downwind.

For the average rendering plant building 30 feet high, the stack should extend to 75 feet above ground. Under the described conditions, the maximum ground-level concentration will then be 0.06 o.u./ft^3 when a chemical scrubber is used. This determination was made by calculating the critical wind speed at which ground-level odor concentration is maximum.

4.5.3 Residual Odors from Afterburner

The maximum ground-level concentration was estimated for an afterburner based on the same assumptions as for the chemical scrubber, except for the stack temperature of 750° F. The resulting plume rise was about 40 feet. The maximum ground-level odor

*The calculation assumes no disappearance of odor molecules and neglects the unknown factors of photochemical reactions in the atmosphere, or other mechanisms of change.

concentration from the 75-foot stack was only 0.01 o.u./ft^3 because of the improvement in plume rise.

Plume rise adds to effective stack height. The rise approaches zero as the difference between stack and ambient temperatures approaches zero.

4.5.4 Odors from Rendering Buildings

The preceding discussion assumes that all odor in the rendering plant is directed up the stack. *If some odors escape from the building itself, ground-level concentrations* will be greater.

The odor concentration was estimated at an elevation of 2 meters (nose-level) 200 meters downwind of a rendering plant building with dimensions of 50 by 50 meters. For an emission rate equal to that for the stack in the preceeding example (20,000 o.u./sec), the odor concentration would be 1.8 o.u./ft^3.[14] A wind speed of 1 m/sec with an F stability was assumed. The plant was considered an area source of uniform emission intensity. The odor concentration would be greater or less than 1.8 o.u./ft^3 at a point closer or farther, respectively, than 200 meters downwind. The odor concentration would also be much greater if the gases escaped the building without being incinerated, scrubbed, or otherwise treated.

Ground-level concentration at a given point is a linear function of emission rate in o.u./sec if all other assumptions remain unchanged. Although building emission rates are not available, a typical dry-rendering cooker vented through a surface condenser with condensate temperature of 80° F might release 12,500,000 o.u./min.[15] In the absence of any other control or a stack, the ground-level concentration would be about 19 o.u./ft^3 200 meters downwind of the rendering building.

The preceding statements about ground-level concentrations are valid for averaging times of about 10 to 60 minutes. Odors are detectable in seconds, and for such short averaging times, odor concentrations will reach values many times greater than for 40-to-60-minute averaging times.

Actual emission rates--and therefore ground-level concentrations--are potentially much greater when odors escape from the building itself than when they are directed up a stack and then subjected to downwash. This is primarily because odor-control devices are assumed to be operating when odors are directed up the stack, whereas escaping odors are not subject to control.

In view of the preceding discussion, it is imperative that (1) odors should be directed through control devices and a sufficiently tall stack, and (2) no strong odor source should be permitted to vent directly into a building unless the building itself is vented through an effective odor-control system.

The services of a professional meteorologist should be secured by those who plan to construct new rendering plants, and by those who have received serious complaints at existing establishments.

4.6 REFERENCES FOR SECTION 4

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5. HEALTH AND WELFARE EFFECTS OF ODORS

5.1 INTRODUCTION

The influence of odors on the health and welfare of an individual is difficult to substantiate. This difficulty arises primarily from the lack of an objective measurement technique. The results of several recent studies that attempted to evaluate the effects of odors on the health and comfort of man are summarized in this section.

5.2 PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS

The conclusions of two recent symposiums on odors are that (1) no data are available to relate odors by themselves to any specific organic disease, and (2) odors bear no relationship to the toxicity of a gas. Several studies have, however, linked odors to the presence of the following symptoms: poor appetite, reduced consumption of water, impaired respiration, nausea, vomiting, insomnia, and mental perturbation.[1-4]

Odors have also been associated with the aggravation of symptoms of chronic respiratory illness;[5] they may cause attacks of asthma or other allergic conditions. It is difficult, however, to prove whether an allergic reaction is the result of the odor sensation or of contact with the odorant substance itself.

5.3 ANNOYANCE

Public opinion surveys often identify malodors as the air pollutant that is most apparent and of greatest personal concern to the individual.[6] A recent national task group evaluating air pollution research goals indicated that odors are of considerable concern to the average person.[3] This group also concluded that odors should be considered undesirable air pollutants, whether or not they are linked to long-term health effects, simply because they constitute an annoyance to people.

Numerous cases of individuals obtaining legal redress because of damages suffered from the presence of odors are cited.[7] The injuries or inconveniences that resulted in compensations for damages include loss of sleep, loss of appetite, nausea, vomiting, and curtailment of the use or enjoyment of property.

5.4 ECONOMIC EFFECTS

The presence of odors can be expected to exert a negative trend on the price of property. The extent of this trend depends upon the degree to which odors are perceived as neighborhood characteristics and upon the extent to which they are considered objectionable by both the buyer and the seller of the property. The results of several studies tend to support the preceding conclusions.[8-11]

5.5 REFERENCES FOR SECTION 5

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6. CONTROL TECHNIQUES FOR ODORS

There are several suitable control techniques that the rendering industry can employ to comply with typical state and local regulations. These techniques involve treatment of odorous streams by condensation, incineration, condensation-incineration combinations, and chemical scrubbing. This chapter discusses the effectiveness and cost of these techniques.

6.1 CONDENSERS

Selection of odor control equipment is influenced to a large degree by the moisture content of the process stream. A high moisture content would almost always necessitate the use of a condenser as the preliminary component of any control system for reasons of both efficiency and economy. Rendering plant gas streams can be divided into three general types according to the percentage of condensables: (1) cooker gases consisting of 95 percent or more condensable moisture, (2) air drier exhaust gases with a maximum moisture content of 30 percent, and (3) low-moisture plant ventilation air.[1]

Although significant control of many high-moisture emissions can be accomplished by condensation alone, this technique is not effective enough to be used independently as a control for rendering plant malodors. Condensation is useful, however, when applied in conjunction with incineration or chemical scrubbing. Under these conditions, a condenser reduces the load and energy requirement of secondary control equipment. For example, condensation of steam from high-moisture gas streams (rendering cooker or blood cooker exhaust) reduces the gas volume by a factor of 10 or more.

Most condensers are designed to provide sub-cooling of the gas stream and condensate to approximately 120° to 140° F.[1] The major purpose of a condenser is to reduce the volume and moisture content of the gas stream prior to additional treatment; however, some malodors condense or dissolve in the condensate. Table 6-1 presents measurements of the odor-removal efficiency for both a direct-contact condenser and a surface condenser.

Table 6-1. ODOR REMOVAL EFFICIENCIES[1]

Inlet conc., o.u./min	Condenser type	Condensate temp., °F	Outlet conc., o.u./min	Odor removal efficiency, %
25,000,000	Surface	80	12,500,000	50
25,000,000	Direct contact	80	250,000	99

6.1.1 Contact Condensers

6.1.1.1 Description

Cooling of a rendering plant process stream can be accomplished through the use of either a direct-contact condenser or a surface condenser. Either type of condenser will result in some odor reduction because of the condensation of malodorous material. The use of a direct-contact condenser results in more efficient odor removal because of the scrubbing action associated with direct-contact cooling and because of greater liquid di-dilution.

Contact condensers are relatively uncomplicated pieces of equipment in which coolant, vapor, and condensate are brought into intimate contact. Water is the usual coolant. The direct-contact gas-liquid heat exchange can be accomplished in any of the following devices: baffle-tray columns, spray chambers, barometric condensers, packed columns, or high-velocity jets. The emphasis in this discussion will be placed on spray chambers and barometric condensers because it is thought that these pieces of equipment are the most applicable and the most commonly used.

The use of baffle-tray columns, packed columns, or high-velocity jets would usually result in unnecessary operating and maintenance problems as well as additional expenses. Three variations of a contact condenser, including a spray chamber and a barometric condenser, are presented in Figure 6-1.

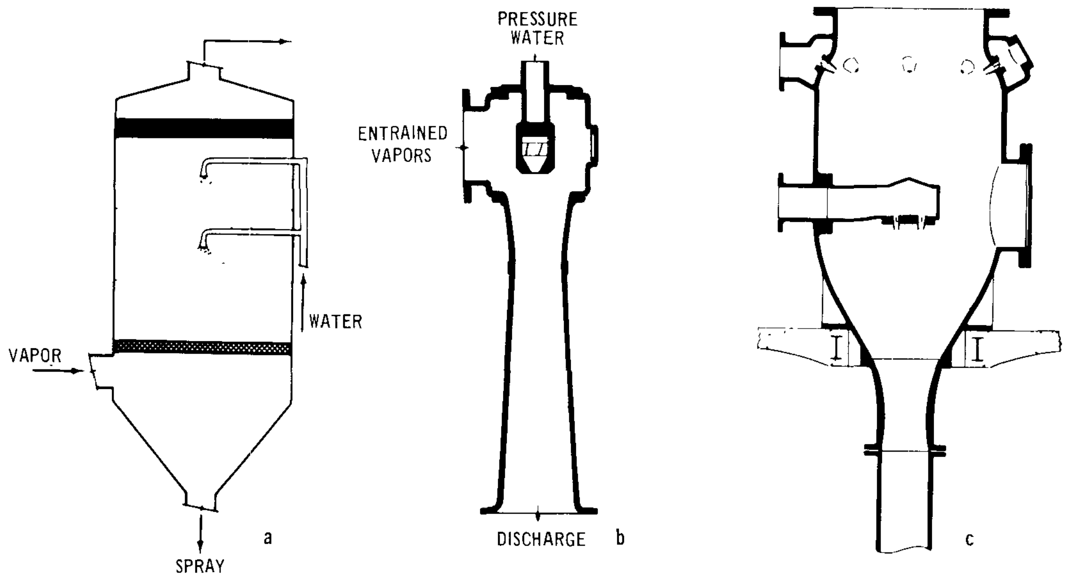

Figure 6-1. Types of condensers (a) spray chamber, (b) jet, and (c) barometric (Courtesy Schutte and Koerting Co., Cornwell Heights, Pa.).

Spray chambers are one of the simplest types of direct-contact coolers. The liquid coolant is introduced into the chamber by either spray nozzles or atomizers and brought into contact with a countercurrent gas stream. The moisture content of the gas stream is condensed and exits with the cooling water. In the case of rendering plants, this contaminated water must be sent to a sewage-treatment facility. The noncondensables exit the spray chamber and are either sent to additional odor-control equipment or exhausted to the atmosphere.

A second type of direct-contact condenser that has found considerable use in the rendering industry is the barometric condenser shown in Figure 6-1. In this design, part of the cooling water is sprayed into the vapor stream near the vapor inlet, and the remainder is directed into the discharge throat. The condenser is usually positioned high enough (34 feet minimum for high-vacuum processes) so that the water can be discharged by gravity from the vacuum in the condenser. Cooling water, condensate, and noncondensables exit the condenser in a single stream and are collected in an enclosed hot well in which the malodorous gases are separated from the liquid effluent. The liquid effluent is drained from the hot well, passed through a grease trap, and sent to the sewage-treatment system. Noncondensable gases are vented and sent to additional control equipment, e.g., afterburner or scrubber.

Some smaller installations utilize a sealed hot well for the actual condensation step. This cooling technique is a low-cost, moderately efficient means of reducing the moisture content of the cooker gases. The cooker off-gases are sent to an enclosed hot well where they are introduced below the liquid level and brought into direct contact with a stream of cooling water. The cooling water flow rate is usually adjusted to provide a liquid effluent exit temperature of approximately 140° F. Noncondensable gases are vented from the hot well and sent to additional control equipment.

The major factor to be considered during the design of a contact condenser is the volume of cooling water required. This volume can be calculated by computing the amount of heat to be removed and determining the allowable cooling water exit temperature. Both the latent heat of vaporization and the amount of sub-cooling of the condensate required should be considered when setting heat-removal requirements. In a contact-type condenser, approximately 16 pounds of water at 70° F is required to condense 1 pound of steam at 250° F and cool the condensate to 140° F.

In a typical cylindrical spray chamber condenser, a contact time of 1 second with a cross-sectional velocity of 400 to 500 feet per minute has been used.[3] Pressure drops for these units are small.

In comparison with surface condensers, contact condensers are more flexible, simpler to operate, and less difficult to maintain. Although the initial equipment cost for a direct-contact condenser is less than that for a surface condenser designed to provide an equivalent amount of cooling, the operating costs for the former are higher. Because cooling water is not recycled, contact condensers require far more water than surface condensers and produce 10 to 20 times more waste water. This large volume of waste water can create a disposal problem.

6.1.1.2 Emission Reduction

The use of a direct-contact condenser can reduce malodorous emissions from rendering plant process streams by approximately 99 percent.[1] This emission reduction is based on a volume reduction of 95 percent and is accompanied by a decrease in malodor concentration from 50,000 to 2,000 odor units per standard cubic foot. The effectiveness of contact cooling can be traced to the scrubbing action associated with this cooling technique. A reduction to 2,000 odor units can be accomplished only if clean water is used in the contact condenser.

6.1.1.3 Condensate Treatment and Aqueous Waste Costs

The amount of treatment required by a particular sewage is usually measured on one of two bases: (1) the amount of suspended solids or (2) the biological oxygen demand (BOD), which measures the amount of impurities by the amount of oxygen required to oxidize it. Liquid effluent from rendering plants (condenser condensate, wash water, etc.) is often high in both suspended solids content and BOD.

Grease traps are usually installed prior to any condensate or sewage treatment facility. Where there is significant grease in the water, treatment with alum or similar chemicals could be required.

If the rendering operation is located near an urban area, the sewage is in many instances sent to a municipal sewage treatment facility. At least half of the industry disposes of its aqueous wastes in this manner. The fee charged will vary with the locality and may include a surcharge based on suspended solids content and BOD. A typical practice is to base the sewage charge on the water consumption of the plant. In this case, the sewage fee is usually similar to the water cost. The fee charged by one municipal treatment plant contacted is composed of both a regular charge based on the volume of water used and a surcharge for suspended solids and BOD. A surcharge of $30 per 1000 pounds of solids and $23 per 1000 pounds BOD is included for solids content and BOD in excess of 300 ppm.[4]

Another way of estimating charges for sewering of wastes in a municipal sewer is as follows:

Water charge	25¢/1000 gal
Collection charge	20¢/1000 gal
Treatment charge	See Table 6-2
Usual range for total sewerage charge	\$0.50 - \$1.00/1000 gal

If surcharges for excessive BOD are levied, the above range of total charge may be extended upward. Table 6-2 gives the treatment charges for municipal sewering of aqueous wastes. These charges cover the capital amortization and the operating and maintenance costs of the municipal sewage treatment plant. The 1-million-gallon-a-day plant would serve a community of about 8,000 people.

Table 6-2. TREATMENT CHARGES FOR MUNICIPAL SEWERING OF AQUEOUS WASTES[5]

Treatment plant capacity, 10^6 gal/day	Treatment charges, \$/10^3 gal
1	0.42
5	0.17
20	0.10
100	0.07

Rendering plants located in rural areas may find it necessary to construct the required sewage treatment plant. Listed below are three types of treatment currently in favor:

1. A preliminary catch basin involving gravity, screening, or other simple mechanical separation, followed by air flotation to remove grease. There is no secondary treatment and no reduction of dissolved BOD. This is one of the cheapest and least effective treatments.

2. A simple holding pond with no outlet. The net aqueous plant outflow is taken care of by ground seepage and evaporation from the pond surface. The water may also be used in irrigation. The odors near the pond may be objectionable.

3. An anaerobic (deep) lagoon followed by natural aeration with a long ditch or another lagoon. Mechanical aeration is uncommon.

Better aqueous waste treatment methods do exist; they may include sedimentation basins and trickling filters for solids and BOD removal, or activated sludge for the removal of both suspended and dissolved impurities. Activated sludge contains aerobic microorganisms that digest the raw waste. During the activated sludge treatment, the effluent is aerated to provide the required oxygen. The total installed cost of a minimum-treatment facility using a preliminary catch basin followed by a lagoon to treat 50,000 gallons per day of waste water is estimated to be approximately \$50,000.[6,7] This size facility would meet the requirements of a plant processing approximately 15,000 pounds per hour of raw material. For a better treatment involving use of an anaerobic lagoon followed by a turbine-agitated lagoon and a hold pond, the total installed cost for the same plant would be about \$90,000.[7]

It is estimated that the use of a direct-contact condenser by a plant similar to Model A (Table 6-3) would result in the production of 1,400 gallons per hour of waste water. A plant comparable to Model B would produce approximately 4,700 gallons per hour of liquid

Table 6-3. BATCH-TYPE MODEL RENDERING PLANTS

Model	Annual sales, $	Number of cookers	Raw material process rate, lb/hr	Peak gas volume to condenser, acfm @ 250 °F
A	184,000	1	1,560	700
B	915,000	3	5,200	2,300
C	2,620,000	6	15,000	6,700
D	3,980,000	9	22,500	10,000

effluent. Both of these estimates are based on no recirculation. Some recirculation could be used if a good secondary control device, like an afterburner, were used.

6.1.1.4 Equipment Costs

This section presents estimates of the capital investment, direct operating cost, and total annual cost (commonly called operating cost) associated with the installation and use of a direct-contact condenser. Definitions of these cost and investment terms and descriptions of the procedure used to arrive at these estimates are provided in Section 7. All condenser costs are based on the use of stainless steel as the construction material because of the corrosive nature of rendering plant off-gases.

The estimation of control costs for the rendering industry is difficult because of the wide range of plant sizes. Costs are presented in this document for four model plants that are assumed to provide a representative view of the industry. The model plants are summarized in Table 6-3.

Approximately 80 percent of the existing rendering plants are thought to be batch operations. Models A through D are representative of this portion of the industry. The remaining 20 percent of existing plants are newer continuous operations that are often adequately controlled.

The capital investment, direct operating cost, and total annual cost of a direct-contact condenser for Model Plants A and B are listed in Table 6-4. The use of a direct-contact condenser for plants similar to Models C and D was not considered because of the large cooling water requirements and the high sewage treatment cost involved. Captive rendering plants and plants located near large bodies of water, however, may be able to utilize kill-floor water or local water if they already have adequate BOD treatment for their waste water. Operating costs for these plants might be lower than the figures given in Table 6-4, and contact condensers might be economically attractive for most of the model plants.

All operating costs and process rates are based upon operation for 2,140 hours per year for Model A and 3,200 hours per year for Model B, derived from production and plant size data in the 1967 U. S. Census of Manufacturers. The cookers were not necessarily assumed to be of the same sizes among plants.

Condensers are sized to handle peak evaporation rates (Table 6-3), which in turn are assumed to be approximately double the average rate. Average evaporation rates were calculated assuming a 50 percent moisture content of the raw feed and a 90 percent moisture reduction during the cook cycle. Cooker off-gases were estimated to consist of 95 percent moisture and 5 percent noncondensables.

Table 6-4. CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF A DIRECT-CONTACT CONDENSER

	Model A	Model B
Raw material process rate, lb/hr	1,560	5,200
Capital investment, $	2,900	5,000
Operation, hr/yr	2,140	3,200
Operating costs, $/yr		
Water	720	3,500
Sewage	2,280	11,400
Electricity	20	70
Total direct cost[a], $	3,000	15,000
Depreciation (10-year straight line), $/yr	290	500
Interest, taxes, insurance (10%), $/yr	290	500
Maintenance (3%), $/yr	90	150
Total annual cost,[a] $/yr	3,700	16,000

[a]Total has been rounded to two significant figures.

The costs of contact condensers for Model Plants A and B were obtained from direct communication with several equipment vendors and manufacturers. Estimates include the cost of a temperature-flow control on the cooling water stream. All equipment costs reflect a January 1973 basis.

The cost of cooling water was based on a charge of $0.25 per 1000 gallons. It was assumed that 16 pounds of water was required to condense and sub-cool each pound of steam. The sewage charge was based on a fee of $0.75 per 1000 gallons of waste water treated. Electrical costs were for the operation of a 1-horsepower pump for Model A and a 2-horsepower pump for Model B. A cost of $0.015 per kilowatt-hour was assumed.

6.1.2 Water-Cooled Surface Condensers

6.1.2.1 Description

Condensation of rendering plant vapors can also be accomplished through the use of a surface condenser. In a surface condenser, a heat transfer surface separates the coolant from the vapor stream. The advantage of this type of condenser is that it produces a much smaller quantity of condensate, which results in reduced sewage treatment costs. Surface condensers also have lower operating costs in comparison to contact condensers since the coolant can be recycled.

The most commonly used surface condensers are shell-and-tube condensers using water as the coolant, and extended surface condensers using ambient air as the cooling medium. This section discussed the use of shell-and-tube (water-cooled) units. Section 6.1.3 evaluates the use of extended surface (air-cooled) condensers.

Most water-cooled surface condensers are of the shell-and-tube type with the coolant on the tube side and the condensing vapors on the shell side. A diagram of a shell-and-tube condenser is presented in Figure 6-2.

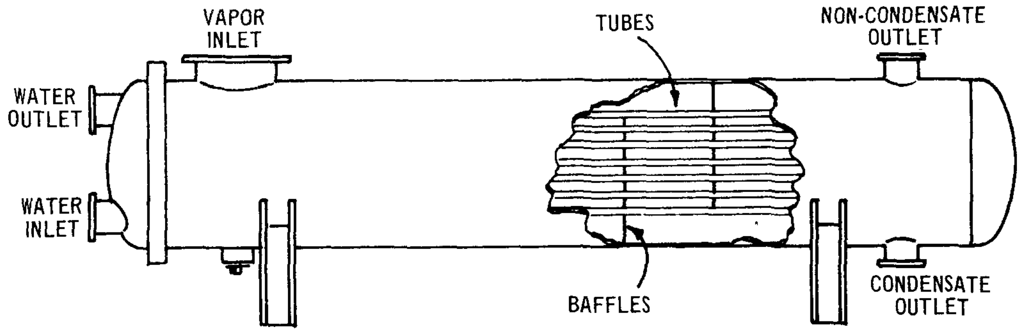

Figure 6-2. Shell-and-tube condenser.

The vapor stream enters the condenser on the shell side and is condensed by contact with the cool tube surface. The condensate is then drained from the bottom of the condenser and sent to a sewage treatment facility. Noncondensable gases are vented from the unit and sent to additional control equipment. The cooling water exits the condenser and is usually sent to a cooling tower where it is chilled and recycled to a condenser for reuse.

When condensers are used as air pollution control devices, care should be taken to minimize the evolution of volatiles from the discharged condensate. This usually requires sub-cooling of the condensate to approximately 140° F or less. In general, sub-cooling requirements for surface condensers should be more stringent than for contact condensers because of the more concentrated nature of the condensate. In a horizontal-tube unit of the type shown in Figure 6-2, condensate sub-cooling can be obtained by: (1) reducing the pressure on the shell side, (2) adding a separate sub-cooler, or (3) using the lower tubes for sub-cooling. The use of a special arrangement to provide cooling of the condensate may not be necessary with vertical-tube condensers since some degree of sub-cooling is provided under ordinary operating conditions.

In the design of a surface condenser, the area available for heat transfer is the critical factor. This area can be computed with the following equation:

$$A = \frac{Q}{U \Delta Tm}$$

where: A = Heat transfer area, ft^2
Q = Heat to be removed, Btu/hr
U = Overall heat transfer coefficient, Btu/hr-ft^2-°F
ΔTm = Logarithmic mean temperature difference, °F

The solution of this equation may be difficult because the overall heat transfer coefficient (U) is dependent on several parameters of the condensing and cooling streams. An overall heat transfer coefficient of 130 Btu per hour per square foot per °F was estimated for a water-cooled shell-and-tube condenser.

6.1.2.2 Emission Reduction

A surface condenser designed to provide sub-cooling of the condensate will reduce odor emissions. In one case, a surface condenser that subcooled the condensate to 80° F reduced the odor emissions by approximately 50 percent.[1] Although the 50 percent reduction was based on measured odor concentrations, the flow rate from the condenser was estimated because of its low velocity. This reduction is usually impractical because cooling-tower water cannot be cooled low enough to cool condensate to 80° F at usual wet-bulb temperatures. In addition, odor concentrations increase across a surface condenser as indicated in Table 6-1. These facts necessitate the venting of noncondensable gases to additional control equipment.

6.1.2.3 Condensate Treatment

Surface condensers avoid the ten-fold water dilution that occurs with contact condensers. This large reduction in volume of contaminated water requiring treatment is the major advantage of a surface condenser. It is estimated that a plant similar to Model B would produce approximately 280 gallons per hour of waste water; a plant similar to Model C, 820 gallons per hour; and a plant similar to Model D, 1200 gallons per hour. A discussion of the sewage treatment required for condenser condensate was presented in Section 6.1.1.3.

6.1.2.4 Equipment Costs

6.1.2.4.1 Introduction--The cost of a water-cooled shell-and-tube condenser is presented for Model plants B, C, and D. It is thought that a plant similar in size to Model A would elect to install a direct-contact condenser under most circumstances. Table 6-5

Table 6-5. CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF A WATER-COOLED SHELL-AND-TUBE CONDENSER

	Model B	Model C	Model D
Raw material Process rate, lb/hr	5,200	15,000	22,500
Capital investment, $			
Shell-and-tube condenser	10,000	20,000	31,000
Cooling tower	12,000	29,000	43,000
Total capital investment	22,000	49,000	74,000
Operation, hr/yr	3,200	3,200	3,200
Operating costs, $/yr			
Water	350	1,000	1,600
Sewage	570	1,700	2,500
Electricity	360	1,100	1,600
Total direct cost[a],$	1,300	3,800	5,700
Depreciation (10-year straight line), $/yr	2,200	4,900	7,400
Interest, taxes, insurance (10%), $/yr	2,200	4,900	7,400
Maintenance (3%)[b], $/yr	660	1,500	2,200
Total annual cost[a], $/yr	6,400	15,000	23,000

[a]Total has been rounded to two significant figures.

[b]Maintenance may also be estimated at 5 percent. (See Section 7.)

lists the capital investment, direct operating cost, and total annual cost associated with the use of a shell-and-tube condenser.

6.1.2.4.2 Discussion--Condenser and cooling-tower costs were based on estimates obtained from several equipment vendors and manufacturers. Condenser costs are for a unit consisting of a carbon steel shell and stainless steel tubes in a fixed-tube sheet. The condensers were assumed to operate at approximately atmospheric pressure and were designed for peak evaporation rates. Design calculations were based on a logarithmic mean temperature difference of 90° F, with a condensate exit temperature of 140° F and an overall heat-transfer coefficient of 130 Btu per hour per square foot per °F. Cooling towers were designed to provide cooling from 115° to 85° F at a wet-bulb temperature of 78° F. All costs reflect a January 1973 basis.

Water costs were assumed to be 10 percent of the cost associated with a direct-contact condenser. Sewage charges were based on a rate of $0.65 per 1000 gallons of condensate (location near larger municipalities than were assumed in Table 6-4). Electrical charges were based on a 10-horsepower motor requirement for Model B, a 30-horsepower requirement for Model C, and a 45-horsepower requirement for Model D. These requirements include both cooling-tower fan and pumping motors. The cost of electricity was assumed to be $0.015 per kilowatt-hour.

The operating costs for Models C and D are based on a 3,200-hour year. As with Models A and B, these estimates were made from production and plant size data in the 1967 U. S. Census of Manufacturers.

6.1.3 Air-Cooled Surface Condensers

6.1.3.1 Description

Air-cooled surface condensers are used extensively in those cases wherein heat rejection from a process is possible by using ambient air as the coolant. Air-cooled condensers are usually constructed with either fin tubes or some other form of extended surface to increase the heat transfer area. A typical fin tube design is shown in Figure 6-3. Condensing steam has a large heat-transfer coefficient, and air has a very small one. Therefore, air is placed on the fin side to take advantage of the large heat-transfer area. Condensation occurs inside the tubes.

Air-cooled condensers offer an advantage over water-cooled units in that they require no water connections, cooling towers, or cooling-water treatment and are simpler to install. Operating costs for an air-cooled condenser may be higher than for an equivalent water-cooled condenser, however, because of the larger power consumption of the fan.

Air-cooled condensers are usually provided with multiple fan units, one of which has a two-speed motor. As the ambient air temperature decreases, a temperature probe in the condensate line senses the corresponding decrease in water temperature and either shuts off fan motors or switches the two-speed fan motor to a lower speed. This conserves power and prevents condenser freeze-up during the winter months.

6.1.3.2 Emission Reduction

The emission reduction associated with the use of a surface condenser was discussed previously in Section 6.1.2.2. If a condenser could be designed to provide cooling of the condensate to 80° F, the odor emissions would be decreased by about 50 percent.[1] Most air-cooled condensers, however, are not designed to provide cooling of the condensate below 140° F, and their main function is to condense water vapor.

6.1.3.3 Condensate Treatment

Condensate treatment is the same as that provided for the condensate from a direct-contact condenser. Condensate volumes range from 280 gallons per hour for Model B to

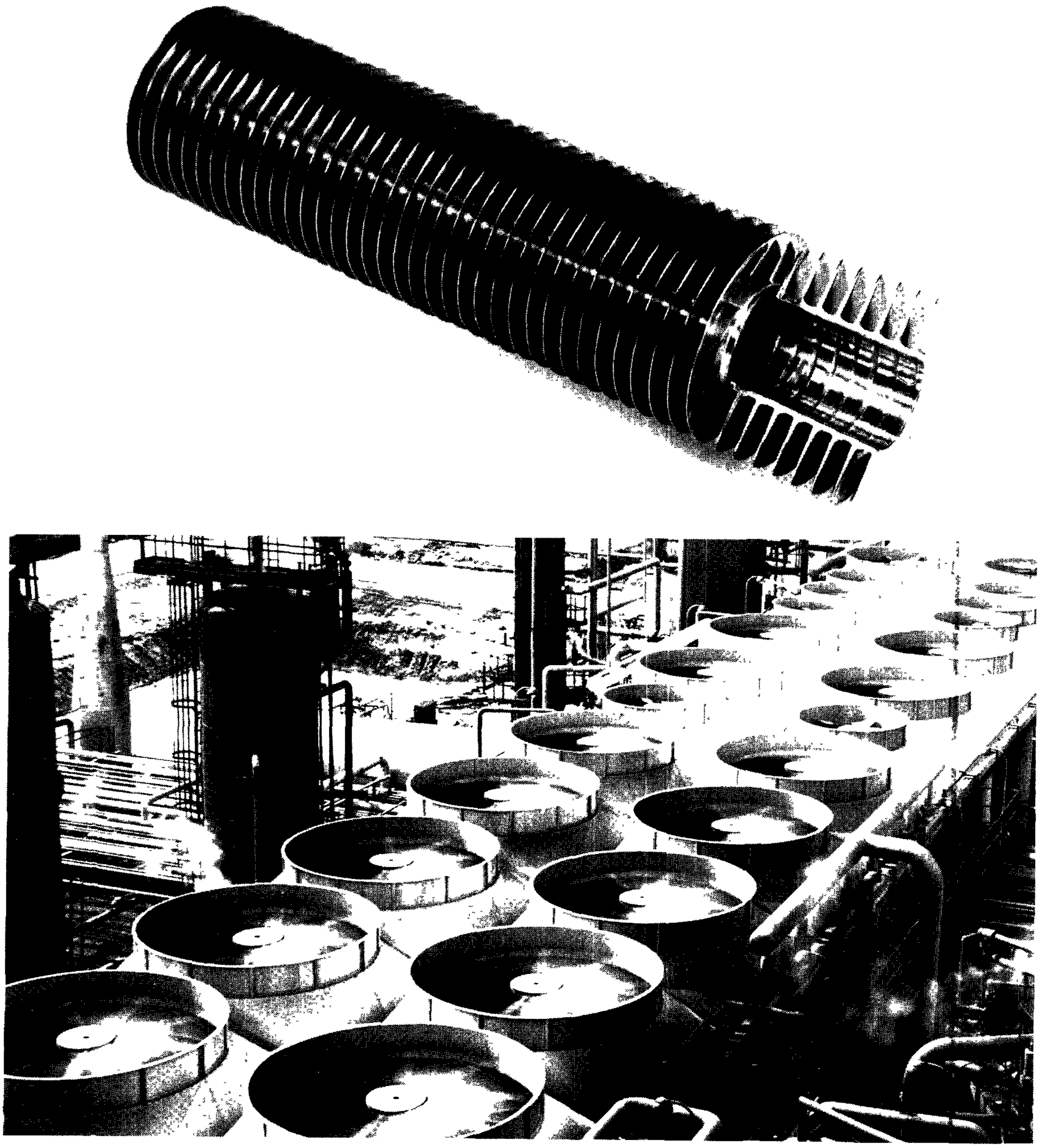

Figure 6-3. Types of air-cooled surface condensers (top) fin tube (courtesy Calumet and Hecla, Inc., Allen Park, Mich.) and (bottom) fin fan (courtesy Hudson Engineering Corp., Houston, Texas).[2]

1200 gallons per hour for a plant comparable to Model D. A discussion of the required sewage treatment was presented in Section 6.1.1.3.

6.1.3.4 Equipment Costs

6.1.3.4.1 Introduction--This section presents the cost of air-cooled condensers for Model plants B, C, and D. The relatively high initial cost of this type of condenser would make its use impractical in a plant similar to Model A Table 6-6 presents estimates of the capital investment, direct operating cost, and total annual cost.

Table 6-6. CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF AN AIR-COOLED SURFACE CONDENSER

	Model B	Model C	Model D
Raw material process rate, lb/hr	5,200	15,000	22,500
Capital investment, $			
Air-cooled surface condenser	16,000	44,000	58,000
Operation, hr/yr	3,200	3,200	3,200
Operating costs, $/yr			
Electricity	540	1,600	2,200
Sewage	570	1,700	2,500
Total direct cost[a]	1,100	3,300	4,700
Depreciation (10-year straight line), $/yr	1,600	4,400	5,800
Interest, taxes, insurance (10%), $/yr	1,600	4,400	5,800
Maintenance (3%), $/yr	480	1,300	1,700
Total annual cost,[a] $/yr	4,800	13,000	18,000

[a]Total has been rounded to two significant numbers.

6.1.3.4.2 Discussion --The costs of air-cooled surface condensers were obtained from recent contacts with several equipment vendors. Costs are based on the use of stainless steel tubes equipped with aluminum fins. Design calculations assumed a logarithmic mean temperature difference of 100° F and an overall heat-transfer coefficient of 7.7 Btu per hour per square foot per °F. Condensers were sized to handle peak evaporation rates. Costs are on a January 1973 basis.

Sewage costs were based on a charge of $0.25 per 1000 gallons of condensate treated. Electrical costs were for the operation of a 15-horsepower fan for Model B, three 15-horsepower fans for Model C, and four 15-horsepower fans for Model D. A rate of $0.015 per kilowatt-hour was used for all calculations.

Comparison of Tables 6-6 and 6-5 indicates higher costs for shell-and-tube than for air-cooled condensers for the model cases taken. In practice, such costs can be altered by relative heat-transfer fouling tendencies of various odorous streams, relative maintenance requirements, meteorological conditions for the locality, and availability and temperature of water.

6.2 INCINERATORS

Flame incineration is an effective control method for rendering-plant odors provided the incineration time and temperature are sufficient for complete oxidation of odorous vapors. In fact, many state and local control agencies have established odor-control regulations based on flame incineration time and temperature.

The presence of the flame appears to have a very important effect on the efficiency of odor removal. It has been suggested that in the absence of a flame, using electrical thermal heat alone, much higher temperatures would be required to obtain the same efficiency achieved with a direct-flame oxidation system. Data on themal destruction of odors by electric heating, however, are very limited.

Incinerators have been used alone and in combination with other control equipment, principally condensers. Total incineration is used to control low-volume, low-moisture streams such as cooker noncondensables. In some instances, a dust collector (centrifugal collector, baghouse, or precipitator) must be used ahead of an incinerator to remove particulate matter.

6.2.1 Description

Figure 6-4 is a diagrammatic representation of a rendering plant afterburner with heat recovery. The burner has a mixing plate or other suitable design so that all of the air used for full combustion comes from the odorous air stream. If the combustion air were taken from outside, a greater amount of fuel would be required to raise to 1200° F the additional air so introduced into the system. As shown, the total gas stream is raised to 1200° F to destroy odor, and about half of the heat is recovered by exchange against the feed stream. From a practical standpoint, 65 percent heat recovery is about the maximum attainable. The offerings of one afterburner manufacturer include units for 35 percent and 42 percent heat recovery. The unit price increases with the percentage of heat recovery, as does the power required to move the gas. Fuel saving greatly offsets this increased power cost, however.

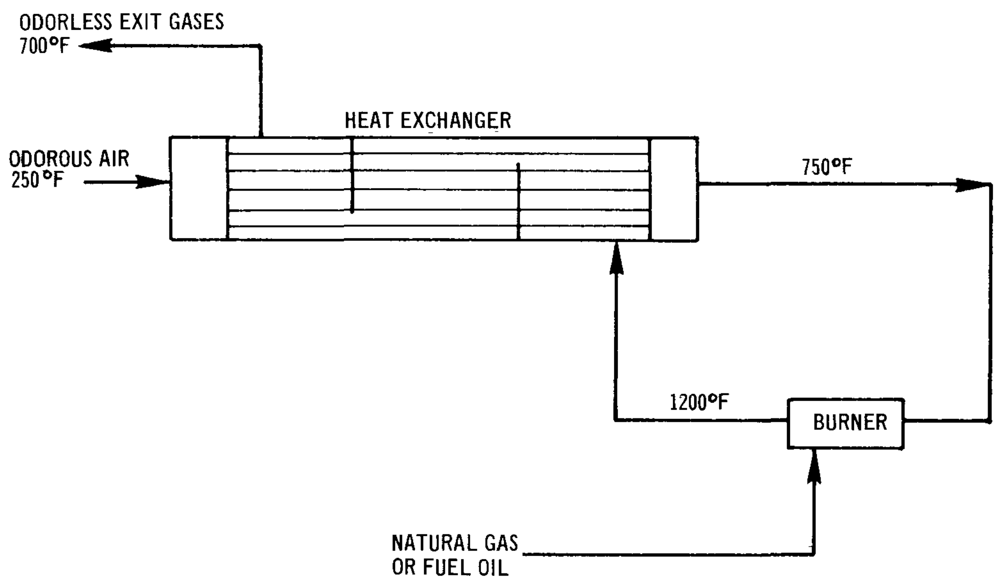

Figure 6-4. Diagrammatic representation of rendering plant afterburner with heat recovery.

Ideally, the heat saving indicated by Figure 6-4 would approach 100 percent if the exit odorless air could be cooled to perhaps 260° F instead of 700° F as indicated. This is not feasible because of the greater heat exchange surface requirements and the phenomenon of temperature crossing. Figure 6-4 shows a diagrammatic heat exchanger in which the cold gas flows through tubes or other passages separated from the hot gas flow. It is obvious that the two shell-side baffles tend to prevent back-mixing and, therefore, aid heat transfer by increasing the temperature differences in each of the three exchanger portions. Each baffle also contributes to increased gas-pressure drop. Similarly, one could get increased heat recovery with two or more shells, but at the expense of further capital cost and pressure drop.

The usual construction of an incinerator employs a steel outer shell lined with a refractory material. The purpose of the refractory is to protect the steel shell from direct exposure to high temperatures and corrosive materials, and to improve thermal efficiency by limiting heat losses. The refractory may have any one of a number of chemical compositions and physical forms. Most refractories used in incinerators are made up of high-duty fire clay and are usually encountered in the form of bricks and castables. In some instances high-temperature alloy metals are used as liners.

Figure 6-5 is a sketch of an incinerator with a heat-recovery unit. The odorous stream enters the incinerator at the inlet elbow and is heated as it passes through the crossover duct and enters the combustion chamber where it is incinerated. Heat is recovered from the incinerated stream as it passes around the tubes of the heat-recovery unit before being discharged through the stack. Heat-recovery afterburners are usually constructed almost entirely of metal.

This type of heat recovery unit is practical (fuel saving over the cost of the heat-recovery unit) for incinerators processing large-volume streams. Other heat-recovery units use waste heat to produce steam. Incinerators are usually fired with gas, but may use distillate fuel oil if gas is unavailable.

The fuel shortage and the rising costs of fuel should draw much attention to the improvement of afterburners and heat recovery, as well as furnish added incentive for the improvement of scrubbers and of odor testing to demonstrate their performance.

6.2.2 Boiler Firebox Incineration

In order to minimize incineration costs, some rendering plants are using boiler fireboxes to incinerate cooker noncondensables and other low-volume, low-moisture reduction streams. Firebox incineration is attractive because it lowers initial capital investment and operating costs by eliminating the need for an incinerator and its associated fuel, operation, and maintenance.

Water-tube, locomotive or HRT boilers, and fired heaters are the units most frequently used as afterburners.[8] Burners used with these units are usually adaptable to incineration, and the fireboxes are usually accessible. Scotch marine boilers, another type, are sometimes adaptable.

The odorous gases may be introduced either through the burner or through the floor or sides of the fireboxes. Figures 6-6a and 6-6b show examples of poor and good installations in which the odorous gases are introduced through the burner.

Boiler firebox conditions approximate those of a well-designed incinerator, provided adequate temperature, retention time, turbulence, and flame are present Completely satisfactory adaptations of boiler fireboxes for use as incinerators, however, are not common. All aspects of operations should be thoroughly evaluated before this method of odor control is used. Some problems that may accompany firebox incineration are discussed below.

Contaminants from cooker noncondensables and other reduction streams can foul the burner and boiler tubes. Some plants use water scrubbers (contact condensers) to clean the reduction streams before passing them through the controls and burners and incinerating them in the boiler firebox.

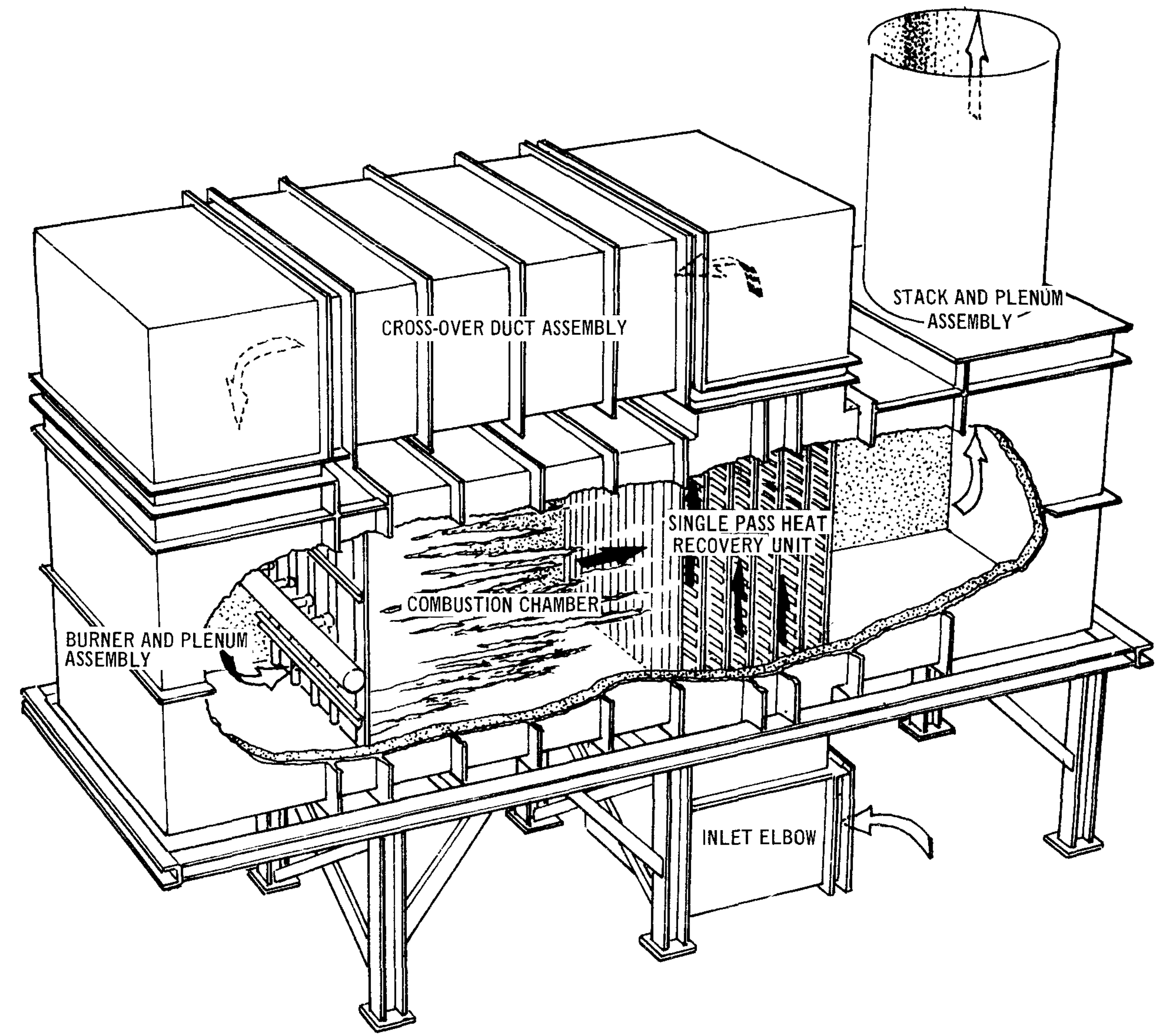

Figure 6-5. Flame incinerator with heat recovery unit. (courtesy Combustion Engineering, Inc., Wellsville, New York)

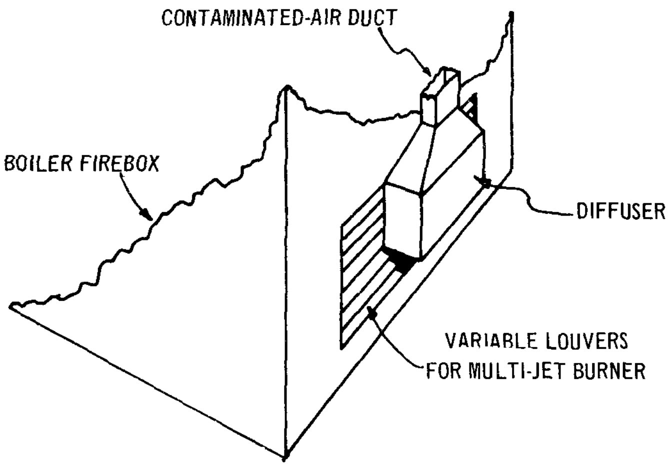

Figure 6-6a. Poor method of introducing odorous air from diffuser to boiler firebox through the burner air register. Diffuser restricts combustion air to burner, also the louvers may partially close, restricting flow of odorous air into boiler firebox.[8]

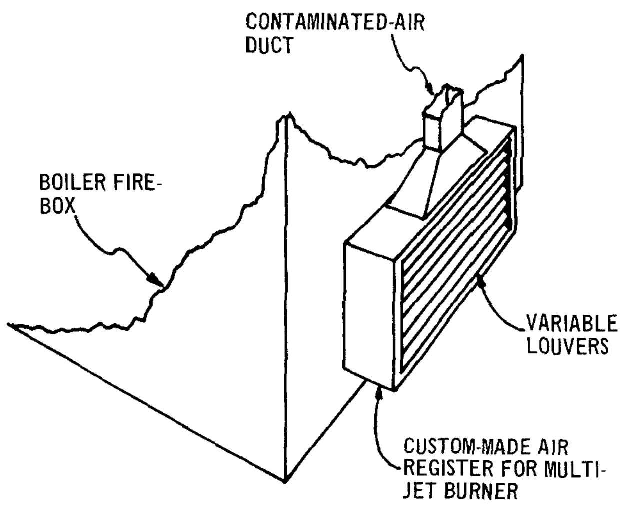

Figure 6-6b. Good method of introducing odorous air to boiler firebox through a custom-made air register. There is good flame contact [8]

The boiler must be fired at an adequate rate at all times when effluent is vented to the firebox, regardless of steam requirements. High-low or modulating burner controls are satisfactory provided that the minimum firing rate is sufficient to incinerate the maximum volume of effluent that can be expected in the boiler firebox. A burner equipped with on-off controls would not be feasible.

There is a possibility of accumulating concentrations of combustible gas with resultant explosion hazards upon lightoff of the boiler. For instance, a batch of raw or partially cooked animal matter might be left overnight in a cooker ducted to a boiler firebox incinerator. This decomposing matter might generate enough methane, hydrogen sulfide, and other organics to produce an explosive mixture in the ductwork leading to the boiler.[8] If, subsequently, the burner were ignited without first purging the line, an explosion could occur. Also, a fire hazard is created by the accumulation of organic material in ductwork. The degree of organic accumulation can sometimes be reduced by frequent steam purging or by heating the ductwork to prevent condensation.

6.2.3 Emission Reduction

The Los Angeles County Air Pollution Control District tested four rendering plants that use incineration to control cookers, blood driers, and feather meal driers. Incineration units at these plants were operated at 1200° F with a stream retention time of 0.3 second. Outlet emissions ranged from 70 to 140 odor units per standard cubic foot, with an average of 105 odor units per standard cubic foot. These results represented an odor-removal efficiency of better than 99 percent.[9]

6.2.4 Equipment Costs

The gas volumes to the incinerator were estimated by reducing peak cooker emissions (700, 2,300, 6,700, and 10,000 acfm for Models A, B, C, and D, respectively) by a factor of 10, and adding 400 acfm per cooker for accompanying presses and processing tanks. The volumes of the incinerated streams are listed in Table 6-7.

Table 6-7. VOLUMES OF INCINERATED STREAMS

Model	Volume of non-condensables from cookers, acfm @ 250 °F	Number of cookers	Volume of streams from presses and processing tanks, acfm @ 250 °F	Approximate volume to incinerator,[a] acfm @ 250 °F
A	70	1	400	500
B	230	3	1,200	1,500
C	670	6	2,400	3,000
D	1,000	9	3,600	5,000

[a]Total has been rounded to two significant figures. These volumes are the basis of the incinerator sizes used in the cost estimates in Table 6-8.

Incinerator costs (Table 6-8) were determined for low-moisture, low-volume streams from cookers (noncondensables only), presses, process tanks, and driers. Condenser costs must be added to these figures to obtain the total cost of control. Condenser costs are listed in Tables 6-4, 6-5, and 6-6, and total costs are listed in Table 6-9.

Incinerator costs for the models were obtained by averaging quotes from several manufacturers. The costs reflect a January 1973 basis.

Electrical costs were for the operation of a 0.75-horsepower fan motor for Model A, a 2.5-horsepower fan for Model B, a 7-horsepower fan for Model C, and a 17.5-horsepower fan for Model D. A rate of $0.015 per kilowatt-hour was used for all calculations.

Table 6-8 indicates that the capital investment of flame incineration is proportionately higher for smaller plants. For instance, Model D's 5,000 acfm incinerator, which handles 10 times the volume of Model A's 500 acfm incinerator, is just slightly over twice the cost. Annual costs are more in line with incinerator sizes but are still proportionately higher for smaller plants because of depreciation, taxes, and maintenance costs.

Table 6-8. CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF INCINERATION

	Model A	Model B	Model C	Model D
Capital investment, $				
Incinerator	9,500	13,000	18,000	20,000
Operation, hr/yr	2,140	3,200	3,200	3,200
Operating costs, $/yr				
Fuel	1,000	4,600	9,200	15,000
Electricity	20	90	250	630
Total direct cost,[a] $	1,000	4,700	9,500	16,000
Depreciation (10-yr straight line), $/yr	950	1,300	1,800	2,000
Interest, taxes, insurance (10%), $/yr	950	1,300	1,800	2,000
Maintenance (6%), $/yr	560	780	1,080	1,200
Total annual costs,[a] $/yr	3,500	8,100	14,000	21,000

[a]Total has been rounded to two significant figures. See Table 6-3 for process rate and Table 6-7 for gas volumes to incinerators.

6.2.5 Fuel Costs

It was assumed that the afterburner fuel was natural gas and that no heat recovery was practiced. It was further assumed that the combustion air was the odorous gas (Section 6.2.1). The following data and assumptions were used:

1. Natural gas cost	$\$1/10^3$ scf
2. Net heating value of gas	900 Btu/scf
3. Net heating value of gas	19,000 Btu/lb
4. Density natural gas	0.046 lb/ft^3
5. Incineration temperature	1200° F
6. Specific heat (average) air	0.255
7. Specific heat (average) gas	0.80

Then, for Model C, 3000 acfm of air to incinerator at 250° F is 10,200 lb/hr of air, basis 70° F standard.

$$10,200 (1200 - 250) 0.255 + X (1200 - 70)\ 0.80 = 19,600X$$

X = fuel rate = 132 lb/hr natural gas

From this, the annual fuel cost at 3200 hours operation is $9200.

For No. 2 fuel oil, we may find the fuel cost for Model C on the following assumptions:

net heating value of no. 2 oil	18,000 Btu/lb
lb/gal	7.2
specific heat (average) oil	0.47
oil cost (6/73)	$0.17/gal

Table 6-9. CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF A CONDENSER-INCINERATOR SYSTEM

	Model A	Model B		
Raw material process rate, lb/hr	1,560	5,200		
Capital investment, $				
Surface condenser (water-cooled)		10,000		
Cooling tower		12,000		
Surface condenser (air-cooled)			16,000	
Contact condenser	2,900			5,000
Incinerator	9,500	13,000	13,000	13,000
Total capital investment, $	12,000	35,000	29,000	18,000
Operation, hr/yr	2,140	3,200	3,200	3,200
Operating costs, $/yr				
Fuel	1,000	4,600	4,600	4,600
Water	720	350		3,500
Sewage	2,280	570	570	11,400
Electrical	40	450	630	160
Total direct cost[a], $	4,000	6,000	5,800	20,000
Depreciation (10-year straight line), $/yr	1,200	3,500	2,900	1,800
Interest, taxes, insurance (10%), $/yr	1,200	3,500	2,900	1,800
Maintenance (3%)[b], $/yr	650	1,400	1,300	930
Total annual cost,[a] $/yr	7,100	14,000	13,000	25,000

[a] Total has been rounded to two significant figures.

[b] Maintenance for incinerators is 6 percent of their investment.

In this case, the fuel rate is 141 lb/hr, and the cost is $10,700/yr.

If all of the combustion air for Model C had been taken from the outside, 10.36 scf of extra air per scf of natural gas would have been added to the stream being heated. This amounts to 16.9 lb air/lb natural gas burned.

$$(10{,}200 + 16.9X)\ (1200 - 250)\ 0.255 + X\ (1200 - 70)\ 0.80 = 19{,}600X$$

The fuel rate increases to 168 lb/hr of natural gas, and the annual cost is $12,000.

6.3 CONDENSER-INCINERATOR SYSTEMS

Condenser-incinerator combinations are usually more practical as well as more efficient than incinerators, especially for controlling cooker streams. When a condenser is used to remove steam from cooker streams before incineration, the volume of the stream is reduced as much as 20 times, and a considerable portion of malodors is removed with the condensate.[9] Other reduction streams that contain from 15 to 40 percent moisture

Table 6-9 (continued). CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF A CONDENSER-INCINERATOR SYSTEM

	Model C		Model D	
Raw material process rate, lb/hr	15,000		22,500	
Capital investment, $				
Surface condenser (water-cooled)	20,000		31,000	
Cooling tower	29,000		43,000	
Surface condenser (air-cooled)		44,000		58,000
Incinerator	18,000	18,000	20,000	20,000
Total capital investment, $	67,000	62,000	94,000	78,000
Operation, hr/yr	3,200	3,200	3,200	3,200
Operating costs, $/yr				
Fuel	9,200	9,200	15,000	15,000
Water	1,000		1,600	
Sewage	1,700	1,700	2,500	2,500
Electrical	1,300	1,900	2,200	2,800
Total direct cost[a], $	13,000	13,000	21,000	20,000
Depreciation (10-year straight line), $/yr	6,700	6,200	9,400	7,800
Interest, taxes, insurance (10%), $/yr	6,700	6,200	9,400	7,800
Maintenance (3%)[b], $/yr	2,600	2,400	3,400	2,900
Total annual cost,[a] $/yr	29,000	28,000	43,000	39,000

[a]Total has been rounded to two significant figures.

[b]Maintenance for incinerators is 6 percent of their investment.

may also warrant the use of a condenser.[10] Factors such as volumes, exit temperatures, fuel costs, water availability, and equipment cost determine condenser feasibility for these streams.

Figure 6-7 shows a typical condenser-incinerator system. The entrainment separator prevents animal matter that may escape the cooker from entering the condenser and incinerator. The use of a water-cooled surface condenser indicates that the system is probably designed to handle a large volume of cooker gases. Notice that the low-moisture streams are added downstream from the condenser.

6.3.1 Emission Reduction

Tests by the Los Angeles County Air Pollution Control District showed the following emissions for rendering plants controlled by condenser-incinerator systems:[9]

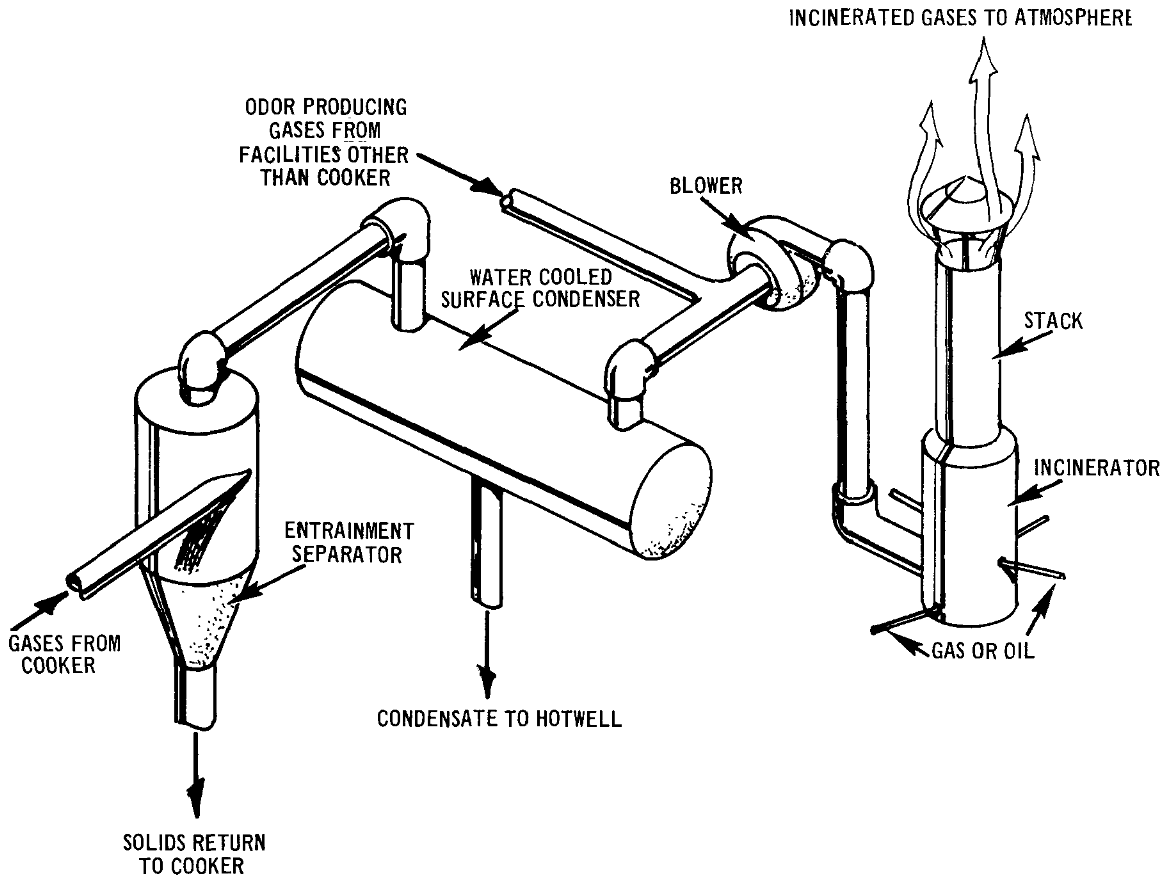

Figure 6-7. Odor-control system with entrainment separator, surface condenser, and incinerator.

1. Contact condenser-incinerator systems:
   a. Three plants with cookers and blood dryers - Avg. 63 o.u./scf*
   b. Six plants with cookers - Avg. 27 o.u./scf

2. Surface condenser-incinerator systems:
   a. Four plants with cookers and blood dryers - Avg. 99 o.u./scf
   b. Three plants with cookers using boiler incineration - Avg. 27 o.u./scf
   c. One plant with cooker, press, and processing tank - Avg. 85 o.u./scf

Figure 6-8, which compares the effectiveness of several incineration and condenser-incinerator systems, shows that the aforementioned odor reductions are slightly better than the results obtained by incineration alone. Although both methods provide greater than 99 percent efficiency, the combination system results in a much lower odor emissions rate.

6.3.2 Equipment Costs

Table 6-9 outlines control costs for existing plants, represented by Models A, B, C, and D. The cost data for contact and surface condensers were calculated in Sections

*The odor unit per standard cubic foot was defined in Section 4.3.

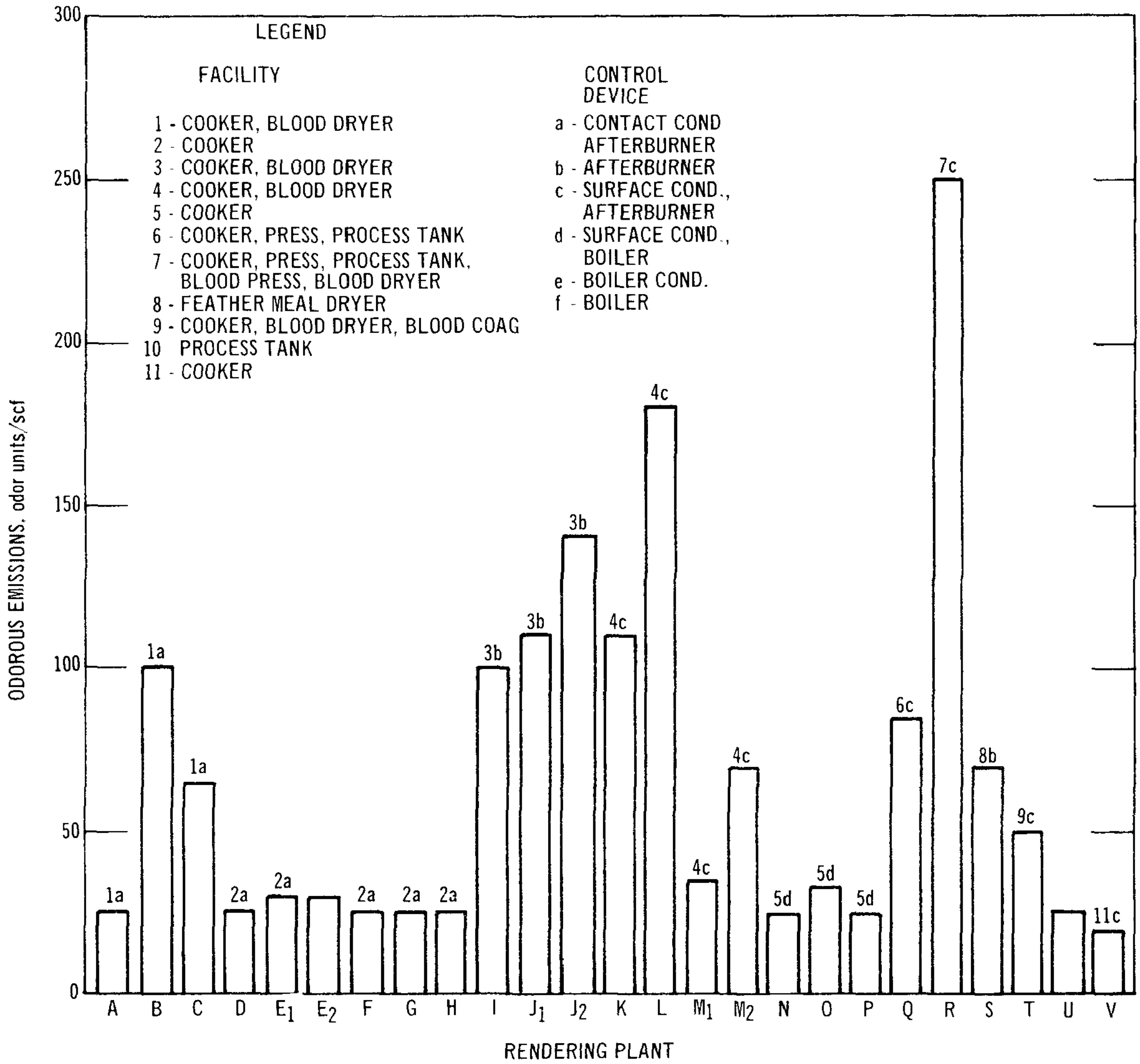

Figure 6-8 Odorous emissions from various facilities.[9]

6.1.1.4, 6.1.2.4, and 6.1.3.4. The cost data for incinerators were calculated in Section 6.2.4.

Cost figures for Model A are determined only for contact-condenser-incinerator systems because, in most cases, water- and air-cooled surface condensers are too costly for this size plant. On the other hand, costs are shown for all three alternatives for Model B (contact and air- and water-cooled condensers coupled with an incinerator) since their costs are more comparable, and the least expensive control system will vary, depending on individual plant circumstances. Local water, electricity, sewage treatment costs, and the actual bids on equipment and installation costs will determine the most economical choice for a plant of Model B's size. Although the control costs for contact condensers are high for Model B, these costs were calculated for city water usage. As pointed out in Section 6.1.1.4, some rendering operations have access to free water, and contact condensers would be economical for these plants.

The most economical controls for Models C and D are water- and air-cooled condenser-incinerator systems. Again, the least expensive control system will vary, depending upon local water and electricity costs and the actual bids on equipment and installation costs.

6.4 SCRUBBING

6.4.1 Description

A control technique that has received increasing attention in recent years is chemical scrubbing. Chemical scrubbing is essentially a gas-absorption technique whereby one or more constituents of a gas stream are removed by dissolving them in a selective liquid solvent. In addition to simply being dissolved, the absorbed gases may chemically react with the scrubbing liquid. Scrubbing offers economic advantages over incineration methods when treating large volumes of air containing relatively low concentrations of malodorous contaminants and saturated air streams.

One limitation on the use of chemical scrubbers has been the inlet concentration of malodorous gases. Odor concentrations greater than 10,000 to 20,000 odor units per cubic foot have complicated the problem of providing adequate gas-liquid contact time in the scrubber.[11] This restriction would preclude the use of scrubbers on a basis similar to incinerators, which are generally designed to treat low volumes of highly concentrated odors. The usual solution to the odor inlet limitation of scrubbers has been to reduce the odor concentration of highly odorous streams to 10,000 to 20,000 odor units per cubic foot by mixing them with percolator pan ventilation air, expeller exhaust, and general plant ventilation air.[11] Scrubbing systems are therefore designed to treat large volumes of air that include most of the rendering plant air streams. One three-stage system, however, is currently being installed to treat high-intensity odors.

Scrubbers are designed to provide thorough contact between the gas and liquid streams to allow interphase diffusion of the gases being absorbed. The required degree of contact can be provided by several types of equipment. Bubble-plate columns, jet scrubbers, packed towers, spray chambers, and venturi scrubbers are types of equipment that have been used for gas absorption work. Figures 6-9 and 6-10 present examples of several of these systems.

Packed towers and spray chambers are the most commonly used equipment because of their relatively low pressure losses. Spray chambers have the advantage of being able to handle exhaust gases containing particulate matter without plugging. Packed towers provide the more effective gas-liquid contacting.

Acid, alkaline, and strong oxidizing solutions are scrubbing liquids that have been employed to control rendering-plant malodors with varying degrees of success. It is conceivable that alkaline or acid scrubbers could be effective control devices if all odorous compounds reacted in the same manner, but the mixture of malodorous gases encountered during the rendering process is not homogenous from an acid-base standpoint (Section 4.2). Some success has been reported for a system using both acid and alkaline scrubbing solutions in a two-stage, spray-chamber unit.[12] This system has been installed in several rendering plants about the country and usually employs a first-stage scrubbing solution of soda ash. Sometimes a second-stage scrubbing solution of sodium bisulfite, calcium hypochlorite, or chlorine water is also employed. Several of these scrubbers can accommodate an entire plant. Applications of this system to date have been primarily in the treatment of general plant ventilation air, expeller exhausts, and percolator pan exhausts. There is some doubt that this scrubber could effectively treat the more concentrated cooker and drier odors unless they were diluted. Dilution increases scrubber size and costs.

Strong oxidizing solutions such as chlorine dioxide, sodium hypochlorite, and potassium permanganate are reported to be effective means of eliminating odors. Given sufficiently vigorous reaction conditions, potassium permanganate is capable of oxidizing

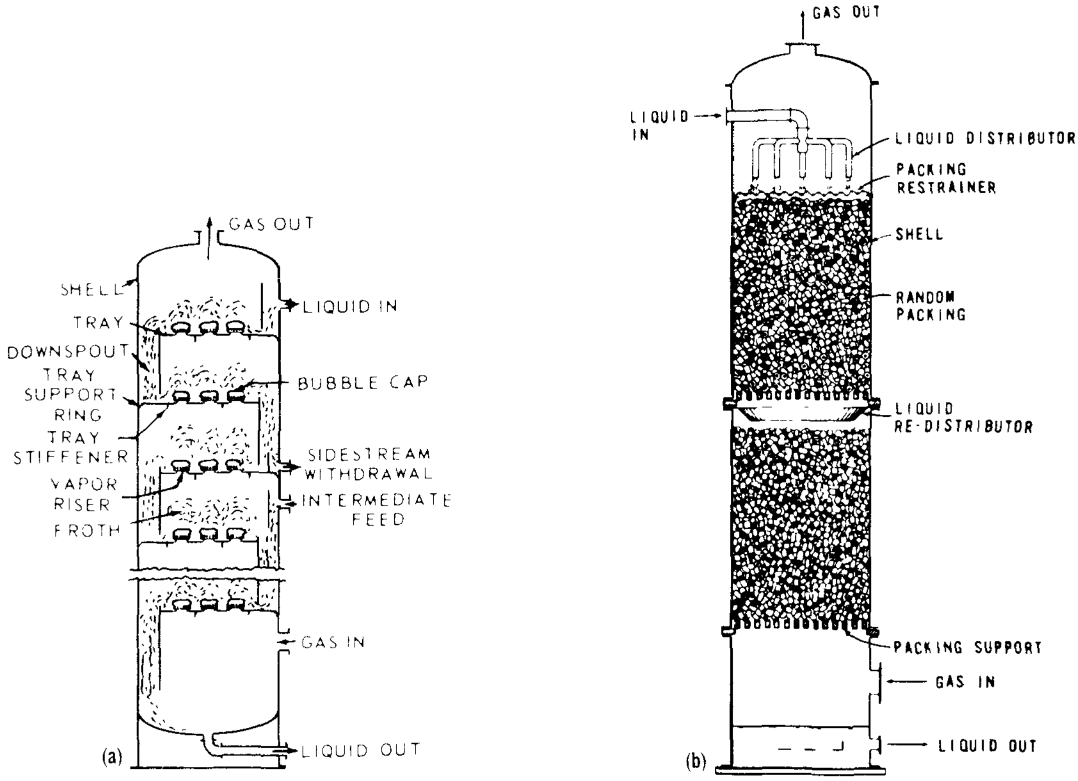

Figure 6-9 Types of absorption equipment: (a) bubble-cap tray tower and (b) packed tower [13]

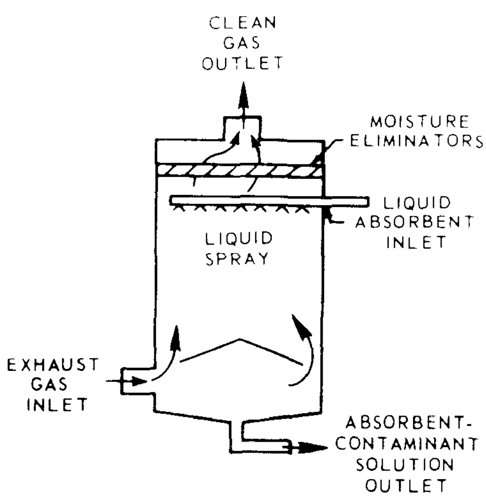

Figure 6-10a. Spray-chamber absorption device.[13]

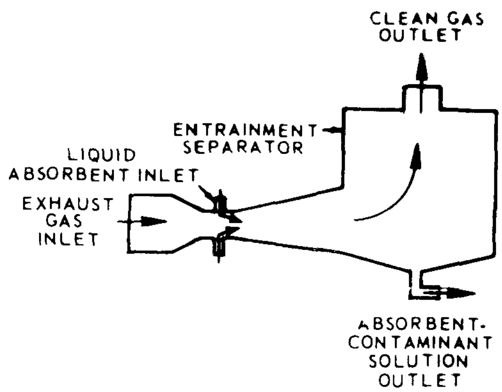

Figure 6-10b. Venturi scrubber absorption device.[13]

most organic compounds.[14] Under the relatively mild conditions usually employed by most scrubbing systems, however, not all organic compounds will readily react. Those odorous compounds that are susceptible to oxidative degradation under relatively mild conditions are aldehydes, reduced sulfur compounds, unsaturated ketones and hydrocarbons, phenols, amines, hydrogen sulfide, and sulfur dioxide.[14] Among the compounds that resist oxidation under these conditions are saturated organic acids and hydrocarbons, ketones, and certain nitrogen ring compounds. Potassium permanganate scrubbing solutions have the disadvantage of being more expensive and requiring more extensive sewage treatment than sodium hypochlorite solutions. Sodium hypochlorite has a faster reaction rate than potassium permanganate and is effective against most of the same spectrum of odorants.[15]

Available data on a two-stage scrubber that uses either a potassium permanganate solution or a sodium hypochlorite solution as the scrubbing liquid indicate that this unit should be able to successfully treat cooker exhaust gases. A diagram of this system is presented in Figure 6-11.

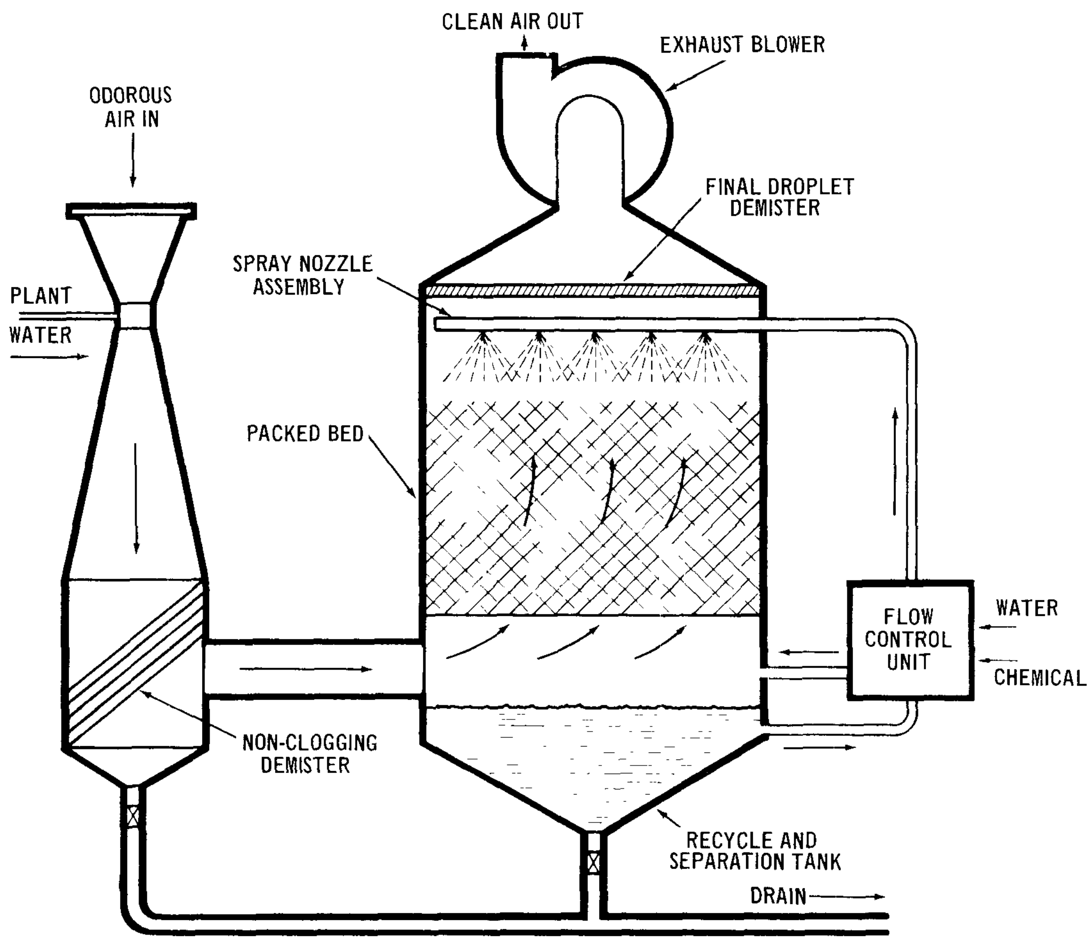

Figure 6-11. Two-stage chemical scrubbing system (courtesy Environmental Research Corp., St Paul, Minn.)

The malodorous gases enter the first stage of the system where they are treated in a venturi scrubber using water as the scrubbing liquid. This step removes particulate matter and cools and saturates the gas stream. The gases are then passed through a packed bed where they contact a countercurrent stream of scrubbing liquid. Malodorous gases are absorbed and oxidized. The scrubbed gas stream exits the packed bed, flows through a mist elimination section, and is exhausted to the atmosphere. The depleted scrubbing liquid is collected and recycled to the scrubber. A portion of the depleted scrubbing solution is continuously removed from the recycle stream and replaced with make-up water and chemicals.

The bleed stream is combined with the waste water from the venturi scrubber and sent to a sewage treatment facility.

The decision on whether to install a full two-stage system in a specific rendering plant would depend on the nature of the gases being scrubbed. A two-stage system would be required to treat gas streams with a high particululate loading or a high odor concentration, i.e., the exhaust from blood driers or cooker off-gases. When treating general ventilation air, percolator pan ventilation air, or expeller exhausts, the venturi scrubber could be eliminated.

6.4.2 Emission Reduction

Available information indicates that scrubbing with a solution of either potassium permanganate or sodium hypochlorite may reduce odor concentrations from 25,000 odor units per cubic foot to between 50 and 200 odor units per cubic foot.[11,16] This reduction was for a system similar to the one shown in Figure 6-11. Odor concentrations at the scrubber inlet and outlet were measured by the recommended ASTM method using odor panels. The 11 plants that were tested had flow rates ranging from 6,000 to 55,000 cubic feet per minute. An EPA observer participated in tests at one of these 11 plants, and believes that the above performance was demonstrated in the case that he observed.

It must be pointed out that these tests were made by the equipment vendor and/or his customers. The Environmental Protection Agency made odor panel tests involving three such scrubbers at two rendering plants in January 1973. These tests did not confirm the earlier claims. Because the EPA tests were not conducted under entirely representative conditions, however, further testing is required.

6.4.3 Sewage Treatment

The amount of treatment required by the scrubbing system waste water is, in most cases, similar to that required by condenser condensate. If a potassium permanganate solution is used as the scrubbing liquid, however, additional sewage treatment may be necessary.

The volume of liquid effluent requiring treatment will depend upon the specific scrubbing system and the individual plant. A two-stage system similar to the one presented in Figure 6-11 will produce approximately 180 gallons of waste water per hour for each 1000 cubic feet per minute of air treated in the venturi, and from 12 to 20 gallons per hour for each 1000 cubic feet per minute of air treated in the packed-bed scrubber. There will be some scrubbing chemical in the waste water from the packed bed. Concentrations can range from 5 to 20 ppm of available chlorine when sodium hypochlorite is the scrubbing chemical.

A more complete discussion of the amount of sewage treatment necessary for rendering plant effluent and the associated cost was presented in Section 6.1.1.3.

6.4.4 Equipment Costs

The capital investment, direct operating cost, and total annual cost of a chemical scrubbing system (Figure 6-11) are presented in Table 6-10 for Models B, C, and D. Condenser costs must be added to these figures to obtain the total costs of control. Unit sizing, equipment investment, and operating costs are based on data obtained from the

Table 6-10. CAPITAL INVESTMENT, DIRECT OPERATING COST, AND TOTAL ANNUAL COST OF A CHEMICAL SCRUBBING SYSTEM

	Model B	Model C	Model D
Raw material process rate, lb/hr	5,200	15,000	22,500
Capital investment, $	30,000	42,000	42,000
Operation, hr/yr	3,200	3,200	3,200
Operating costs, $/yr			
Water	420	660	660
Sewage	1,300	2,000	2,000
Chemicals (sodium hypochlorite)	540	710	710
Electricity	1,400	2,200	2,200
Labor	2,000	2,000	2,000
Total direct cost[a], $	5,700	7,600	7,600
Depreciation (10-year straight line), $/yr	3,000	4,200	4,200
Interest, taxes, insurance (10%), $/yr	3,000	4,200	4,200
Maintenance (3%), $/yr	900	1,300	1,300
Total annual cost,[a] $/yr	13,000	17,000	17,000

[a]Total has been rounded to two significant figures.

scrubber manufacturer. A standard 14,000 ft^3/min unit was quoted to handle Model B, and the standard 21,000 ft^3/min unit was offered to handle either Model C or D. The use of a scrubbing system for Model A was not considered because of the large capital investment.

Water costs were based on a fee of $0.25 per 100 gallons. Sewage treatment costs were based on a charge of $0.75 per 1000 gallons. Electrical costs assumed a power requirement of 38 horsepower for Model B and 60 horsepower for Models C and D. Costs were based on a fee of $0.015 per kilowatt-hour. Chemical costs were based on a charge of $0.028 per gallon of 1 percent sodium hypochlorite solution. Model B was assumed to use 6 gallons per hour, and Models C and D were assumed to use 8 gallons per hour of this solution. Some labor has been included for handling of chemical scrubbing liquids and for operation of the scrubber.

6.5 REFERENCES FOR SECTION 6

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7. METHODS OF ESTIMATING CAPITAL INVESTMENT AND TOTAL ANNUAL COST FOR CONTROL EQUIPMENT

7.1 INTRODUCTION

The equipment costs used in this document are the free-on-board (f.o.b.) charge for either a specific piece or system of control equipment. Estimates of equipment costs were obtained by averaging quotes from manufacturers and vendors of control equipment. The equipment cost estimates served as the basis for the calculation of the capital investment and the total annual costs.

7.2 CAPITAL INVESTMENT

The capital investment for a piece or system of control equipment includes the following:

1. Purchase price (f.o.b. charge).
2. Cost of installation.
3. Engineering and supervision.
4. Instrumentation and control.
5. Piping and ductwork.
6. Electrical equipment and materials.

In the preceding list, the cost of installation includes the cost of labor, foundations, supports, platforms, construction expenses, and other factors directly related to the erection of the purchased equipment.[1]

Capital investment depends to a large extent on the circumstances of the plant installing the equipment. Factors such as freight charges, local labor costs, foundation requirements, and location of equipment affect capital investment and are unique for each plant.

The multipliers in Table 7-1 represent, as best as can be determined, an average or typical cost associated with installation, engineering, electrical connections, piping, etc. Capital investment is determined by multiplying f.o.b. cost by the multiplier. The multipliers were obtained from manufacturers, vendors, and the literature.[2] All estimates were adjusted for special construction materials and required operating specifications. An example of the former is the use of stainless steel on the tube side of shell-and-tube condensers.

7.3 TOTAL ANNUAL COST

Total annual cost (also called operating cost) is a combination of the total direct operating cost and the indirect operating costs. Indirect costs include depreciation, taxes, insurance, interest, and maintenance. Depreciation was taken as 10-year straight-line, which amounts to 10 percent of the total capital requirement per year. Annual interest, taxes, and insurance costs were estimated at 10 percent of the total capital investment, and maintenance at 3 percent, unless otherwise noted. The 3 percent maintenance estimate is accurate for contact condensers, but may be low for other control equipment. The reader may wish to recalculate operating costs, using 5 percent of the total capital investment for maintenance, to get more accurate values for the total annual costs of the other control equipment.

Table 7-1. ESTIMATION OF CAPITAL INVESTMENT

Type of equipment	Model	FOB cost, $	Multiplier	Capital requirement, $
Contact condenser	A	1,600	1.8	2.900
	B	2,800		5,000
Shell-and-tube condenser	B	4,300	2.4	10,000
	C	8,200		20,000
	D	13,000		31,000
Cooling tower	B	4,900	2.4	12,000
	C	12,000		29,000
	D	18,000		43,000
Air-cooled condenser	B	8,000	2.0	16,000
	C	22,000		44,000
	D	29,000		58,000
Incinerator	A	5,300	1.8	9,500
	B	7,000		13,000
	C	9,500		17,000
	D	11,000		20,000
Chemical scrubber	B	19,000	1.6	30,000
	C	26,000		42,000
	D	26,000		42,000

The total direct operating cost is a combination of the water, chemicals, fuel, sewage treatment, and electricity charges associated with the operation of a piece of control equipment. Specific charges were discussed in detail in Section 6.

7.4 REFERENCES FOR SECTION 7

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15. SUPPLEMENTARY NOTES This document was prepared in-house as a 111(d) document to accompany new source performance standards for rendering plant odors. Because this standard was abandoned, the report is issued as an information document.

16. ABSTRACT

This information document describes the inedible animal and poultry rendering industry and the control of odors therefrom. Industry statistics are presented. Rendering processes are described, along with the chemical nature and quantities of odors released. Odor effects on health and welfare are discussed. Control techniques for the odors are described and include use of condensers, afterburners, and chemical scrubbers. The capital and annual costs of control by each method are given on an early 1973 basis. Particular emphasis was placed upon costs for good control at existing plants already having mediocre control - such as by condenser. Costs for aqueous waste control are included where applicable.

17. KEY WORDS AND DOCUMENT ANALYSIS

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