9.5.5 Poultry Slaughtering

Emission Factor Documentation for AP-42
Section 9.5.5 Draft Report

and references from Chapter 2

January 1997
Never published

Emission Factor Documentation for AP-42
Section 9.5.5

Poultry Slaughtering

Draft Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group

EPA Contract 68-D2-0159
Work Assignment No. 4-04

MRI Project No. 4604-04

January 1997

Emission Factor Documentation for AP-42
Section 9.5.5

Poultry Slaughtering

Draft Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group
Research Triangle Park, NC 27711

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EPA Contract 68-D2-0159
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NOTICE

This document is a preliminary draft. It has not been formally released by the U. S. Environmental Protection Agency and should not at this stage be construed to represent Agency policy. It is being circulated for comments on its technical merit and policy implications.

PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment No. 4-04. Mr. Dallas Safriet was the requester of the work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 9.5.5
Poultry Slaughtering

1. INTRODUCTION

The document *Compilation of Air Pollutant Emission Factors* (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State and local air pollution control programs, and industry.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors usually are expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as making source-specific emission estimates for areawide inventories for dispersion modeling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations. The purpose of this report is to provide background information from test reports and other information to support preparation of AP-42 Section 9.5.5, Poultry Slaughtering.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the poultry slaughtering industry. It includes a characterization of the industry, a description of the different process operations, a characterization of emission sources and pollutants emitted, and a description of the technology used to control emissions resulting from these sources. Section 3 is a review of emission data collection (and emission measurement) procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. Section 4 describes the results of the literature search. Section 5 presents the AP-42 Section 9.5.5, Poultry Slaughtering.

2. INDUSTRY DESCRIPTION

2.1 INDUSTRY CHARACTERIZATION[1,2]

The poultry slaughtering and processing industry is classified under Standard Industrial Classification (SIC) 2015 which is made up of establishments primarily engaged in slaughtering, dressing, packing, freezing, and canning poultry, rabbits, and other small game, or in manufacturing products from such meats, for their own account or on a contract basis for the trade. This industry also includes the drying, freezing, and breaking of eggs. Establishments engaged primarily in cleaning, oil treating, packing, and grading of eggs are classified under SIC 5144, and are not addressed in this report.

The 1992 Census of Manufactures indicated that 193.8 thousand people were employed in the industry, an increase of 31 percent from the 1987 census. The leading States in employment in 1992 were Arkansas, Georgia, Alabama, and North Carolina, accounting for approximately 46 percent of the industry's employment.

Poultry production in the United States during 1995 totaled 19.1 billion kilograms (kg) (42.1 billion pounds [lb]). For purposes of this report, poultry production includes broilers, turkeys, and chickens. The leading States in total poultry production were Arkansas, Georgia, North Carolina, and Alabama, accounting for approximately 48 percent of total production. In 1992, there were 591 poultry slaughter and processing plants operating in the United States. Table 2-1 presents the number of U.S. poultry slaughter and processing plants by State operating in 1992. No data are available on the sizes or capacities of specific plants.

In 1995, there were 7,325,670,000 broilers slaughtered in the United States. These broilers produced 15.5 billion kg (34.2 billion lb) of carcass, averaging 2.1 kg (4.7 lb) per animal. Table 2-2 presents 1995 broiler production figures by State.

In 1995, there were 292,626,000 turkeys slaughtered in the United States. These turkeys produced 3.1 billion kg (6.8 billion lb) of carcass, averaging 10.5 kg (23.2 lb) per animal. Table 2-3 presents 1995 turkey production figures by State.

TABLE 2-1. NUMBER OF POULTRY SLAUGHTER AND PROCESSING PLANTS BY STATE, 1992[a]

State	Number of plants
Georgia	49
Arkansas	47
California	41
Alabama	37
Missouri	29
North Carolina	29
Pennsylvania	28
Minnesota	27
Mississippi	26
New York	21
Texas	20
Iowa	19
Ohio	19
Virginia	17
Florida	16
New Jersey	16
South Carolina	12
Illinois	11
Indiana	11
Tennessee	11
Maryland	10
Michigan	10
Wisconsin	9
Delaware	8
Washington	8

TABLE 2-1. (CONTINUED)

Nebraska	7
Oklahoma	6
Oregon	6
Colorada	5
Louisiana	5
Kentucky	4
Massachusetts	4
South Dakota	3
West Virginia	3
Maine	2
Utah	2
U.S. Total	591

[a]Reference 1. U.S. total includes figures for States not shown to avoid disclosing individual operations.

TABLE 2-2. BROILER PRODUCTION BY STATE, 1995[a]

State	Broilers processed, 1,000 lb
Georgia	5,136,000
Arkansas	4,982,900
Alabama	4,230,000
North Carolina	3,417,500
Mississippi	2,962,400
Texas	1,746,800
Delaware	1,394,400
Maryland	1,360,200
Virginia	1,196,500
California	1,179,000
Oklahoma	852,700
Missouri	800,500
South Carolina	680,400
Florida	615,100
Pennsylvania	607,000
Tennessee	572,000
West Virginia	391,200
Kentucky	258,000
Minnesota	249,600
Ohio	215,000
Washington	197,500
Oregon	105,500
Wisconsin	104,300
Iowa	72,000
Nebraska	18,600
New York	6,900

TABLE 2-2. (CONTINUED)

Hawaii	3,800
Michigan	2,850
Other States[b]	863,350
U.S. Total	34,222,000

[a]Reference 2. Does not include States producing less than 500,000 birds.
[b]Connecticut, Illinois, Indiana, Louisiana, North Dakota, and South Dakota combined to avoid disclosing individual operations.

TABLE 2-3. TURKEY PRODUCTION BY STATE, 1995[a]

State	Turkeys processed, 1,000 lb
North Carolina	1,419,840
Minnesota	854,550
Missouri	551,250
Arkansas	535,600
California	462,000
Virginia	441,800
Indiana	335,120
Pennsylvania	230,000
Iowa	227,200
Ohio	192,400
South Carolina	184,824
Colorado	158,670
West Virginia	90,240
South Dakota	87,360
Illinois	74,880
Kansas	44,800
Georgia	43,935
North Dakota	35,070
New York	12,979
Delaware/Maryland	2,971
Massachusetts	2,153
New Jersey	1,980
Vermont	639
New Hampshire	347
Connecticut	291
Other States[b]	783,678
U.S. Total	6,774,577

[a]Reference 2.
[b]Michigan, Nebraska, Oklahoma, Oregon, Texas, Utah, and Wisconsin combined to avoid disclosing individual operations.

In 1995, there were 204,585,000 chickens slaughtered in the United States. These chickens produced 0.5 billion kg (1.1 billion lb) of carcass, averaging 2.4 kg (5.2 lb) per animal. Table 2-4 presents 1995 chicken production figures by State.

2.2 PROCESS DESCRIPTION[3,4]

Poultry are unloaded from crates or modules of the transportation system into a covered reception or arrival area. The area is well ventilated to control temperature and humidity, and is heated or cooled depending on the season. Figure 2-1 presents a flow diagram for a typical poultry processing plant.

Poultry from the reception area are attached by both legs to an overhead conveyor for transportation into the facility. When the birds are hung on the conveyor line, they struggle for a short period which loosens feathers and dust trapped in the feathers. The hanging-on area, as it is called, is well lighted to enable the staff to inspect the birds and well ventilated to remove dust and feathers.

All poultry are required to be stunned prior to slaughter. Stunning is usually conducted in an electrically charged water bath. The electric current passes from the bath through the bird and is grounded through the shackles that attach the bird to the conveyor. Another instrument for stunning birds is a dry stunner which uses a charge grid or plate and hand-operated stunners.

Exsanguination is performed by severing the carotid artery and one or both of the jugular veins in the neck and allowing the blood to drain from the bird. Exsanguination is performed manually with a knife, or mechanically by guiding the bird's head across a single, revolving, circular blade or between a pair of revolving blades. Most facilities allow 90 to 180 seconds for bleeding prior to the next step, scalding.

After exsanguination, the birds are scalded by immersion in hot water or by spray scalding to facilitate feather removal. Scalding water temperatures range from 50 to 63°C (122 to 145°F) depending on the type of bird being processed and the desired skin color. Scalding time ranges greatly from 45 seconds to greater than 3 minutes, depending on the water temperature. To aid in feather removal, some facilities may add chemicals that reduce water surface tension and promote

TABLE 2-4. CHICKEN PRODUCTION BY STATE, 1995[a]

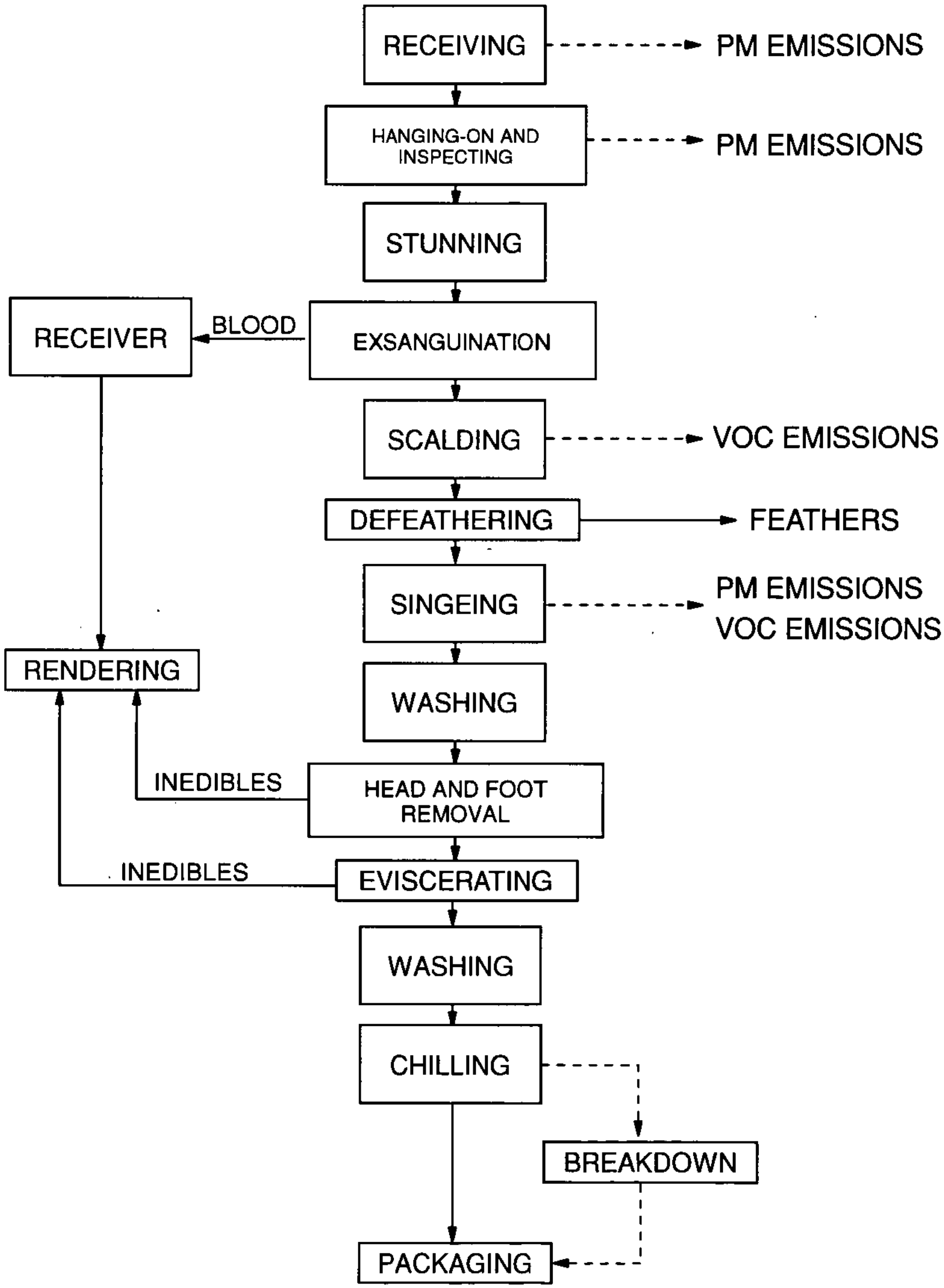
State	Chickens processed, 1,000 lb
Arkansas	117,000
Georgia	100,650
North Carolina	96,000
Pennsylvania	72,500
Alabama	63,900
Iowa	57,000
Ohio	55,130
California	54,360
Texas	51,480
Mississippi	35,880
Indiana	28,350
Florida	25,440
Oklahoma	23,932
Missouri	23,375
Maryland	22,000
Maine	19,660
Michigan	19,500
Minnesota	19,080
Virginia	18,411
Nebraska	16,920
South Carolina	16,500
New York	15,075
Washington	14,800
Illinois	12,369
Connecticut	12,320
Louisiana	10,150

TABLE 2-4. (CONTINUED)

Colorado	7,880
Oregon	7,250
Wisconsin	7,030
West Virginia	6,375
Kentucky	6,270
Utah	5,900
Delaware	5,307
South Dakota	4,360
Tennessee	3,740
New Jersey	3,500
Massachusetts	3,005
Montana	2,144
Idaho	1,887
Kansas	1,600
Hawaii	1,084
New Hampshire	830
New Mexico	820
North Dakota	675
Rhode Island	665
Vermont	275
Wyoming	32
Other States[b]	699
U.S. Total	1,073,110

[a]Reference 2.
[b]Alaska, Arizona, and Nevada combined to avoid disclosing individual operations. V

Figure 2-1. Flow diagram for a typical poultry processing plant.



RECEIVING
PM EMISSIONS
HANGING-ON AND INSPECTING
PM EMISSIONS
STUNNING
RECEIVER
BLOOD
EXSANGUINATION
SCALDING
VOC EMISSIONS
DEFEATHERING
FEATHERS
SINGEING
PM EMISSIONS
VOC EMISSIONS
RENDERING
WASHING
INEDIBLES
HEAD AND FOOT REMOVAL
INEDIBLES
EVISCERATING
WASHING
CHILLING
BREAKDOWN
PACKAGING

poultry.PRZ

wetting of the feathers. Scalding takes place in covered tanks heated indirectly with heat exchangers, or less commonly, with direct steam injection. Scald tanks are generally equipped with a cover or hood to capture steam and odors which are ducted away.

After scalding, feathers are removed mechanically using rotating or oscillating rubber "fingers" or disks that rub the feathers free of the follicles. The defeathering machine is continuously flushed with water to prevent clogging. In some facilities, removal of any remaining pin feathers or down is generally accomplished by hand. The remaining fine hairs and pin feathers are removed by singeing using an arc flame.

After defeathering, the carcasses are thoroughly washed using a spray washer to prepare for the next step when the body cavity is opened. Often, the spray wash step is accompanied by rubbing with oscillating soft rubber fingers to insure complete cleaning of all outer surfaces.

The heads of the carcasses are removed by an automatic head puller. By pulling the heads, rather than severing them, the esophagus and trachea are removed with the heads. Next, the feet are removed just above the spur using an automatic rotating knife. The carcasses are then transferred to the evisceration line.

To eviscerate a carcass, a cut is made through the abdominal wall under the tail and around the vent to free the intestines of any connection to the skin or abdominal wall muscle. All organs of the body cavity are removed through this opening. The heart, liver, and gizzard are saved as giblets. The inedible viscera are pulled free and disposed. Finally, the carcass is washed thoroughly to remove blood or foreign material.

Cleaned, eviscerated carcasses are chilled by immersion in cold water or water and ice, or less commonly by air, to retard microbiological growth on the meat. The chilled carcasses are packed in crates for shipment or cut into parts and then packaged into portions.

2.3 EMISSIONS

No emission data quantifying VOC, HAP, or PM emissions from the poultry processing industry were identified during the development of this report. However, engineering judgment and comparison of poultry slaughtering plant processes with similar processes in other industries may provide an estimation of the types of emissions that may be expected from poultry processing plant operations.

Animal holding areas, feed storage, singeing operations, and other heat sources may be sources of PM and PM-10 emissions. Animal holding areas, scalding tanks, singeing operations, sanitizing operations, wastewater systems, and heat sources may be sources of VOC, HAP, and other criteria pollutant emissions.

2.4 EMISSION CONTROL TECHNOLOGY

A number of VOC and particulate emission control techniques are potentially available to the poultry processing industry. These options include the traditional approaches of wet scrubbers, dry sorbants, and cyclones. Other options include condensation and chemical reaction. No information is available for the actual controls used at poultry processing plants. The controls presented in this section are ones that theoretically could be used. The specific type of control device or combination of devices would vary from facility to facility depending upon the particular nature of the emissions and the pollutant loading in the gas stream. The VOC emissions from poultry processing operations are likely to be very low and associated with a high moisture content.

Control of VOC from a gas stream can be accomplished using one of several techniques but the most common methods are absorption, adsorption, and afterburners. Absorptive methods encompass all types of wet scrubbers using aqueous solutions to absorb the VOC. The most common scrubber systems are packed columns or beds, plate columns, spray towers, or other types of towers. Gas absorption is a diffusion controlled, gas-liquid mass transfer process. Most scrubber systems require a mist eliminator downstream of the scrubber.

Adsorptive methods could include one of four main adsorbents: activated carbon, activated alumina, silica gel, or molecular sieves. Of these four, activated carbon is the most widely used for VOC control while the remaining three are used for applications other than pollution control. Gas adsorption is a relatively expensive technique and may not be applicable to a wide variety of pollutants. The adsorbent is regenerated by heating or use of steam, which gives rise to new emissions to be controlled.

Particulate control commonly employs methods such as venturi scrubbers, dry cyclones, wet or dry electrostatic precipitators (ESP's), or dry filter systems. The most common controls are likely to be the venturi scrubbers or dry cyclones. Wet or dry ESP's could be used depending upon the particulate loading of the gas stream. These three systems are commonly used for particulate removal in many types of processing facilities.

Condensation methods and scrubbing by chemical reaction may be applicable techniques depending upon the type of emissions. Condensation methods may be either direct contact or indirect contact with the shell and tube indirect method being the most common technique. It also offers heat recovery as a bonus for certain applications. Chemical reactive scrubbing may be used for odor control in selective applications. The major problem with this technique is that it is very specific.

REFERENCES FOR SECTION 2

1. Bureau of the Census, U. S. Department of Commerce, *1992 Census of Manufactures*, Industry Series, MC92-I-20A, Meat Products, Industries 2011, 2013, and 2015, Washington, D.C., U. S. Government Printing Office, June 1995.

2. U. S. Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, *Poultry Production and Value*, May 2, 1996.

3. W. J. Stadelman, V.M. Olson, G.A. Schemwell, and S. Pasch, *Egg and Poultry-Meat Processing*, Hartnolls Limited, Bodmin, Cornwall, England, 1988.

4. G. C. Mead, *Processing of Poultry*, Elsevier Science Publishers, Ltd., Essex, England, 1989.

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

Data for this investigation were obtained from a number of sources within the Office of Air Quality Planning and Standards (OAQPS) and from outside organizations. The Factor Information and Retrieval (FIRE), Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF), and VOC/PM Speciation Data Base Management System (SPECIATE) data bases were searched by SCC code for identification of the potential pollutants emitted and emission factors for those pollutants. A general search of the Air CHIEF CD-ROM also was conducted to supplement the information from these data bases.

Information on the industry, including number of plants, plant location, and annual production capacities, was obtained from the United States Department of Agriculture and other sources. A search of the Test Method Storage and Retrieval (TSAR) data base was conducted to identify test reports for sources within the poultry slaughtering industry. The EPA library was searched for additional test reports. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the poultry processing industry. In addition, representative trade associations, including the ______________ and the __________, were contacted for assistance in obtaining information about the industry and emissions.

To screen out unusable test reports, documents, and information from which emission factors could not be developed, the following general criteria were used:

1. Emission data must be from a primary reference:

a. Source testing must be from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.

2. The referenced study should contain test results based on more than one test run. If results from only one run are presented, the emission factors must be down rated.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 DATA QUALITY RATING SYSTEM[1]

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data were excluded from consideration:

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods (i.e., comparison of EPA Method 5 front half with EPA Method 5 front and back half);

3. Test series of controlled emissions for which the control device is not specified;

4. Test series in which the source process is not clearly identified and described; and

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

Test data sets that were not excluded were assigned a quality rating. The rating system used was that specified by EFIG for preparing AP-42 sections. The data were rated as follows:

A—Multiple test runs that were performed using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in

EPA reference test methods, although these methods were used as a guide for the methodology actually used.

B—Tests that were performed by a generally sound methodology but lack enough detail for adequate validation.

C—Tests that were based on an unproven or new methodology or that lacked a significant amount of background information.

D—Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent to which such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 EMISSION FACTOR QUALITY RATING SYSTEM[1]

The quality of the emission factors developed from analysis of the test data was rated using the following general criteria:

A—Excellent: Developed from A- and B-rated source test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B—Above average: Developed only from A- or B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. The source category is specific enough so that variability within the source category population may be minimized.

C—Average: Developed only from A-, B- and/or C-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. In addition, the source category is specific enough so that variability within the source category population may be minimized.

D—Below average: The emission factor was developed only from A-, B-, and/or C-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E—Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are footnoted.

The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. Details of the rating of each candidate emission factor are provided in Section 4.

REFERENCE FOR SECTION 3

1. *Procedures for Preparing Emission Factor Documents, Second Revised Draft Version*, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1995.

4. AP-42 SECTION DEVELOPMENT

4.1 INTRODUCTION

This section describes the references and test data that were evaluated to determine if pollutant emission factors could be developed for AP-42 Section 9.5.5, Poultry Slaughtering.

4.2 REVIEW OF SPECIFIC DATA SETS

No source tests or other documents that could be used to develop emission factors for the AP-42 section were located during the literature search.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

No emission factors were developed because no source tests or emissions data were found.

5. PROPOSED AP-42 SECTION

The proposed AP-42, Section 9.5.5, Poultry Slaughtering, is presented on the following pages as it would appear in the document.

ICP #1
Ch 2

1992 Census of Manufactures

MC92-I-20A

INDUSTRY SERIES

Meat Products

Industries 2011, 2013, and 2015

Issued June 1995

U.S. Department of Commerce
Ronald H. Brown, Secretary
David J. Barram, Deputy Secretary

Economics and Statistics Administration
Everett M. Ehrlich, Under Secretary
for Economic Affairs

BUREAU OF THE CENSUS
Martha Farnsworth Riche, Director

Description of Industries and Summary of Findings

This report shows 1992 Census of Manufactures statistics for establishments classified in each of the following industries:

SIC code and title

2011	Meat Packing Plants
2013	Sausages and Other Prepared Meats
2015	Poultry Slaughtering and Processing

The industry statistics (employment, payroll, cost of materials, value of shipments, inventories, etc.) are reported for each establishment as a whole. Aggregates of such data for an industry reflect not only the primary activities of the establishments but also their activities in the manufacture of secondary products as well as their miscellaneous activities (contract work on materials owned by others, repair work, etc.). This fact should be taken into account in comparing industry statistics (tables 1 through 5a) with product statistics (table 6) showing shipments by all industries of the primary products of the specified industry. The extent of the "product mix" is indicated in table 5b, which shows the value of primary and secondary products shipped by establishments classified in the specified industry and the value of primary products of the industry shipped as secondary products by establishments classified in other industries.

Establishment data were tabulated based on industry definitions included in the *1987 Standard Industrial Classification (SIC) Manual*[1]. The 1987 edition represents a major revision for manufacturing industries from the 1972 edition and its 1977 supplement. In addition to the 1987 SIC revision, changes were made to the product class (five-digit) and product code (seven-digit) categories. The product class and product code comparability between the 1992 and 1987 censuses is shown in appendix C. This appendix presents, in tabular form, the linkage from 1992 to 1987, and 1987 to 1992.

All dollar figures included in this report are at prices current for the year specified and, therefore, unadjusted for changes in price levels. Consequently, when making comparisons to prior years, users should take into consideration the inflation that has occurred.

[1]*Standard Industrial Classification Manual: 1987*. For sale by Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Stock No. 041-001-00314-2.

INDUSTRY 2011, MEAT PACKING PLANTS

This industry is made up of establishments primarily engaged in the slaughtering, for their own account or on a contract basis for the trade, of cattle, hogs, sheep, lambs, and calves for meat to be sold or to be used on the same premises in canning, cooking, curing, and freezing, and in making sausage, lard, and other products. Also included in this industry are establishments primarily engaged in slaughtering horses for human consumption. Establishments primarily engaged in slaughtering, dressing, and packing poultry, rabbits, and other small game are classified in industry 2015; and those primarily engaged in slaughtering and processing animals not for human consumption are classified in industry 2048. Establishments primarily engaged in manufacturing sausages and meat specialties from purchased meats are classified in industry 2013; and establishments primarily engaged in canning meat for baby food are classified in industry 2032.

The 1992 definition of this industry is the same as that used in the 1987 Standard Industrial Classification (SIC) system. The SIC number and title also are the same.

In the 1992 Census of Manufactures, Industry 2011, Meat Packing Plants, had employment of 122.4 thousand. The employment figure was 7 percent above the 113.9 thousand reported in 1987. Compared with 1991, employment increased 1 percent. The 1991 data are based on the Census Bureau's annual survey of manufactures (ASM), which is a sample survey conducted each year between censuses.

The leading States in employment in 1992 were Iowa, Nebraska, Kansas, and Texas, accounting for approximately 45 percent of the industry's employment. These same States were the leaders in 1987 when they accounted for 40 percent of the industry's employment.

The total value of shipments for establishments classified in this industry was $50.4 billion.

Establishments in virtually all industries ship secondary products as well as products primary to the industry in which they are classified and have some miscellaneous receipts, such as resales and contract receipts. Industry 2011 shipped $46.8 billion of meat products considered primary to the industry, $1.3 billion of secondary products, and had $2.4 billion of miscellaneous receipts, resales, and contract work. Thus, the ratio of primary products to the total of both secondary and primary products shipped by establishments in this industry was 97 percent (specialization ratio). In 1987, the specialization ratio was 98 percent.

Establishments in this industry also accounted for 99 percent of products considered primary to the industry no matter where they were actually produced (coverage ratio). In 1987, the coverage ratio was 100 percent.

The products primary to industry 2011, no matter in what industry they were produced, appear in table 6a and aggregate to $46.8 billion. For further explanation of specialization and coverage ratios, see table 5b and the appendixes.

The total cost of materials, services, and fuels and energy used by establishments classified in the meat packing industry amounted to $43.6 billion. Data on specific materials consumed appear in table 7.

Single-establishment companies in this industry with less than 20 employees were excluded from the mail portion of the census. The data for these establishments (and a small number of larger establishments whose reports were not received at the time the data were tabulated) were obtained from administrative records of other agencies or developed from industry averages. These establishments accounted for 5 percent of the total value of shipments.

INDUSTRY 2013, SAUSAGES AND OTHER PREPARED MEATS

This industry is made up of establishments primarily engaged in manufacturing sausages, cured meats, smoked meats, canned meats, frozen meats, and other prepared meats and meat specialties, from purchased carcasses and other materials. Prepared meat plants operated by packing houses as separate establishments are also included in this industry. Establishments primarily engaged in canning or otherwise processing poultry, rabbits, and other small game are classified in industry 2015. Establishments primarily engaged in canning meat for baby food are classified in industry 2032. Establishments primarily engaged in cutting up and resale of purchased fresh carcasses, for the trade, (including boxed beef) are classified in wholesale trade, industry 5147.

The 1992 definition of this industry is the same as that used in the 1987 Standard Industrial Classification (SIC) system. The SIC number and title also are the same.

In the 1992 Census of Manufactures, Industry 2013, Sausages and Other Prepared Meats, had employment of 85.5 thousand. The employment figure was 9 percent above the 78.7 thousand reported in 1987. Compared with 1991, employment increased 7 percent. The 1991 data are based on the Census Bureau's annual survey of manufactures (ASM), which is a sample survey conducted each year between censuses.

The leading States in employment in 1992 were Wisconsin, Texas, Illinois, and California, accounting for approximately 29 percent of the industry's employment. These same States were the leaders in 1987 when they accounted for 30 percent of the industry's employment.

The total value of shipments for establishments classified in this industry was $20.0 billion.

Establishments in virtually all industries ship secondary products as well as products primary to the industry in which they are classified and have some miscellaneous receipts, such as resales and contract receipts. Industry 2013 shipped $17.3 billion of sausages and prepared meats considered primary to the industry, $880.8 million of secondary products, and had $1.8 billion of miscellaneous receipts, resales, and contract work. Thus, the ratio of primary products to the total of both secondary and primary products shipped by establishments in this industry was 95 percent (specialization ratio). In 1987, the specialization ratio was 96 percent.

Establishments in this industry also accounted for 98 percent of products considered primary to the industry no matter where they were actually produced (coverage ratio). In 1987, the coverage ratio also was 98 percent.

The products primary to industry 2013, no matter in what industry they were produced, appear in table 6a and aggregate to $17.7 billion. For further explanation of specialization and coverage ratios, see table 5b and the appendixes.

The total cost of materials, services, and fuels and energy used by establishments classified in the sausage and prepared meats industry amounted to $14.5 billion. Data on specific materials consumed appear in table 7.

Single-establishment companies in this industry with less than 15 employees were excluded from the mail portion of the census. The data for these establishments (and a small number of larger establishments whose reports were not received at the time the data were tabulated) were obtained from administrative records of other agencies or developed from industry averages. These establishments accounted for 12 percent of the total value of shipments.

INDUSTRY 2015, POULTRY SLAUGHTERING AND PROCESSING

This industry is made up of establishments primarily engaged in slaughtering, dressing, packing, freezing, and canning poultry, rabbits, and other small game, or in manufacturing products from such meats, for their own account or on a contract basis for the trade. This industry also includes the drying, freezing, and breaking of eggs. Establishments primarily engaged in cleaning, oil treating, packing, and grading of eggs are classified in wholesale trade, industry 5144; and those engaged in the cutting up and resale of purchased fresh carcasses are classified in wholesale and retail trade.

The 1992 definition of this industry is the same as that used in the 1987 Standard Industrial Classification (SIC) system. The SIC number and title also are the same.

In the 1992 Census of Manufactures, Industry 2015, Poultry Slaughtering and Processing, had employment of 193.8 thousand. The employment figure was 31 percent above the 147.9 thousand reported in 1987.

The leading States in employment in 1992 were Arkansas, Georgia, Alabama, and North Carolina, accounting for approximately 46 percent of the industry's employment. These same States were the leaders in 1987 when they accounted for 44 percent of the industry's employment.

The total value of shipments for establishments classified in this industry was $23.8 billion.

Establishments in virtually all industries ship secondary products as well as products primary to the industry in which they are classified and have some miscellaneous receipts, such as resales and contract receipts. Industry 2015 shipped $22.7 billion of poultry products considered primary to the industry, $327.4 million of secondary products, and had $721.1 million of miscellaneous receipts, resales, and contract work. Thus, the ratio of primary products to the total of both secondary and primary products shipped by establishments in this industry was 99 percent (specialization ratio). In 1987, the specialization ratio was 98 percent.

Establishments in this industry also accounted for 97 percent of products considered primary to the industry no matter where they were actually produced (coverage ratio). In 1987, the coverage ratio was 98 percent.

The products primary to industry 2015, no matter in what industry they were produced, appear in table 6a and aggregate to $23.5 billion. For further explanation of specialization and coverage ratios, see table 5b and the appendixes.

The total cost of materials, services, and fuels and energy used by establishments classified in the poultry slaughtering and processing industry amounted to $17.1 billion. Data on specific materials consumed appear in table 7.

Single-establishment companies in this industry with less than 15 employees were excluded from the mail portion of the census. The data for these establishments (and a small number of larger establishments whose reports were not received at the time the data were tabulated) were obtained from administrative records of other agencies or developed from industry averages. These establishments accounted for 4 percent of the total value of shipments.

Table 2. Industry Statistics for Selected States: 1992 and 1987

[Excludes data for auxiliaries. States with 100 employees or more are shown. For meaning of abbreviations and symbols, see introductory text. For explanation of terms, see appendixes.]

Industry and geographic area	E[1]	1992: All establishments: Total (no.)	1992: All establishments: With 20 employees or more (no.)	1992: All employees: Number[2] (1,000)	1992: All employees: Payroll (million dollars)	1992: Production workers: Number (1,000)	1992: Production workers: Hours (millions)	1992: Production workers: Wages (million dollars)	1992: Value added by manufacture (million dollars)	1992: Cost of materials (million dollars)	1992: Value of shipments (million dollars)	1992: New capital expenditures (million dollars)	1987: All employees[2] (1,000)	1987: Value added by manufacture (million dollars)
INDUSTRY 2011, MEAT PACKING PLANTS														
United States	-	1 387	431	122.4	2 452.8	105.5	226.5	1 956.6	6 928.0	43 586.4	50 434.4	343.2	113.9	5 266.9
Alabama	E5	26	5	.7	12.0	.5	.8	6.6	47.0	71.6	118.0	(D)	1.0	30.5
Arizona	-	12	4	F	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.7	F	(D)
Arkansas	-	22	4	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	F	(D)
California	E4	73	27	3.5	79.9	2.9	6.6	61.2	156.1	1 181.6	1 338.9	27.4	3.3	162.0
Colorado	E1	40	12	5.1	100.4	4.5	9.9	90.2	266.8	2 558.0	2 809.6	14.5	H	(D)
Florida	E4	24	10	.4	6.9	.3	.7	4.8	8.3	75.7	84.1	.5	.8	15.1
Georgia	E1	35	13	2.1	37.5	1.6	3.5	25.2	69.8	396.8	468.5	4.6	2.2	58.8
Hawaii	E6	6	2	.2	3.3	.1	.3	2.5	4.3	19.2	23.5	(D)	.2	6.6
Idaho	-	13	5	F	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.8	46.5
Illinois	-	82	28	7.0	137.9	6.2	13.1	113.0	317.6	2 313.1	2 623.9	8.4	5.7	256.4
Indiana	E1	42	15	3.4	68.0	2.9	5.6	52.7	103.7	726.3	829.6	6.3	H	(D)
Iowa	-	63	30	16.9	340.8	14.9	33.3	285.1	918.1	5 198.7	6 111.8	29.8	12.8	582.9
Kansas	-	44	14	12.3	221.2	11.3	24.1	192.9	446.3	5 819.0	6 254.2	14.8	10.8	518.0
Kentucky	E1	28	11	2.2	47.1	1.7	3.5	31.8	84.6	440.5	522.4	3.1	H	(D)
Louisiana	E3	17	6	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.3	C	(D)
Maryland	E1	11	4	.3	4.7	.2	.5	3.5	9.0	48.0	57.0	(D)	.3	9.4
Michigan	-	46	14	2.3	46.8	2.0	4.4	38.0	104.0	726.2	829.2	(D)	1.9	92.5
Minnesota	-	30	10	5.6	112.1	4.2	8.6	88.1	671.1	1 898.2	2 566.9	10.3	4.9	513.0
Mississippi	-	25	6	H	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	2.5	137.6
Missouri	-	49	6	1.7	30.4	1.4	3.2	25.1	32.6	434.2	463.4	2.0	1.8	82.6
Montana	E7	23	2	.1	1.5	.1	.2	1.1	1.9	14.5	16.4	(D)	(NA)	(NA)
Nebraska	-	48	22	13.7	276.6	12.3	27.3	236.2	1 192.2	7 172.0	8 345.8	16.3	9.8	512.2
New Jersey	E1	14	5	.3	8.2	.3	.5	5.8	17.3	58.6	76.2	.3	E	(D)
New Mexico	E6	10	4	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.2	F	(D)
New York	E3	41	5	.4	6.6	.3	.6	4.9	17.5	73.0	90.8	.6	.8	27.1
North Carolina	E1	32	15	2.9	56.4	2.3	4.8	42.2	120.1	520.6	639.5	(D)	2.6	75.3
North Dakota	-	10	2	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	C	(D)
Ohio	-	57	19	2.8	70.0	1.9	4.3	46.4	166.8	601.8	770.3	10.2	H	(D)
Oklahoma	E5	42	7	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.7	19.9
Oregon	-	20	4	.3	7.1	.2	.5	5.1	14.0	65.3	79.7	(D)	.5	27.3
Pennsylvania	-	68	27	4.3	108.5	3.5	7.3	77.6	219.1	1 423.2	1 642.4	24.1	3.6	161.5
South Carolina	E1	27	8	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	1.0	31.6
South Dakota	-	16	6	3.8	77.4	3.5	7.3	69.1	286.4	981.9	1 266.3	4.1	H	(D)
Tennessee	E8	25	6	1.0	16.6	.7	1.6	12.4	79.4	171.0	250.2	2.7	2.5	101.4
Texas	-	109	32	11.9	221.4	10.7	24.0	188.1	551.5	5 158.8	5 700.5	33.9	12.7	253.4
Utah	-	17	4	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	G	(D)
Virginia	-	22	6	H	(D)	(D)	(D)	(D)	(D)	(D)	(D)	1.1	4.5	210.5
Washington	-	23	7	1.9	35.8	1.7	3.7	29.9	75.6	1 051.7	1 131.0	(D)	2.0	79.5
West Virginia	E4	16	2	.1	1.4	.1	.2	1.1	1.2	8.8	10.0	.1	C	(D)
Wisconsin	E1	46	16	3.1	67.7	2.7	5.3	48.6	298.6	1 282.7	1 584.2	7.7	3.2	191.8
INDUSTRY 2013, SAUSAGES AND OTHER PREPARED MEATS														
United States	E1	1 264	623	85.5	2 026.3	65.7	139.9	1 353.3	5 491.3	14 455.0	19 972.4	379.7	78.7	4 457.0
Alabama	E6	12	4	.7	11.9	.5	1.1	7.9	22.1	60.5	82.2	(D)	.6	14.9
Arkansas	-	6	4	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	F	(D)
California	E1	129	63	5.5	136.4	4.1	8.5	85.6	462.9	914.7	1 382.3	19.2	6.3	370.3
Colorado	-	25	9	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	G	(D)
Connecticut	E3	15	7	.3	8.6	.2	.5	4.4	19.6	37.6	57.2	(D)	.6	30.3
Delaware	-	4	3	C	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	E	(D)
Florida	-	33	14	2.4	52.0	1.8	3.9	36.5	111.0	379.8	491.1	9.5	2.3	137.3
Georgia	E2	36	14	2.7	54.4	2.1	4.9	39.4	143.5	392.9	536.1	9.0	2.6	101.7
Hawaii	E5	15	4	.2	3.5	.2	.3	2.0	7.8	17.4	25.3	.5	C	(D)
Idaho	-	5	3	F	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	C	(D)
Illinois	E1	85	48	5.7	160.3	4.3	9.5	106.5	442.6	912.6	1 362.4	39.2	5.9	362.3
Indiana	E3	19	8	1.6	37.1	1.2	2.3	24.2	110.8	340.8	451.4	5.6	1.4	54.7
Iowa	-	29	17	4.3	119.2	3.6	7.9	93.6	281.3	1 028.7	1 305.7	29.6	3.5	275.4
Kansas	-	23	13	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	G	(D)
Kentucky	E1	21	7	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	F	(D)
Louisiana	-	25	6	.5	11.0	.4	.8	5.6	22.4	95.3	118.0	(D)	.7	29.7
Maine	E5	7	3	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	E	(D)
Maryland	-	20	9	1.3	23.9	1.1	1.9	17.7	62.6	116.9	179.4	(D)	1.4	76.0
Massachusetts	E1	31	13	1.4	34.7	.8	1.8	18.1	72.6	211.3	285.6	3.6	G	(D)
Michigan	-	40	25	H	(D)	(D)	(D)	(D)	(D)	(D)	(D)	10.0	3.6	199.1
Minnesota	-	22	12	1.6	32.2	1.3	2.3	19.0	65.8	262.7	330.8	4.4	1.2	39.9
Mississippi	E5	11	3	F	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.9	14.5
Missouri	-	32	16	2.5	53.1	2.1	4.6	39.4	102.1	401.2	503.7	19.4	1.7	101.7
Montana	E1	9	2	.2	3.4	.1	.3	2.5	8.1	14.3	22.3	(D)	C	(D)
Nebraska	E1	30	19	2.3	44.1	1.9	4.1	30.5	84.5	358.3	442.8	4.7	1.9	70.8
New Hampshire	-	4	3	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	F	(D)
New Jersey	E2	41	21	2.1	63.2	1.6	3.5	37.7	145.3	328.6	469.8	5.4	2.0	123.7
New Mexico	-	4	1	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(NA)	(NA)
New York	E2	88	32	2.2	65.9	1.6	3.3	39.2	151.6	385.4	536.5	8.1	3.5	201.8
North Carolina	-	48	26	3.0	52.6	2.4	4.9	38.0	152.9	394.0	539.2	(D)	2.3	92.7
North Dakota	-	5	2	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	C	(D)
Ohio	-	41	26	3.7	85.3	3.0	6.7	60.8	179.0	731.8	913.6	15.7	3.1	176.2
Oklahoma	E2	13	6	1.2	28.7	.9	2.1	18.2	73.2	265.7	338.4	8.8	G	(D)
Oregon	-	21	11	1.4	30.2	1.0	2.1	15.6	103.7	129.0	233.4	4.0	1.1	71.0
Pennsylvania	E1	75	49	4.8	120.7	3.5	7.4	73.8	340.3	938.4	1 287.1	14.2	5.0	290.8

See footnotes at end of table.

Table 2. Industry Statistics for Selected States: 1992 and 1987—Con.

[Excludes data for auxiliaries. States with 100 employees or more are shown. For meaning of abbreviations and symbols, see introductory text. For explanation of terms, see appendixes.]

Industry and geographic area	1992												1987	
		All establishments		All employees		Production workers								
	E[1]	Total (no.)	With 20 employees or more (no.)	Number[2] (1,000)	Payroll (million dollars)	Number (1,000)	Hours (millions)	Wages (million dollars)	Value added by manufacture (million dollars)	Cost of materials (million dollars)	Value of shipments (million dollars)	New capital expenditures (million dollars)	All employees[2] (1,000)	Value added by manufacture (million dollars)
INDUSTRY 2013, SAUSAGES AND OTHER PREPARED MEATS—Con.														
Rhode Island	-	8	1	.1	2.9	.1	.2	2.5	8.0	15.3	23.2	.5	(NA)	(NA)
South Carolina	-	9	4	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	.5	23.2
South Dakota	-	2	1	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	E	(D)
Tennessee	-	25	13	1.8	42.0	1.2	2.7	26.2	133.1	259.0	398.2	3.1	2.9	178.6
Texas	-	81	46	6.6	157.0	4.9	11.0	98.6	335.0	1 325.3	1 661.4	34.4	5.3	220.3
Utah	-	7	3	.2	4.6	.2	.4	2.9	15.2	76.4	91.4	.4	C	(D)
Virginia	E4	25	14	H	(D)	(D)	(D)	(D)	(D)	(D)	(D)	5.7	1.2	62.2
Washington	-	19	10	.9	21.1	.7	1.5	13.0	79.3	131.9	202.9	4.8	1.1	64.8
Wisconsin	-	43	24	6.7	189.6	5.2	11.2	133.7	798.1	1 353.2	2 153.1	30.5	6.4	568.9
INDUSTRY 2015, POULTRY SLAUGHTERING AND PROCESSING														
United States	-	591	432	193.8	3 091.5	172.6	341.5	2 518.4	6 656.5	17 066.7	23 757.1	466.4	147.9	4 118.4
Alabama	-	37	32	20.1	277.2	18.2	33.9	234.3	538.4	1 471.1	2 001.8	35.6	11.2	227.9
Arkansas	-	47	44	29.1	451.7	26.4	54.3	382.6	912.6	2 740.7	3 655.4	80.6	23.4	526.4
California	-	41	29	8.9	158.8	8.0	14.5	130.2	281.4	845.5	1 129.8	9.4	5.6	276.2
Colorado	E9	5	4	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	F	(D)
Delaware	-	8	8	5.1	76.3	4.7	8.4	61.3	149.5	444.5	593.4	16.2	4.5	85.1
Florida	-	16	7	2.9	45.7	2.2	4.4	34.0	29.6	245.6	275.0	18.3	2.5	29.7
Georgia	-	49	44	21.2	331.2	19.0	36.7	273.8	686.8	1 616.6	2 298.0	50.4	18.0	375.9
Illinois	E3	11	6	1.3	30.1	1.1	1.9	18.8	88.1	114.6	201.9	2.8	1.6	35.5
Indiana	-	11	10	2.7	42.2	2.2	4.4	30.6	116.3	203.1	323.9	6.3	G	(D)
Iowa	-	19	14	3.1	55.7	2.8	5.6	47.2	150.9	388.2	542.6	5.1	3.0	86.7
Kentucky	-	4	3	F	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	C	(D)
Louisiana	-	5	3	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	G	(D)
Maine	E2	2	2	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	E	(D)
Maryland	-	10	7	3.3	54.8	2.9	6.3	40.1	104.3	300.4	404.0	8.0	3.6	110.9
Massachusetts	E2	4	3	.4	6.4	.4	.7	5.1	11.6	34.1	45.6	.8	C	(D)
Michigan	-	10	4	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	2.0	93.7
Minnesota	-	27	16	6.5	108.5	5.9	11.8	91.7	233.2	560.2	811.6	11.6	7.0	206.1
Mississippi	E1	26	24	11.1	148.7	9.9	19.1	118.6	309.4	843.3	1 152.6	22.5	6.2	196.2
Missouri	-	29	25	8.5	130.1	7.7	14.6	108.9	356.8	791.9	1 149.1	25.7	5.6	194.8
Nebraska	-	7	6	1.8	40.7	1.5	3.1	30.7	27.3	141.4	179.5	6.6	1.6	60.2
New Jersey	E3	16	11	2.2	39.7	1.8	3.8	27.6	65.3	267.2	351.5	6.8	G	(D)
New York	E2	21	6	.6	10.3	.5	1.0	9.4	23.1	38.4	61.0	.8	.8	22.4
North Carolina	E1	29	25	18.2	259.4	16.6	32.3	219.9	662.0	1 547.2	2 206.5	35.6	14.9	528.3
Ohio	E1	19	12	1.4	22.5	1.2	2.6	17.8	53.3	146.2	200.1	2.4	G	(D)
Oklahoma	-	6	3	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	G	(D)
Oregon	-	6	5	1.0	18.6	.8	1.8	16.2	25.0	72.3	97.7	(D)	.6	20.0
Pennsylvania	E1	28	21	5.4	101.4	4.3	8.6	74.9	170.2	549.2	719.2	8.4	5.6	162.4
South Carolina	-	12	5	1.8	30.0	1.6	3.4	25.4	118.7	153.4	274.0	4.4	1.6	70.6
South Dakota	E2	3	2	E	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	E	(D)
Tennessee	-	11	9	4.1	68.9	3.7	7.6	57.6	161.3	456.9	621.5	5.9	2.0	50.9
Texas	-	20	15	9.3	153.3	8.4	17.9	131.3	238.6	899.1	1 146.3	20.2	5.6	152.5
Utah	-	2	1	F	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	E	(D)
Virginia	-	17	12	9.2	156.0	8.1	17.1	125.0	382.4	934.5	1 315.9	15.2	8.4	235.7
Washington	E5	8	4	.9	20.1	.7	1.7	15.2	28.7	111.4	139.7	(D)	.6	13.7
West Virginia	-	3	2	G	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	F	(D)
Wisconsin	E2	9	7	2.6	51.7	2.0	3.7	30.6	92.4	222.7	319.1	15.9	2.2	40.6

Note: For qualifications of data, see footnotes on table 1a.

[1]Payroll and sales data for some small single-establishment companies with up to 20 employees (cutoff varied by industry) were obtained from administrative records of other Government agencies rather than from census report forms. These data were then used in conjunction with industry averages to estimate the items shown for these small establishments. This technique was also used for a small number of other establishments whose reports were not received at the time data were tabulated. The following symbols are shown for those States where estimated value of shipments data based on administrative-record data account for 10 percent or more of figure shown: E1—10 to 19 percent; E2—20 to 29 percent; E3—30 to 39 percent; E4—40 to 49 percent; E5—50 to 59 percent; E6—60 to 69 percent; E7—70 to 79 percent; E8—80 to 89 percent; E9—90 percent or more.

[2]Statistics for some producing States have been withheld to avoid disclosing data for individual companies. However, for States with 100 employees or more, number of establishments is shown and employment-size range is indicated by one of the following symbols: C—100 to 249 employees; E—250 to 499 employees; F—500 to 999 employees; G—1,000 to 2,499 employees; H—2,500 to 4,999 employees; I—5,000 to 9,999 employees; J—10,000 to 24,999 employees; K—25,000 to 49,999 employees; L—50,000 to 99,999 employees; M—100,000 employees or more.

Table 3c. Supplemental Industry Statistics Based on Sample Estimates: 1992

[For meaning of abbreviations and symbols, see introductory text. For explanation of terms, see appendixes]

Item	Meat packing plants (SIC 2011)		Sausages and other prepared meats (SIC 2013)		Poultry slaughtering and processing (SIC 2015)	
	Amount (million dollars)	Relative standard error of estimate[1] (percent)	Amount (million dollars)	Relative standard error of estimate[1] (percent)	Amount (million dollars)	Relative standard error of estimate[1] (percent)
Purchased services:						
Cost of purchased services for the repair of-						
Buildings and other structures	27.4	(X)	26.7	(X)	31.0	(X)
Response coverage ratio (percent)[2]	76.8	(X)	81.7	(X)	83.9	(X)
Machinery	180.5	(X)	147.3	(X)	204.0	(X)
Response coverage ratio (percent)[2]	82.9	(X)	82.1	(X)	85.1	(X)
Other purchased services:						
Communications	18.2	(X)	19.5	(X)	14.5	(X)
Response coverage ratio (percent)[2]	83.0	(X)	77.0	(X)	82.6	(X)
Legal	8.2	(X)	10.1	(X)	12.0	(X)
Response coverage ratio (percent)[2]	82.8	(X)	80.3	(X)	81.4	(X)
Accounting and bookkeeping	5.2	(X)	11.3	(X)	5.8	(X)
Response coverage ratio (percent)[2]	77.1	(X)	80.4	(X)	79.4	(X)
Advertising	121.6	(X)	179.7	(X)	60.1	(X)
Response coverage ratio (percent)[2]	80.8	(X)	80.8	(X)	81.3	(X)
Software and other data processing	5.4	(X)	7.7	(X)	3.1	(X)
Response coverage ratio (percent)[2]	75.7	(X)	80.0	(X)	79.9	(X)
Refuse removal, including hazardous waste	88.1	(X)	15.2	(X)	69.3	(X)
Response coverage ratio (percent)[2]	80.0	(X)	81.3	(X)	85.7	(X)
New machinery and equipment expenditures	270.4	(X)	283.0	(X)	349.5	(X)
Automobiles, trucks, etc., for highway use	4.9	25	5.5	14	14.6	4
Computers and peripheral data processing equipment	6.1	3	6.3	6	5.0	1
All other	207.9	1	174.8	1	329.9	1
Adjustment ratio[3]	1.2	(X)	1.3	(X)	1.2	(X)
Cost of materials, components, parts, etc., used	41 036.4	(X)	12 723.5	(X)	16 174.6	(X)
Materials purchased or transferred from foreign sources[4]	116.7	16	640.6	13	8.0	2
Materials purchased or transferred from domestic sources	40 919.7	1	12 082.9	1	16 166.5	1
Adjustment ratio[3]	1.4	(X)	1.4	(X)	1.4	(X)

Note: The amounts shown for purchased services reflect only those services that establishments purchase from other companies. Amounts purchased by separate central administrative offices and services provided to establishments by central administrative offices are excluded.

[1]For description of relative standard error of estimate, see Qualifications of the Data in appendixes.
[2]A response coverage ratio is derived for this item by calculating the ratio of the weighted employment (establishment data multiplied by sample weight, see appendix B) for those ASM establishments that reported to the weighted total employment for all ASM establishments classified in the industry.
[3]Detail has been adjusted upwards to account for nonresponse. Inverse of the ratio shown represents a measure of the response of the inquiry. (See appendixes for further explanation.)
[4]Data may understate the true cost of imported parts, components, and supplies since some respondents do not know the origin of these materials. Includes cases where materials were purchased from secondary suppliers or where they were transferred from company-operated warehouses or other distribution points. Direct purchases from foreign suppliers and importers by domestic manufacturing establishments are believed to be reported accurately.

Table 4. Industry Statistics by Employment Size of Establishment: 1992

[For meaning of abbreviations and symbols, see introductory text. For explanation of terms, see appendixes]

Industry and employment size class	E[1]	All establishments (no.)	All employees: Number (1,000)	All employees: Payroll (million dollars)	Production workers: Number (1,000)	Production workers: Hours (millions)	Production workers: Wages (million dollars)	Value added by manufacture (million dollars)	Cost of materials (million dollars)	Value of shipments (million dollars)	New capital expenditures (million dollars)	End-of-year inventories (million dollars)
INDUSTRY 2011, MEAT PACKING PLANTS												
Total	-	1 387	122.4	2 452.8	105.5	228.5	1 956.6	6 928.0	43 586.4	50 434.4	343.2	1 054.3
Establishments with an average of—												
1 to 4 employees	E6	519	.9	14.0	.8	1.5	10.6	26.6	198.0	224.7	1.4	4.1
5 to 9 employees	E5	256	1.7	23.6	1.4	2.7	18.2	42.5	261.2	303.4	2.3	8.1
10 to 19 employees	E3	181	2.5	40.6	2.1	4.2	31.4	70.4	427.3	497.7	3.5	10.6
20 to 49 employees	E3	183	5.6	95.4	4.4	9.0	69.2	182.5	1 031.8	1 215.6	8.0	23.8
50 to 99 employees	E1	84	6.2	125.8	4.9	10.3	89.7	276.3	1 758.7	2 034.2	12.9	47.7
100 to 249 employees	E2	69	10.8	220.1	9.0	19.0	166.6	477.5	4 881.7	5 363.6	35.0	116.7
250 to 499 employees	E1	35	12.1	245.2	9.9	20.8	176.0	669.3	4 802.9	5 473.6	122.9	94.9
500 to 999 employees	-	20	14.6	307.9	12.5	27.5	240.9	888.9	4 424.6	5 300.8	22.0	123.2
1,000 to 2,499 employees	-	36	68.0	1 380.1	60.4	133.4	1 153.9	4 294.1	25 800.3	30 020.8	135.2	623.2
2,500 employees or more	-	4	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
Covered by administrative records[2]	E9	818	2.2	28.7	1.9	3.6	22.2	24.9	178.2	203.2	1.6	4.1
INDUSTRY 2013, SAUSAGES AND OTHER PREPARED MEATS												
Total	E1	1 264	85.5	2 026.3	65.7	139.9	1 353.3	5 491.3	14 455.0	19 972.4	379.7	1 058.1
Establishments with an average of—												
1 to 4 employees	E8	271	.5	8.5	.4	.7	5.6	21.9	62.9	84.7	1.2	4.9
5 to 9 employees	E7	189	1.3	20.0	1.0	1.9	12.6	51.1	136.8	188.0	2.4	10.0
10 to 19 employees	E4	181	2.5	46.9	1.8	3.7	28.9	120.2	293.3	411.9	8.1	25.4
20 to 49 employees	E1	235	7.5	172.9	5.4	10.7	99.1	409.0	1 117.8	1 532.5	20.3	86.1
50 to 99 employees	E1	150	10.7	236.4	7.9	16.2	148.0	713.2	1 536.5	2 253.5	45.2	129.0
100 to 249 employees	-	148	24.0	581.3	18.4	39.4	366.5	1 722.7	4 528.4	6 247.7	103.3	338.4
250 to 499 employees	E1	71	24.7	589.0	19.3	42.3	407.2	1 589.5	4 392.8	5 996.9	121.8	302.2
500 to 999 employees	-	15	14.3	371.3	11.6	25.0	285.4	863.7	2 386.5	3 257.3	77.3	151.1
1,000 to 2,499 employees	-	4	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
Covered by administrative records[2]	E9	362	1.3	16.4	1.0	1.8	10.6	37.0	106.4	143.4	2.1	7.9

See footnotes at end of table.

Table 4. Industry Statistics by Employment Size of Establishment: 1992—Con.

[For meaning of abbreviations and symbols, see introductory text. For explanation of terms, see appendixes]

Industry and employment size class	E[1]	All establishments (no.)	All employees: Number (1,000)	All employees: Payroll (million dollars)	Production workers: Number (1,000)	Production workers: Hours (millions)	Production workers: Wages (million dollars)	Value added by manufacture (million dollars)	Cost of materials (million dollars)	Value of shipments (million dollars)	New capital expenditures (million dollars)	End-of-year inventories (million dollars)
INDUSTRY 2015, POULTRY SLAUGHTERING AND PROCESSING												
Total	-	591	193.8	3 091.5	172.8	341.5	2 518.4	6 656.5	17 066.7	23 757.1	466.4	832.3
Establishments with an average of—												
1 to 4 employees	E5	85	.1	2.5	.1	.3	2.0	5.2	15.8	21.1	.3	.5
5 to 9 employees	E7	36	.2	3.5	.2	.4	2.7	15.4	21.0	36.4	.8	1.0
10 to 19 employees	E3	38	.5	7.9	.5	.9	6.2	21.8	49.4	71.0	1.2	2.5
20 to 49 employees	E1	66	2.3	38.1	1.9	3.6	28.3	127.4	314.5	443.0	10.4	28.3
50 to 99 employees	-	42	3.0	50.3	2.6	4.8	39.7	160.3	346.3	505.7	14.0	25.2
100 to 249 employees	E1	82	13.6	224.4	11.7	23.8	170.3	537.5	1 399.2	1 955.8	52.2	97.3
250 to 499 employees	E1	87	31.7	522.7	27.8	56.3	412.6	1 133.0	3 081.8	4 216.6	77.2	153.0
500 to 999 employees	-	101	71.4	1 108.4	63.7	122.6	905.5	2 044.9	6 250.6	8 287.5	152.8	265.0
1,000 to 2,499 employees	-	54	71.0	1 133.7	64.2	128.8	951.1	2 611.0	5 588.1	8 220.0	157.5	259.5
Covered by administrative records[2]	E9	94	.3	3.7	.3	.5	3.0	8.4	20.3	28.7	.7	1.1

Note: For qualifications of data, see footnotes on table 1a. Data shown as (D) are included in underscored figures above.

[1]Payroll and sales data for some small single-establishment manufacturing companies with up to 20 employees (cutoff varied by industry) were obtained from administrative records of other Government agencies rather than from census report forms. These data were then used in conjunction with industry averages to estimate the items shown for these small establishments. This technique was also used for a small number of other establishments whose reports were not received at the time data were tabulated. The following symbols are shown for those employment-size classes where estimated data based on administrative-record data account for 10 percent or more of figures shown: E1—10 to 19 percent; E2—20 to 29 percent; E3—30 to 39 percent; E4—40 to 49 percent; E5—50 to 59 percent; E6—60 to 69 percent; E7—70 to 79 percent; E8—80 to 89 percent; E9—90 percent or more.

[2]Report forms were not mailed to small single-establishment companies with up to 20 employees (cutoff varied by industry). Payroll and sales data for 1992 were obtained from administrative records supplied by other agencies of the Federal Government. Those data were then used in conjunction with industry averages to estimate the items shown. Data are also included in respective employment-size classes shown.

Table 5a. Industry Statistics by Industry and Primary Product Class Specialization: 1992

[Table presents selected statistics for establishments according to their degree of specialization in products primary to their industry. Measures of plant specialization shown are (1) industry specialization: ratio of primary product shipments to total product shipments (primary plus secondary, excluding miscellaneous receipts) for the establishment; and (2) product class specialization: ratio of largest primary product class shipments to total product shipments (primary plus secondary, excluding miscellaneous receipts) for the establishment. See appendix for method of computing ratios. For meaning of abbreviations and symbols, see introductory text. For explanation of terms, see appendixes]

Industry or product class code	Industry or primary product class	All establishments (number)	All employees: Number (1,000)	All employees: Payroll (million dollars)	Production workers: Number (1,000)	Production workers: Hours (millions)	Production workers: Wages (million dollars)	Value added by manufacture (million dollars)	Cost of materials (million dollars)	Value of shipments (million dollars)	New capital expenditures (million dollars)
2011	**Meat packing plants:**										
	All establishments in industry	1 387	122.4	2 452.8	105.5	228.5	1 956.6	6 928.0	43 586.4	50 434.4	343.2
	Establishments with this product class primary:										
20111	Beef, not canned or made into sausage	162	56.3	1 065.3	50.0	110.3	907.9	2 985.4	28 725.7	31 652.1	121.9
20112	Veal, not canned or made into sausage	11	.7	18.9	.6	1.3	12.4	32.5	248.0	284.3	1.3
20113	Lamb and mutton, not canned or made into sausage	10	.7	13.1	.6	1.3	10.6	46.5	277.7	323.3	.6
20114	Pork, not canned or made into sausage	74	37.8	812.5	32.8	71.3	656.4	1 908.9	9 453.0	11 345.2	159.2
20116	Pork, processed or cured (not canned or made into sausage)	12	7.8	175.3	6.6	14.1	117.8	696.7	1 350.6	2 039.6	14.6
20117	Sausages and similar products (not canned)	36	4.4	87.7	3.2	6.3	53.6	375.6	502.4	876.3	18.0
20118	Canned meats (except dog, cat, and baby food)	1	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
20119	Hides, skins, and pelts	7	.3	7.9	.3	.5	4.2	10.3	96.5	107.0	(D)
2011B	Miscellaneous byproducts of meat packing plants	11	.5	8.8	.4	.8	6.8	19.6	86.2	106.5	.4
2013	**Sausages and other prepared meats:**										
	All establishments in industry	1 264	85.5	2 026.3	65.7	139.9	1 353.3	5 491.3	14 455.0	19 972.4	379.7
	Establishments with this product class primary:										
20136	Pork, processed or cured, including frozen, not canned or made into sausage	121	19.1	453.2	15.1	32.1	310.4	1 109.1	3 137.1	4 249.4	81.0
20137	Sausage and similar products, not canned	269	31.9	815.5	24.1	51.8	551.0	2 102.3	4 668.6	6 784.8	132.8
20138	Canned meats (except dog, cat, and baby food), containing 20 percent or more meat	20	2.8	67.6	2.3	4.5	49.8	380.0	547.8	919.9	15.3
2013B	Other processed, frozen, or cooked meats	177	21.7	492.2	16.8	36.7	316.8	1 424.7	4 724.3	6 165.4	101.5
2015	**Poultry slaughtering and processing:**										
	All establishments in industry	591	193.8	3 091.5	172.8	341.5	2 518.4	6 656.5	17 066.7	23 757.1	466.4
	Establishments with this product class primary:										
20151	Young chickens (usually under 20 weeks of age) whole or parts	179	115.0	1 726.7	103.8	205.1	1 448.3	3 238.1	9 439.8	12 671.3	249.4
20152	Hens and/or fowl (including frozen whole or parts)	10	1.5	20.5	1.4	2.8	15.1	37.0	58.6	95.8	2.2
20153	Turkeys (including frozen, whole or parts)	38	21.2	348.1	18.7	37.1	276.8	702.1	2 160.7	2 877.8	48.4
20154	Other poultry and small game (including frozen, whole or parts)	5	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)	(D)
20155	Processed poultry and small game (except soups) containing 20 percent or more poultry or meat	101	41.1	741.6	36.0	71.4	585.7	2 076.1	4 149.7	6 237.7	116.4
20159	Liquid, dried, and frozen eggs	35	3.8	81.3	3.1	6.3	56.5	198.7	518.0	725.6	24.1

Note: For qualifications of data, see footnotes on table 1a.

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PDR10120001500505319615 00Poultry Production and Value

Poultry Production and Value by States, 1994-95

Value of Production and Sales Up 4 Percent

The combined value of production from broilers, eggs, and turkeys and the value of sales from chickens in 1995, was $18.6 billion, up 4 percent from the $17.9 billion in 1994, according to the Agricultural Statistics Board. Total poultry value consisted of: 63 percent from broilers, 21 percent from eggs, 15 percent from turkeys, and less than 1 percent from other chickens.

Value of Broiler Production Up 3 Percent

The value of broilers produced during 1995 was $11.8 billion, up 3 percent from the $11.4 billion in 1994. The total number of broilers produced in 1995 was 7.33 billion, up 4 percent from 1994. The 1995 average price per pound on a live weight equivalent basis was 34.4 cents per pound, compared to 35.0 cents per pound in 1994.

Value of Egg Production Up 5 Percent

Value of egg production in 1995 was $3.96 billion, up 5 percent from the $3.78 billion in 1994. Egg production totaled 74.3 billion eggs, up fractionally from the 73.9 billion eggs produced in 1994. In 1995, eggs averaged 64.0 cents per dozen, compared with 61.4 cents in 1994.

Value of Turkey Production Up 5 Percent

The value of turkeys produced during 1995 was $2.77 billion, up 5 percent from the $2.64 billion the previous year. Turkey production in 1995 totaled 6.77 billion pounds live weight, compared with 6.54 billion pounds in 1994. The average price received by producers during 1995 was 41.0 cents per pound, compared with 40.4 cents in 1994.

Value of Sales from Chickens Down 12 Percent

The value of sales from chickens (excluding broilers) in 1995 was $68.2 million, down 12 percent from the $77.5 million a year ago. Prices averaged 6.4 cents per pound, compared with 7.6 cents in 1994. The number of chickens sold in 1995 totaled 205 million, up 2 percent from the total sold during the previous year.

Value of Production: Broilers, Eggs, Turkeys, Chickens, and Total, United States, 1986-95

Year	Broilers 1/	Eggs	Turkeys	Chickens 2/	Total
			1,000 Dollars		
1986	6,784,088	3,543,295	1,951,087	127,730	12,406,200
1987	6,177,127	3,209,327	1,703,137	111,827	11,201,418
1988	7,435,300	3,073,382	1,951,351	99,011	12,559,044
1989	8,777,915	3,876,822	2,235,145	142,409	15,032,291
1990	8,365,704	4,021,355	2,393,375	94,392	14,874,826
1991	8,383,046	3,914,659	2,352,986	72,199	14,722,890
1992	9,174,136	3,397,462	2,396,364	89,105	15,057,067

1993	: 10,416,962	3,800,237	2,509,127	96,409	16,822,735
1994	: 11,371,723	3,780,377	2,643,765	77,496	17,873,361
1995	: 11,762,683	3,958,976	2,774,301	68,155	18,564,115

1/ Excludes States which produced less than 500,000 broilers.
2/ Value of sales.

Eggs: Production, Price, and Value by State and United States, 1994-95 1/

State	Eggs Produced		Price per Dozen 2/		Value of Production	
	1994	1995	1994	1995	1994	1995
	----- Million ----		---- Dollars ----		--- 1,000 Dollars ---	
AL	2,733	2,693	.902	.961	205,431	215,664
AR	3,803	3,608	1.040	.979	329,593	294,353
CA	6,602	6,444	.464	.537	255,277	288,369
CO	778	805	.660	.706	42,790	47,361
CT	972	944	.997	1.040	80,757	81,813
DE	152	138	1.080	1.130	13,680	12,995
FL	2,538	2,374	.465	.481	98,348	95,158
GA	4,543	4,376	.745	.794	282,045	289,545
HI	195	186	.859	.872	13,959	13,516
ID	254	238	.648	.607	13,716	12,039
IL	768	762	.640	.684	40,960	43,434
IN	5,452	5,496	.508	.516	230,801	236,328
IA	3,808	4,032	.398	.434	126,299	145,824
KS	352	325	.388	.440	11,381	11,917
KY	680	679	.637	.654	36,097	37,006
LA	442	472	1.110	.984	40,885	38,704
ME	1,403	1,364	.922	.971	107,797	110,370
MD	852	1,003	.637	.640	45,227	53,493
MA	207	133	.987	1.020	17,026	11,305
MI	1,435	1,387	.425	.435	50,823	50,279
MN	2,669	2,823	.400	.418	88,967	98,335
MS	1,513	1,443	.964	.990	121,544	119,048
MO	1,713	1,705	.433	.490	61,811	69,621
MT	99	104	.550	.570	4,538	4,940
NE	2,027	2,364	.360	.380	60,810	74,860
NH	39	44	.970	1.090	3,153	3,997
NJ	451	444	.710	.746	26,684	27,602
NM	301	303	.598	.648	15,000	16,362
NY	1,049	1,071	.572	.626	50,002	55,871
NC	3,214	3,152	.735	.773	196,858	203,041
ND	51	47	.360	.384	1,530	1,504
OH	5,644	5,964	.487	.509	229,052	252,973
OK	799	897	.899	.860	59,858	64,285
OR	708	709	.783	.816	46,197	48,212
PA	5,597	5,655	.511	.562	238,339	264,843
RI	56	34	.949	.996	4,429	2,822
SC	1,326	1,289	.637	.658	70,389	70,680
SD	525	481	.325	.345	14,219	13,829
TN	256	254	.720	.790	15,360	16,722
TX	3,860	3,950	.616	.663	198,147	218,238
UT	491	513	.451	.471	18,453	20,135
VT	20	21	.993	1.050	1,655	1,838
VA	940	916	.885	.895	69,325	68,318
WA	1,371	1,455	.730	.769	83,403	93,241
WV	250	239	1.150	1.180	23,958	23,502
WI	883	849	.410	.433	30,169	30,635
WY	2.8	2.4	.676	.741	158	148

Oth St 3/	84	74	.497	.641	3,477	3,901
US 4/	73,911	74,268	.614	.640	3,780,377	3,958,976

1/ Estimates cover the 12 month period Dec 1, previous year through Nov 30.
2/ Average of all eggs sold by producers, including hatching eggs.
3/ AK, AZ and NV combined to avoid disclosure of individual operations. AK price estimate discontinued in 1995.
4/ States may not add to U.S. total due to rounding.

Broilers: Production, Price, and Value by State and Total, 1994 1/ 2/

State	Number Produced	Pounds Produced	Price per Pound 3/	Value of Production
	1,000 Head	1,000 Pounds	Dollars	1,000 Dollars
AL	909,600	4,184,200	.345	1,443,549
AR	1,078,600	4,853,700	.375	1,820,138
CA	226,200	1,131,000	.330	373,230
DE	258,300	1,369,000	.335	458,615
FL	132,700	570,600	.335	191,151
GA	1,005,000	4,723,500	.350	1,653,225
HI	1,120	5,000	.515	2,575
IA	15,000	82,500	.360	29,700
KY	56,500	237,300	.300	71,190
MD	285,000	1,311,000	.330	432,630
MI	650	3,200	.340	1,088
MN	47,800	248,600	.340	84,524
MS	602,600	2,711,700	.340	921,978
MO	153,100	658,300	.380	250,154
NE	2,800	18,200	.360	6,552
NY	1,200	5,600	.340	1,904
NC	643,500	3,217,500	.330	1,061,775
OH	33,100	165,500	.345	57,098
OK	185,800	798,900	.380	303,582
OR	21,500	107,500	.310	33,325
PA	119,300	596,500	.335	199,828
SC	147,200	588,800	.350	206,080
TN	124,700	548,700	.330	181,071
TX	371,000	1,669,500	.395	659,453
VA	252,700	1,187,700	.335	397,880
WA	40,900	200,400	.350	70,140
WV	89,400	384,400	.335	128,774
WI	17,500	82,300	.300	24,690
Oth Sts 4/	194,770	867,400	.355	305,824
Total 5/	7,017,540	32,528,500	.350	11,371,723
15 Weekly Sts 6/	6,245,800	29,047,800	.349	10,129,377

1/ December 1, 1993, through November 30, 1994.
2/ Broiler production including other domestic meat-type breeds.
3/ Liveweight equivalent prices, derived from ready-to-cook (RTC) prices using the following formulas: RTC price minus processing cost X (dressing percentage) = liveweight equivalent price.
4/ CT, IL, IN, LA, ND, & SD, combined to avoid disclosing individual operations.
5/ Excludes States producing less than 500,000 birds.
6/ 15 states in the weekly estimating program: AL, AR, CA, DE, FL, GA, MD, MS,

NC, PA, SC, TN, TX, VA and WV.

Broilers: Production, Price, and Value
by State and Total, 1995 1/ 2/

State	Number Produced	Pounds Produced	Price per Pound 3/	Value of Production
	1,000 Head	1,000 Pounds	Dollars	1,000 Dollars
AL	900,000	4,230,000	.340	1,438,200
AR	1,107,300	4,982,900	.355	1,768,930
CA	235,800	1,179,000	.325	383,175
DE	263,100	1,394,400	.340	474,096
FL	139,800	615,100	.355	218,361
GA	1,070,000	5,136,000	.345	1,771,920
HI	940	3,800	.525	1,995
IA	15,000	72,000	.350	25,200
KY	64,500	258,000	.320	82,560
MD	295,700	1,360,200	.340	462,468
MI	630	2,850	.340	969
MN	48,000	249,600	.335	83,616
MS	644,000	2,962,400	.335	992,404
MO	190,600	800,500	.350	280,175
NE	2,900	18,600	.360	6,696
NY	1,400	6,900	.345	2,381
NC	670,100	3,417,500	.340	1,161,950
OH	43,000	215,000	.315	67,725
OK	198,300	852,700	.355	302,709
OR	21,100	105,500	.320	33,760
PA	121,400	607,000	.335	203,345
SC	162,000	680,400	.345	234,738
TN	130,000	572,000	.325	185,900
TX	395,200	1,746,800	.370	646,316
VA	260,100	1,196,500	.335	400,828
WA	40,300	197,500	.345	68,138
WV	88,900	391,200	.335	131,052
WI	22,200	104,300	.335	34,941
Oth Sts 4/	193,400	863,350	.345	297,674
Total 5/	7,325,670	34,222,000	.344	11,762,222
15 Weekly Sts 6/	6,483,400	30,471,400	.344	10,473,683

1/ December 1, 1994, through November 30, 1995.
2/ Broiler production including other domestic meat-type breeds.
3/ Liveweight equivalent prices, derived from ready-to-cook (RTC) prices using the following formulas: RTC price minus processing cost X (dressing percentage) = liveweight equivalent price.
4/ CT, IL, IN, LA, ND, & SD, combined to avoid disclosing individual operations.
5/ Excludes States producing less than 500,000 birds.
6/ 15 states in the weekly estimating program: AL, AR, CA, DE, FL, GA, MD, MS, NC, PA, SC, TN, TX, VA and WV.

Turkeys: Production, Price, and Value
by State and United States, 1994

State	Number Raised	Pounds Produced	Price per	Value of

	1/		Pound 2/	Production
	1,000 Head	1,000 Pounds	Dollars	1,000 Dollars
AR	25,000	510,000	0.44	224,400
CA	21,000	449,400	0.43	193,242
CO	4,900	164,640	3/	3/
CT	20	468	1.00	468
GA	1,410	42,018	0.41	17,227
IL	3,800	78,280	0.43	33,660
IN	14,000	336,000	0.43	144,480
IA	8,800	249,920	0.40	99,968
KS	1,600	34,400	0.42	14,448
MD & DE	140	3,150	0.48	1,517
MA	140	3,724	1.22	4,543
MN	41,500	846,600	0.36	304,776
MO	20,500	477,650	0.43	205,390
NH	15	374	1.19	445
NJ	85	2,040	0.85	1,734
NY	500	13,250	0.40	5,300
NC	60,000	1,362,000	0.40	544,800
ND	1,150	25,300	0.36	9,108
OH	6,000	176,400	0.36	63,504
PA	10,500	201,600	0.42	84,672
SC	5,800	172,840	0.40	69,136
SD	2,500	75,750	0.36	27,270
VT	30	675	0.99	688
VA	22,000	409,200	0.42	171,864
WV	4,800	89,280	0.42	37,498
Oth Sts 4/	30,415	815,928	0.39	383,647
US	286,605	6,540,877	0.404	2,643,765

1/ Based on turkeys placed Sep 1, 1993 through Aug 31,1994. Excludes young turkeys lost.
2/ Equivalent live returns to producers in most States.
3/ Not published to avoid disclosure of individual operations. Value of production included Other States.
3/ MI, NE, OK, OR, TX, UT, and WI combined to avoid disclosing individual operations.

Turkeys: Production, Price, and Value by State and United States, 1995

State	Number Raised 1/	Pounds Produced	Price per Pound 2/	Value of Production
	1,000 Head	1,000 Pounds	Dollars	1,000 Dollars
AR	26,000	535,600	0.45	241,020
CA	22,000	462,000	0.46	212,520
CO	4,300	158,670	3/	3/
CT	15	291	1.25	364
GA	1,450	43,935	0.44	19,331
IL	3,600	74,880	0.42	31,450
IN	14,200	335,120	0.42	140,750
IA	8,000	227,200	0.39	88,608
KS	1,600	44,800	0.44	19,712
MD & DE	160	2,971	0.48	1,430
MA	105	2,153	1.23	2,648
MN	40,500	854,550	0.35	299,093
MO	22,500	551,250	0.42	231,525

NH	17	347	1.17	406
NJ	88	1,980	0.90	1,782
NY	505	12,979	0.42	5,451
NC	61,200	1,419,840	0.41	582,134
ND	1,670	35,070	0.35	12,275
OH	6,500	192,400	0.35	67,340
PA	11,500	230,000	0.40	92,000
SC	6,120	184,824	0.41	75,778
SD	2,800	87,360	0.40	34,944
VT	31	639	1.14	728
VA	23,500	441,800	0.45	198,810
WV	4,800	90,240	0.45	40,608
Oth Sts 4/	29,465	783,678	0.40	373,594
US	292,626	6,774,577	0.410	2,774,301

1/ Based on turkeys placed Sep 1, 1994 through Aug 31,1995. Excludes young turkeys lost.
2/ Equivalent live returns to producers in most States.
3/ Not published to avoid disclosure of individual operations. Value of production included Other States.
4/ MI, NE, OK, OR, TX, UT, and WI combined to avoid disclosing individual operations.

Chickens: Lost, Sold, Price, and Value
by State and United States, 1994 1/

State	Number Lost 2/	Number Sold	Pounds Sold	Price per Pound	Value of Sales
	---- 1,000 Head ----		1,000 Pounds	Dollars	1,000 Dollars
AL	1,540	9,000	64,800	.111	7,193
AR	2,400	15,000	97,500	.170	16,575
CA	3,100	14,300	52,910	.020	1,058
CO	510	2,200	9,020	.070	631
CT	388	2,486	12,430	.034	423
DE	69	592	4,381	.052	228
FL	1,400	5,100	27,030	.052	1,406
GA	2,323	16,069	102,842	.100	10,284
HI	143	336	1,176	.144	169
ID	88	830	3,154	.023	73
IL	350	2,300	12,650	.013	164
IN	1,450	9,600	33,600	.035	1,176
IA	1,800	9,400	47,000	.012	564
KS	110	1,100	4,950	.100	495
KY	320	1,750	5,775	.060	347
LA	240	1,550	8,990	.050	450
ME	574	3,497	17,485	.034	594
MD	410	3,315	24,863	.054	1,343
MA	80	445	2,225	.034	76
MI	520	3,500	16,100	.015	242
MN	1,600	6,800	24,480	.013	318
MS	1,100	5,500	33,000	.075	2,475
MO	820	4,300	23,650	.170	4,021
MT	64	461	1,844	.020	37
NE	1,280	4,500	18,000	.012	216
NH	14	101	505	.034	17
NJ	160	1,000	3,600	.040	144
NM	335	560	2,184	.040	87
NY	530	3,100	14,570	.025	364
NC	1,825	12,500	90,000	.115	10,350

ND	50	120	528	.013	7
OH	2,200	14,700	54,390	.010	544
OK	504	2,960	17,168	.165	2,833
OR	335	1,700	7,140	.020	143
PA	2,200	12,000	60,000	.055	3,300
RI	22	70	350	.034	12
SC	500	3,200	16,000	.112	1,792
SD	210	790	3,160	.070	221
TN	145	950	4,275	.130	556
TX	1,800	11,000	44,000	.067	2,948
UT	265	1,625	6,500	.030	195
VT	40	65	325	.034	11
VA	445	4,100	20,910	.111	2,321
WA	620	3,800	13,680	.020	274
WV	440	1,200	6,120	.120	734
WI	450	1,800	6,660	.010	67
WY	11	8	38	.050	2
Oth Sts 3/	41	132	532	.031	16
US	35,821	201,412	1,022,490	.076	77,496

1/ Estimates cover the 12 month period Dec 1, previous year through Nov 30 and excludes broilers.
2/ Includes death and other losses during the 12 month period.
3/ AK, AZ, and NV combined to avoid disclosing individual operations. AK value of sales estimates discontinued. Number lost, and number and pounds sold are included in U.S. total.

Chickens: Lost, Sold, Price, and Value
by State and United States, 1995 1/

State	Number Lost 2/	Number Sold	Pounds Sold	Price per Pound	Value of Sales
	---- 1,000 Head ----		1,000 Pounds	Dollars	1,000 Dollars
AL	1,800	9,000	63,900	.100	6,390
AR	2,600	18,000	117,000	.130	15,210
CA	2,700	15,100	54,360	.019	1,033
CO	450	1,970	7,880	.040	315
CT	484	2,464	12,320	.029	357
DE	102	727	5,307	.043	228
FL	1,892	4,800	25,440	.040	1,018
GA	2,380	15,250	100,650	.095	9,562
HI	143	301	1,084	.121	131
ID	80	510	1,887	.030	57
IL	375	2,170	12,369	.010	124
IN	2,100	8,100	28,350	.025	709
IA	3,100	9,500	57,000	.006	342
KS	150	400	1,600	.050	80
KY	300	1,900	6,270	.060	376
LA	230	1,750	10,150	.058	589
ME	722	3,932	19,660	.029	570
MD	602	2,973	22,000	.046	1,012
MA	86	601	3,005	.029	87
MI	550	3,900	19,500	.010	195
MN	1,400	5,300	19,080	.007	134
MS	2,000	5,200	35,880	.053	1,902
MO	980	4,250	23,375	.130	3,039
MT	63	536	2,144	.030	64
NE	1,290	4,230	16,920	.006	102
NH	24	166	830	.029	24
NJ	150	1,000	3,500	.020	70

NM	:	450	200	820	.020	16
NY	:	550	3,350	15,075	.015	226
NC	:	1,825	12,800	96,000	.096	9,216
ND	:	60	150	675	.007	5
OH	:	2,750	14,900	55,130	.010	551
OK	:	590	3,860	23,932	.130	3,111
OR	:	276	1,250	7,250	.020	145
PA	:	2,400	14,500	72,500	.045	3,263
RI	:	17	133	665	.029	19
SC	:	600	3,300	16,500	.095	1,568
SD	:	290	1,090	4,360	.050	218
TN	:	185	850	3,740	.100	374
TX	:	1,900	11,700	51,480	.051	2,625
UT	:	195	1,475	5,900	.026	153
VT	:	9	55	275	.029	8
VA	:	536	3,610	18,411	.103	1,896
WA	:	590	4,000	14,800	.020	296
WV	:	205	1,250	6,375	.104	663
WI	:	540	1,900	7,030	.010	70
WY	:	10	7	32	.050	2
	:					
Oth Sts 3/	:	27	175	699	.015	10
	:					
US	:	40,758	204,585	1,073,110	.064	68,155

1/ Estimates cover the 12 month period Dec 1, previous year through Nov 30 and excludes broilers.
2/ Includes death and other losses during the 12 month period.
3/ AK, AZ, and NV combined to avoid disclosing individual operations. AK value of sales estimates discontinued. Number lost, and number and pounds sold are included in U.S. total.

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7

Conversion of live poultry to poultry meat

The terminology of the poultry meat industry differs from large animal or the red meat industries in that poultry processing refers to slaughtering, feather removal and evisceration. In the red meat industries processing refers to conversion of animal carcasses into consumer products. The conversion of poultry carcasses into a number of products is called further processing. A schematic outline of the unit operations in the conversion of live poultry to human food is given in Fig. 7.1.

There are some variations in processing different species of poultry. Some of the variations are discussed as each step in processing is described. As broiler chicken meat constitutes the majority of poultry meats, broiler processing steps will be considered as the normal procedure. Modifications for other species will follow for each procedure. If no modifications are given all species use basically the same procedures.

ASSEMBLY OF LIVE BIRDS

Poultry processors are generally responsible for picking birds up at the site of production and delivering the birds to the processing facility. Broiler chickens are placed in crates. These crates were generally made of wood prior to 1965. Since then high density polyethylene or fiber glass crates have largely replaced the wooden crates. The new crates offer advantages of easier cleaning, uniformity in weight whether wet or dry, and ability to get more crates on a truck due to thinner wall thickness. The number of broiler chickens placed in a crate depends on size of bird; length of haul; and environmental conditions, especially temperature and humidity.

While crates are most often used some other systems are in use. Cages on rollers or handled by fork lift trucks are being used with success. There are also poultry transport trucks used to a limited extent with broilers but much more extensively with mature chicken hens and especially with turkeys.

Turkeys are frequently hauled on special turkey handling trailers or trucks. When hauled in crates, the crate size is considerably higher than crates used for chickens. Length and width of the turkey crates are the same as for chicken crates. Numbers of

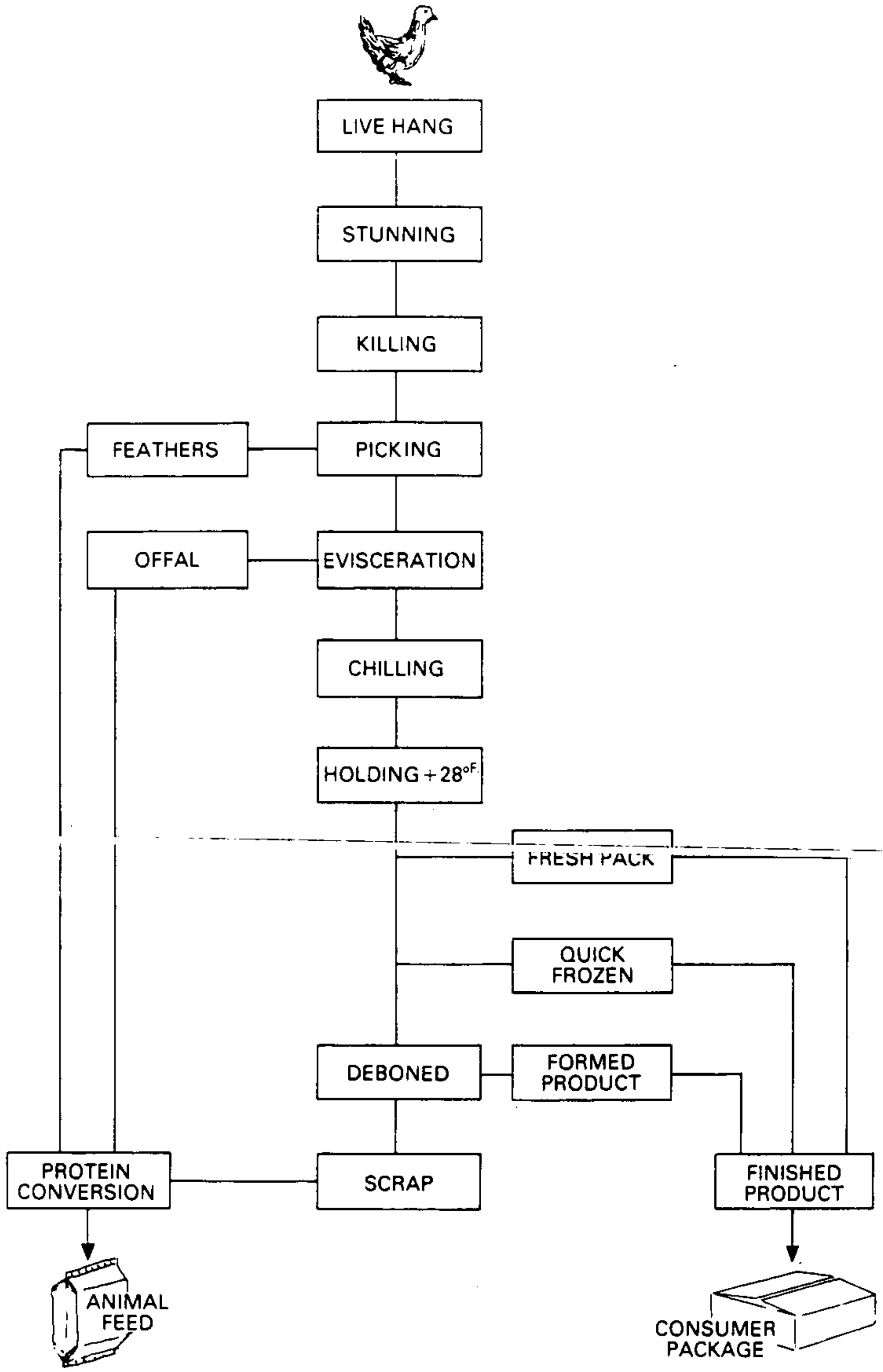

Fig. 7.1 — Unit operations in the conversion of live poultry to food products.

birds per crate are dictated by the same factors that control the loading of chicken broiler crates plus the factor of total weight.

Ducks are usually hauled on trailers. The loading is unique as the ducks are herded onto the trailers and off the trailers into holding pens where water is provided at the processing plant. Geese are handled the same as ducks when numbers are sufficient to justify the equipment. With small numbers of geese, turkey sized crates are often used. Other species such as pheasants, quail, guinea fowl and pigeons are usually handled in crates.

A major concern during assembly of poultry is the minimizing of bruises on the carcass. When poultry, either chickens or turkeys, are handled during catching and loading great care must be exercised. Catching crews used must be trained in handling procedures so as to eliminate bruising of tissue or breaking of bones. Each processing plant quality control operation should have records on bruising of birds handled by each catching crew. Records should cover location and color of bruises to help in identifying the cause of the bruise. It was reported by Hamdy *et al.*, (1961b) that visible bruising can occur up to a few seconds after the carotid artery is severed for slaughtering. Bruises caused up to 12 hours prior to slaughter are pink to red. After 12 hours the bruise is blue to purple and after 24 hours a greenish color develops. The green colored bruise remains a similar hue until the discoloration disappears, usually after four to five days (Hamdy *et al.*, 1961a). Bruises heal faster on younger birds (Hamdy *et al.*, 1961b). Hewell (1986) reported that up to 50% of downgrading bruises can occur in the broiler house prior to catching operations. Goodwin (1986) stated that most bruises occur within 12 to 24 hours prior to processing. Some of the reasons listed by Goodwin (1986) are house construction, equipment placing and management factors such as not allowing feeders to run empty during the final 24 hours, or failing to have the house ready when the catching crews arrive. Ideally, all equipment such as feeders and waterers should be removed from floor pens prior to the arrival of the catching crew. In this way the prospect for bruising is reduced to how well or poorly the crew handles the birds when crating or cooping them.

Hamdy *et al.*, (1961a) reported that 90% of all bruises were less than 12 hours old. Childs *et al.*, (1969) reported that 58.4% of bruises on the breast and legs, of severity sufficient to require downgrading because of trimming, occurred prior to catching operations. Taylor and Helbacka (1968) found significant differences among catching crews as to the numbers of bruised birds. No differences could be attributed to time the birds were held in crates on the trucks. In their studies of over 6000 flocks, percentages of bruised birds varied by monthly averages from 16.6% to 28.4% over a two year time span. Taylor and Helbacka (1968) reported about 1% fewer bruises on birds loaded in the dark as compared to daylight loading.

Breast blisters can be attributed to sex, weight and litter management. Caked and wet litter definitely contribute to blisters and the latter to scabby hips (Goodwin, 1986). In heavy birds an excessive percentage of breast blisters has been related to long hauls in wooden crates. These were field observations with no control data for comparisons.

A second consideration during assembly is allowing sufficient time to clear the digestive tract without extending the time to the point of reducing yield of salable product. A number of studies have been conducted. Consensus is that birds should be off feed for a least four hours to reduce fecal contamination. Shrinkage of edible tissues is detectable when feed and water are withheld in excess of 12 hours (May and Brunson, 1955). Wabeck (1972) reported a linear relationship between percentage shrinkage and time off feed. Loss after 24 hours was approximately double the loss after 12 hours. When eviscerated yield was calculated using initial weight at the time feed was withdrawn there was an increasing loss as time increased. When eviscerated yield was calculated using weight at time of slaughter, there was an increase in yield as time increased up to 12 hours. The nutritive value of broiler breast meat was not affected to a significant degree by the time off feed prior to slaughter according to Ang and Hamm (1985).

HANGING ON THE KILL LINE

The removal of birds from crates or cages must be done in a manner so as to minimize bruising and broken bones. If a crate dumper is used the belt height must be kept at the proper level and the operator must not dump too many birds on the belt which could result in bruised, scratched or smothered broilers.

With turkeys, because of their size, it is essential that the truck cage level be adjusted to shackle level to minimize lifting required of the hangers. With ducks, care must be given to no crowding of the ducks in the holding pens or chutes through which they are driven. If ducks are allowed to pile up there will be skin scratches and if piling is severe, smothered ducks.

The hanging of all poultry on shackles should be done so as to minimize struggling of the birds. Birds that struggle excessively as evidenced by wild wing flapping can bruise their wings as well as birds adjacent to them on the line. According to Addis *et al.*, (1963) such birds are also likely to yield tougher meat due to the rapid depletion of glycogen from the tissues and the lower pH of the meat at the onset of rigor mortis.

Attempts were made to use carbon dioxide gas to immobilize broilers and turkeys in their crates so as to minimize struggling while the birds were being removed from the crates and hung on the killing line. It was demonstrated that carbon dioxide immobilization of chickens (Kotula *et al.*, 1961) and turkeys (Drewniak *et al.*, 1955) was possible but the practice was not adopted by commercial processors of either chickens or turkeys.

HUMANE SLAUGHTER

In the USA the law requires that all animals be stunned prior to slaughter. The method of choice in the poultry industry is electric shock.

There are a number of electric stunning systems. The most effective stunners are those that insure positive contact between the head and feet of the bird with the source of current and the ground. The amperage used in stunning must be carefully controlled. If too little current is used the desired immobilization is not achieved. When too high an amperage is used the heart is stopped too soon and wing tips are often pink. When processing heavy tom (male) turkeys use of excessive current results in such a violent reaction that the clavicle is often broken leaving bone fragments in the muscle tissues.

Pollard *et al.* (1973) compared four systems of stunning with respect to carcass quality. The methods were (a) no stun, (b) saline solution contact stun, (c) plate contact stun, and (d) saline solution contact stun plus a plate contact stun. Treatments c and d resulted in the whitest appearing carcasses. They used 1.5 amperes of current.

Goodwin *et al.* (1961) compared electric shock and carbon dioxide immobilization as to their possible effect on tenderness of turkey meat. No differences were reported between stunning methods or between stunning and no stunning with respect to tenderness of breast or thigh muscles.

SLAUGHTER AND BLOOD LOSS

Poultry are dispatched by cutting the jugular vein and the carotid artery. Davis and Coe (1954) found that significantly faster bleeding occurred when both blood vessels were severed. Decapitation of chickens resulted in a reduced flow of blood. Total blood loss amounted to about 4% of live weight during a three minute bleeding period. The blood loss with such severing of the major blood vessels varies from 35% to 50% of the total blood in the bird (Newell and Shaffner, 1950b). Kotula and Helbacka (1966) reported that salable parts of chickens contained from 36.7% to 45% of the total blood of the live bird using radioactive tracer techniques. Blood constitutes about 10% of the total body weight of young chickens and the percentage of total weight represented by blood decreases as birds mature according to Newell and Shaffner (1950a) and Kotula and Helbacka (1966). As chickens grow the percentage of total weight represented by blood becomes somewhat less for females than for males (Newell and Shaffner, 1950a).

The use of carbon dioxide immobilization for chickens increases the flow of blood during the first 30 seconds after cutting the blood vessels. After a three minute bleeding time approximately equal percentages of blood were lost (Kotula *et al.*, 1957). Mountney *et al.* (1956) found that turkeys stunned by electric shock had bleeding rate influenced by the severity of the shock treatment. A very severe shock slowed bleeding rate but did not affect total blood loss over a three minute time span. The consensus of research reviewed was first reported by Pearce and Lavers (1949). The longer the bleeding time, the more blood removed and the fewer downgraded birds due to lack of blood removal. Most processors allow from 90 to 180 seconds for bleeding of the bird prior to scalding.

SCALDING

In most processing plants feather release is attained by immersion of birds in hot water. A few plants, usually small, still dry-pick. For dry picking feather release is achieved by piercing the medulla section of the brain. In some of the research papers cited in the section on slaughter and bleeding (Kotula and Helbacka, 1966; Davis and Coe, 1954) brain piercing was used as a control procedure for comparative purposes.

There are four terms used to describe different scalding conditions: soft, semi, sub, and hard. Soft and semi-scalds are used most often with broilers and heavy fowl while most turkey processors and 'souper' chicken (spent hens) processors use sub-scald procedures. In some sections of the USA sub-scalding of broilers is practiced so as to obtain a whiter skin color.

The soft-scald uses a water temperature of 50 °C (122 °F) for varying times of up to 150 seconds depending on equipment and birds being processed. Semi-scald water temperatures are 53 °C to 55 °C (126 °to 130 °F) with time varying from one to two minutes. Water temperatures of 59 °F to 60 °C (138 °F to 140 °F) are used for sub-scalding with times of immersion varying from 45 to 90 seconds. The hard-scald uses water in excess of 63 °C (145 °F) with times varying widely depending on water temperature and type of birds being scalded for plucking. The hard-scald is used mainly for mature birds and waterfowl in small plants. In plants specializing in duck or goose processing sub-scalding procedures are usually used.

The purpose of the several scalding procedures is to get feather release with minimal damage to the bird. Klose *et al.* (1961) postulated that the soft-scald might be acting through a nerve-muscle relaxing mechanism. Pool *et al.* (1954) reported that scalding time is a much less critical factor than scalding temperature in feather release. They found that turkeys scalded by sub-scald procedures had a better appearance than turkeys scalded for the same time at 56 °C (132 °F). Sub-scalding resulted in a complete removal of the epidermal layer of the skin. This necessitates keeping the skin surface moist throughout chilling, packaging and freezing to prevent severe discoloration and a toughening of the dry skin. Klose and Pool (1954) suggested that temperatures above 60 °C (140 °F) were acceptable in appearance if the skin were kept moist. Wise and Stadelman (1961) demonstrated that higher scald temperatures resulted in a toughening of outer layers of turkey breast meat. Shannon *et al.* (1957) showed that tenderness of breast meat of chickens was reduced by higher scald temperatures but even more by longer scalding times. It was shown by Wise and Stadelman (1959) that the toughening effect of scalding was limited to surface layers of the breast muscle. The depth of the effect is influenced by both time and temperature of scalding.

The scalding procedure requires close attention as to both time and temperature. Adequate heat must be applied to effect a relaxation of muscles in the feather follicles. If the temperature is in excess of 55 °C (131 °F) the time of scalding becomes critical. Either the time must be short enough so no part of the epidermal layer of the skin is removed or long enough to obtain complete removal during defeathering. Scalding procedures have a direct effect on appearance of the defeathered carcass and tenderness of surface muscles.

Attempts have been made to use microwaves to attain feather release. Thus far, no successful commercial system has been developed. It is possible but in order to get body feathers released, wing tips are generally cooked.

DEFEATHERING

Brain piercing for dry picking results in a relaxation of muscles of the feather follicles for from 30 to 60 seconds. It is essential that feather removal be essentially completed during this time or torn skin results.

Feather removal is achieved by rotating rubber fingers beating on the body surface to rub the feathers free of the follicles. One type of picker is shown in Fig. 7.2.

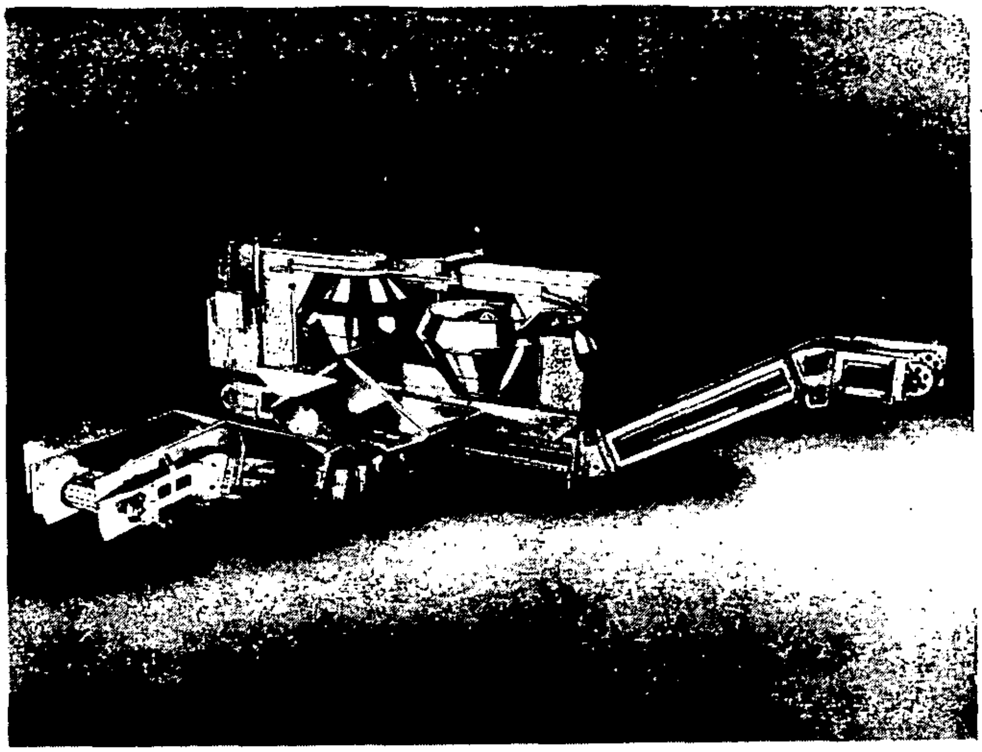

Fig. 7.2 — A dual cyclomatic picker used in some smaller plants. The unit is a patch picker handling up to 30 kg of broilers per picker load. In most large plants pickers remove the feathers while the birds are on shackles.

It was reported by Klose *et al.* (1959) and Pool *et al.* (1959) that machine picking of turkeys resulted in cooked meat about twice as tough as obtained with hand picked birds. Pool *et al.* (1959) found that the degree of toughening could be increased by increasing the duration or the severity of the beating action of the mechanical pickers on young chickens. The same observation was reported by Wise and Stadelman (1957) for turkeys.

Based on the research reported mechanical picker manufacturers have developed lighter weight fingers for picking breast and thigh portions of the carcass so as to do minimal damage to the meat tenderness. Mechanical pickers now available to the industry use more of a rubbing action so that toughening as reported for equipment available in the 1950s is obsolete information with regard to present state-of-the-art equipment.

Feather removal for waterfowl uses an additional step following rough feather removal. Ducks or geese on a line are dragged through hot wax containing rosin. The wax is cooled to become pliable and then stripped from the carcass taking residual feathers and down with the wax.

The final step in feather removal is to remove any pin feathers not removed by the picking procedures. Protruding pin feathers are not allowed on the breast or thighs of USDA graded poultry in the USA. Workers generally remove any such pin feathers by hand. Adequate feathering of poultry to be processed is essential if an acceptable appearance of the carcass or parts with skin on is to be achieved.

The final process on the kill line is a thorough washing of the external surface of the carcass. Pressurized water jets are most often used, frequently with soft rubber fingers, to assure a complete removal of residual feathers or other materials from the skin surface.

When processing fowl or turkeys a flame singeing of the surface of the carcass is done just prior to the washing. Singeing is done to remove filoplumes which appear to be hairs protruding from the skin surface. Singeing must be controlled as the high temperatures in the flame will cook muscle under the skin between the feather tracts just as overscalding might do, with the same result — toughening of the muscle irreversibly.

Following washing, carcasses are transferred to the evisceration line to complete the unit operations involved in processing poultry.

EVISCERATION AND INSPECTION

The usual positioning of poultry on the eviscerating line is hanging by the feet in shackles. For large turkeys a three point suspension is sometimes used hanging the bird by the head and both feet. In plants equipped with mechanical eviscerating equipment only the two point suspension is used.

To eviscerate a bird the head, upper esophagus and crop are removed from the front of the carcass. An incision is made through the abdominal wall under the tail. The cut is continued around the vent so that intestines are free of any connection to the skin or abdominal wall muscles. All organs of the body cavity are removed through this opening. The heart, liver and gizzard are saved as giblets. The intestines, proventriculus, lower esophagus, spleen, lungs and reproductive organs are discarded. In order to get a thorough clearing of organs from the abdominal cavity a vacuum nozzle is generally utilized. Kidneys are normally not removed from young birds in the USA. Some countries have regulations requiring kidney removal from all poultry carcasses. Kidneys are removed by a specially shaped vacuum nozzle.

After the abdomen is open and partially cleared of intestinal organs but before any part of the bird is separated from the carcass, an employee of the USDA inspects each carcass for wholesomeness. The inspector passes the bird, condemns it as unfit for human food, or has an assigned plant employee trim the carcass free of any parts not considered to be wholesome. Procedures for the USDA inspection are being modified so further details will not be given.

When the carcass is passed by the inspector the inedible viscera is pulled free of the carcass and dropped into a carry-off system. The giblets are trimmed and cleaned. The carcass is given a thorough washing, inside and outside, to remove blood clots or other foreign material. The feet and hocks are then cut from the carcass. Care must be taken so as to not cut through the cartilage cap on the lower end of the tibia or leg bone. As poultry bones ar porous, a cutting through the cartilage cap is reason for trimming the leg from the carcass and condemning it.

In the evisceration of laying hens there are additional processes. These are the collection of eggs from the oviduct and ova from the ovary. Ova collected are usually

1 cm or more in diameter. Ova collected are kept identified with each carcass until the bird is passed as wholesome by the government inspector.

During evisceration it is important not to cut across major muscles. Cutting of muscles prior to adequate aging was reported by Lowe (1948) to result in a toughening of the cut muscle. Klose *et al.* (1971) confirmed this observation for breast muscle but found no such toughening effect in thigh muscles. Smith *et al.* (1969) found that both chicken and turkey breast muscles cut free of their attachment to the skeletal structure were subject to cold-shortening when subjected to the normal chilling procedures. Minimum shortening occurred when the excised muscles were aged at 16 °C (62 °F).

MODIFIED EVISCERATION ATTEMPTS

Attempts have been made by Hamm *et al.* (1982) at modifying procedures during evisceration whereby breast and thigh muscles and skin were stripped from the carcass prior to evisceration. Viscera is then inspected after which legs and wings are removed and the frame is used for mechanical deboning to harvest as much edible product as feasible. Benoff *et al.* (1982) reported that cost of meat yields of hot-deboned broilers decreased as broilers were grown to older ages. Using seven week-old broilers as normal or 100%, the cost of nine week old birds was 93%, 10-week-old birds 88%, 11-week-old birds 89%, and 95% for 12-week-old birds. Costs included live bird production and processing costs.

Boyd and Ball (1973) recommended that meat cut from the carcass with less than four to eight hours aging would be most suitable for formulating into processed rolls because of a lack of tenderness. Lyon *et al.* (1983) found that hot deboned dark meat had a higher emulsifying capacity and pH than regularly aged meat. Sausage made from hot deboned meat had a greater cooking loss and shrink and was chewier than cooked sausage made from aged, cold deboned meat. Some recommended aging times to allow tenderness development in different species of poultry are given in Table 7.1.

A number of research studies have been reported on attempts to improve the tenderness of the hot deboned muscle tissues. Stewart *et al.*, (1984) recommended aging of carcasses for four hours prior to removal of meat from the bones. Such a delay would negate many of the advantages of the hot stripping process. Mathus and Janky (1983) used a 5% sodium chloride brine solution for chilling the hot stripped meat from fowl prior to canning with some success but the process resulted in high sodium levels in the meat. Hamm (1983) found that muscle stripped from the breast prior to evisceration could be tenderized by tumbling for 20 minutes and then aging at refrigerated temperatures for 16 hours or longer.

The texture, cooked yields and water holding capacity of poultry meat are also affected by the time post-mortem that meat is cut from the bones. Bassila-Kardouche and Stadelman (1978) found that hot-deboned turkey meat could be brought to an acceptable level of tenderness for turkey rolls by mixing pre-rigor meat with 1.5% sodium chloride and 0.45% polyphosphates in a mixer for 30 minutes. They also reported a greater cooked yield and superior water binding capacity for the turkey meat with salt and phosphate added. Lyon *et al.* (1983a) reported that addition

Table 7.1 — Recommended minimum aging times to asssure an acceptable level of tenderness development in the breast muscle tissues. Longer aging times will result in fewer carcases that might be considered to be tough†

Species	Class	Recommended aging time (hours)
Chicken	Broilers	4
	Roasters	6
	Fowl	4
Turkey	Fryers	24
	Young hens	8
	Young toms (males)	8
Ducks	Roaster	4

† These values are for ice and water chilling. Special treatments of carcasses or muscles to improve tenderness are discussed in the text. Tenderness development occurs at all times the meat is held at temperatures of −3 °C (27 °F) or higher.

of 2% sodium chloride to hot-stripped ground fowl meat resulted in an improvement in cooked yield and moisture retention in chicken patties. Nixon and Miller (1967) reported higher cooked yields in turkey rolls made with hot-boned meat than with meat from conventionally chilled turkeys. They found that hot deboning of turkeys prior to evisceration did not affect total boneless meat yield and cut the cost of deboning in half. The shear values of rolls prepared from the hot-deboned meat were greater than for conventionally processed meat rolls. However, sensory panel evaluations indicated no differences.

WASHING AND CHILLING

The final operation on the evisceration line is a complete washing of the inside and outside of the carcass. Water is absorbed by the carcass, mostly in the membranes of the body cavity and between the skin and muscle tissues, during the washing. Amount of absorption is dependent on rigor of the washing and the cuts in opening the body cavity.

Most poultry meat is chilled in cold water or water and ice. The most used chillers in the USA drop the washed bird from the evisceration line into a prechiller which also serves as a very effective washer. A chiller is shown in Fig. 7.3. Another type of chiller is shown in Fig. 7.4. The water is agitated and USDA regulations stipulate that the prechiller water temperature must be less than 18.3 °C (65 °F). Regulations also govern the minimum replacement rate of clean water depending on the class of poultry being chilled. A second chiller is in line and has a water temperature of less than 2° C (35° F). The USDA inspectors monitor the amount of weight gained by carcasses in the final washer and chiller. The rate of chilling of turkey hens under several handling conditions is shown in Fig. 7.5.

Amount of gain allowed varies with the class of poultry and with what disposition is to be made of the product. Higher levels of water uptake are allowed for broilers

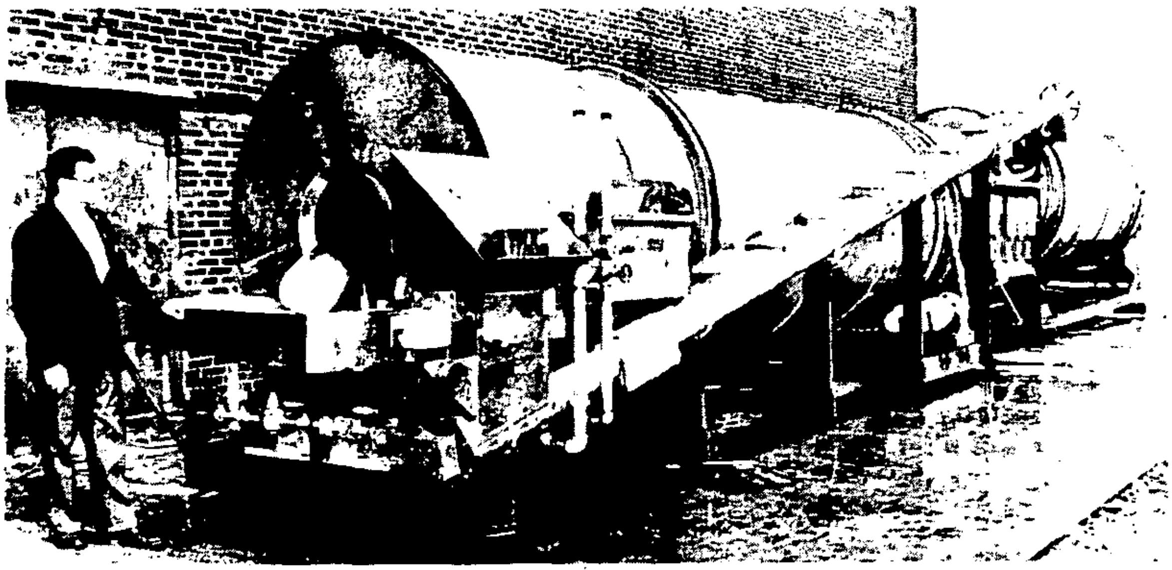

Fig. 7.3 — A rotary chiller. The tank is partially filled with ice and water with the birds moved through by a rotating auger. (Photo courtesy of Morris Associates, Raleigh, N.C.)

that are to be distributed as non-frozen product than for frozen carcasses. With turkeys, the larger the bird the less water uptake, as a percentage of carcass weight, is allowed.

The chilling of poultry is essential for control of microbiological growth on the surface. As cooling the product takes time, the onset and resolution of rigor mortis may occur during the chilling process. Pool *et al.* (1959) reported that tenderness development was a biochemical process. Goodwin *et al.* (1962) studied the effects of rate of chilling and muscle flexing on tenderness development. They found that tumble chilling in ice and water slowed the development of tenderness slightly. The tumble chilled turkeys had significantly greater water uptake than tank chilled birds. Water retention in the tumble chilled birds was superior to the tank chilled carcasses. Working with chicken and turkey fryers, Klose *et al.* (1960) reported that mechanically agitated chilling operations accelerated the rate of chilling, increased the amount of water absorption, but did not influence the rate of tenderness development.

Tarver *et al.* (1956) found that slush ice, crushed ice, circulated slush ice and aerated slush ice were of equal value in the rate of cooling poultry carcasses. Mickelberry *et al.* (1962) found that an ice and water mixture of from one-third to two-thirds ice resulted in nearly equal cooling rates. However, the coolant with one-third ice had significantly greater water absorption by both broiler and roaster chickens. Kotula *et al.* (1966) reported that the cut used in opening the body cavity for evisceration could affect the amount of water absorbed during chilling. Cutting so as to open the thigh areas resulted in greater water uptake. Thomson *et al.* (1961) reported that use of 21 °C (70 °F) water as a prechill prior to immersion in ice water resulted in greater water uptake than colder water in the prechiller.

The selection of a chilling system must take into account the effect of chilling rates

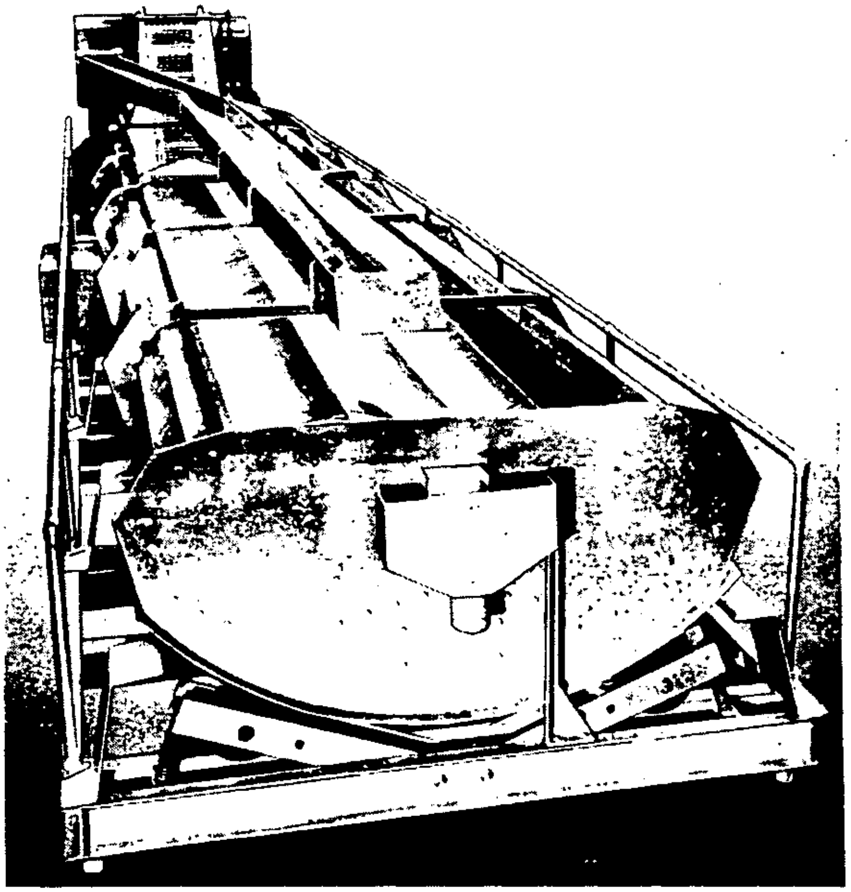

Fig. 7.4 — Continuous rocker-chiller showing five regular sections, one drive tank, ingoing end plate, transfer conveyor end section, and water circulating system.

on cold shortening of muscles (Smith *et al.* 1969) as well as water uptake and getting adequate cooling in the process time available. The rate of chilling turkey carcasses by various systems is shown in Fig. 7.5.

CUTTING INTO PARTS

The sale of poultry has changed dramatically during the last few years in the USA. In some areas of the world the sale of live poultry to consumers is still the most common type of transaction. The next step in marketing was to sell slaughtered carcasses with most of the feathers removed. Such carcasses were known as New York dressed. Eviscerated whole birds were the next step to greater convenience for the user. Recently the sale of frying chicken has shifted to parts. Except for the holiday season the turkey market is moving in the same direction. So the customers will know what they are getting, attempts have been made at standardized terminology and cutting methods.

DEFINITIONS OF PARTS

In 1983 working group V of the World's Poultry Science Association European Federation (Jensen, 1983) published a list of terms in nine European languages for

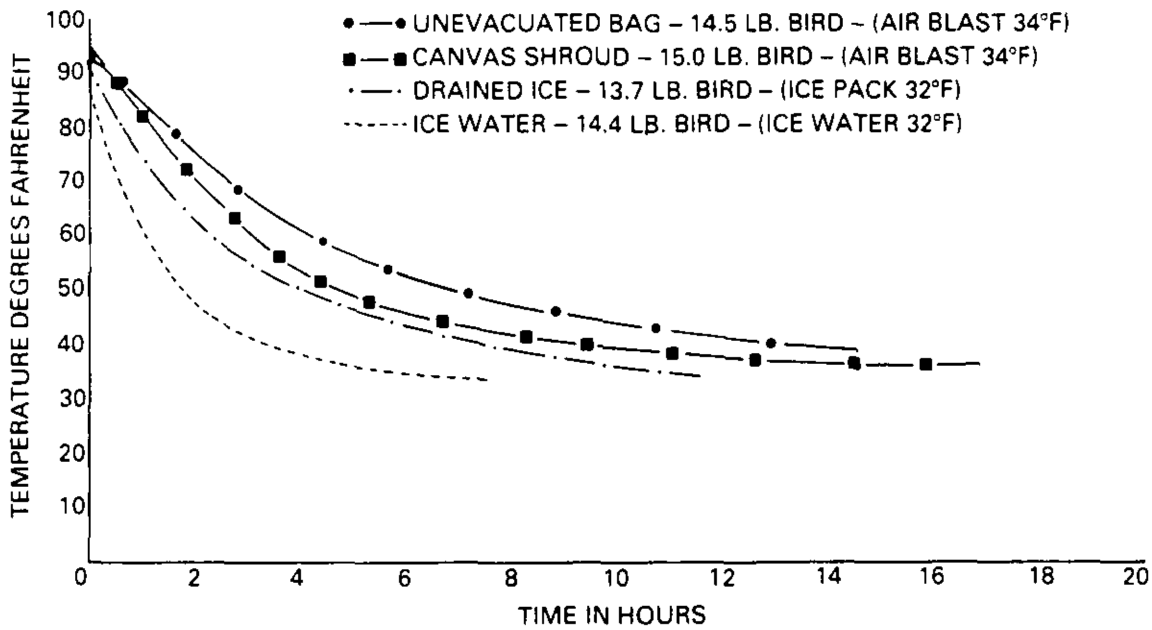

Fig. 7.5 — Comparative cooling rates of eviscerated turkeys with various cooling systems.

description of parts of the carcass. Fifty terms were included in this list. Prior to this Germs *et al.* (1982), of working group V, reported on methods for dissection of broiler carcasses and a description of the parts. The descriptions of parts were as pictures. The main concern was to have uniform reporting of research results. A similar concern was evidenced in the USA in the publication by Swanson *et al.* (1964). A concern by poultry processors and the food service industry to obtain more uniformity in size of cuts resulted in the report by Hudspeth *et al.*, (1973). The cuts and common names of these cuts are:

'Anterior portion cuts:

'Front quarters. The anterior quarter cuts were made as follows: A longitudinal cut was made beginning at the first thoracic vertebra and extending posteriorly through the sixth thoracic vertebra cutting the keel in half. (Common name: front or forequarter)

'Split breast w/back. Wings were removed as described under wings. The breast was then split by a longitudinal cut beginning at the first thoracic vertebra and extending posteriorly through the sixth thoracic vertebra splitting both vertebrae column and sternum. (Common name: breast w/back).

'Keel cut breast. This cut was made at the distal end (or tip of the sternal crest) and continued dorsally across the fifth and sixth vertebral ribs until the pectoralis muscles were separated from the whole breast. The remaining breast portion was then split in the manner of the split breast with back. (Common name: Keel cut breast).

'Wishbone cut breast. The clavicle or wishbone was removed from the carcass by a cut beginning at the anterior end of the sternum and extending dorsally along the coracoid. This piece was separated from the breast at the junction of the clavicle and coracoid. The remainder of the breast was split as previously described for the split breast with back. (Common name: wishbone cut).

'Quartered breast. Breasts were quartered using two cuts: (1) A longitudinal cut to yield two halves as in the breast with back cut; (2) A cut through each half beginning at the point of the sternal crest and extending transversely between the second and third sternal ribs and across the fifth and sixth vertebral ribs, severing the spine at approximately the seventh lumbar vertebra. (Common name: quartered breast portion with back).

'Split breast. The piece was obtained by cutting on each side of the vertebral column beginning at the mid-point of the sternal ribs until the breast was completely severed from the back. The last cut split the whole breast through the mid-point of the sternum. Note that a portion of the back is removed. (Common name: split breast or G. I. breast).

'Breast with ribs. A cut was made on each side of the back beginning at the position posterior to the seventh rib and extending anteriorly to a point where the breast with ribs (sternal and vertebral ribs) and scapula were completely separated from the back. The breast was then split down the center of the sternum. Note that a portion of the back is removed. (Common Name: split breast with ribs).

'Stripped breast w/scapula.By placing a knife in the body cavity at the anterior end of the vertebral column, a cut was made in the ventral posterior direction to split the breast through the center of the sternum. The skin was then cut along the entire length of the vertebral column, and around the last thoracic rib in such a fashion as to loosen the skin from the carcass. Manual pressure was applied on the breast portion and the split breast w/scapula were pulled away from the remaining ribs. Note a portion of the back is removed. (Common name: split breast with shoulder portion).

'Wings. The wings were removed by a cut through the shoulder joint at the proximal end of the humerus.

'Wings w/breast portion. These were cut by removing approximately 2.5 cm of pectoralis major with the shoulder joint. The portion of the pectoralis major removed was that which completely encompassed the shoulder joint.

'Wing segments. The wing tip was removed at the distal end of the forearm; the forearm was removed by cutting through the joint at the distal end of the humerus; and the proximal wing portion as described above by cutting through the shoulder joint.

'Posterior portion cuts:

'Rear quarter. The rear quarter was obtained by a cut beginning at the seventh thoracic vertebra and extending posteriorly splitting the lumbar-sacral vertebra in half. (Common name: whole leg w/back or hindquarter).

'Drumstick. The drumstick was separated from the thigh by a cut through the joint formed by the femur, fibula and tibia. (Common name: drumstick).

'Three piece leg. The entire leg with back was cut into three pieces employing the use of a band saw as follows: Each leg was cut at a point 2.5 cm above and one 2.5 cm below the joint formed by the femur, fibula and tibia. The remaining portion consisting of the back and the upper portion of the two thighs was then cut longitudinally beginning at the seventh thoracic vertebra and extending posteriorly splitting the lumbar-sacral vertebra in half. (Common names for pieces: drumstick portion, drumstick-thigh portion, and thigh portion with back).

'Thigh with back portion. The drumstick was first removed as previously described. A longitudinal cut of the thigh-back portion was then made beginning at the seventh thoracic vertebra and extending posteriorly on either side of the lumbar and sacral vertebrae completely removing this portion of the back bone. (Common name: thigh with back portion).

'Strip cut thigh. This piece was obtained by a cut through the junction of the thigh muscles with the pelvic girdle to the hip joints disjointing the femur. The leg was then separated from the back by pulling the loin or 'oyster' muscle off with the thigh. The thigh and drumstick were separated at the joint as previously described. Note that a portion of the back was removed. (Common name: thigh with connecting fat and skin).

'Square cut thigh. The square cut thigh was made as in the strip cut thigh except the loin or oyster muscle was left on the remaining back. The thigh and drumstick were separated at the joint as previously described. (Common name: thigh).

'Drumstick with thigh portion. The drumstick with thigh portion cut was made by cutting the femur 2.5 cm above the joint formed by the femur, fibula and tibia. The resulting portion contained the fibula and tibia and approximately 2.5 cm of the femur. (Common name: drumstick with thigh portion).

'Thigh with back. The initial cut was made as described for the drumstick cut with the second cut made as described in the thigh portion w/back in the three piece leg section.'

In 1986 the Food Safety Inspection Service (FSIS) of the USDA published guidelines for specified cuts of poultry (FSIS, 1986). These guidelines are to clarify and assure compliance with the provisions of regulations regarding cut-up poultry parts, especially for labeling purposes. These guidelines are:

'A. Proper cut of thighs, drumsticks and wings. Thighs, drumsticks, and wings should be separated from other parts with clean cuts through connecting joints. These parts may still be considered properly cut if the medullary cavity (marrow) of the bone shaft is not exposed. If the part is improperly cut, both ends shall be labeled portions of drumstick, thigh, or wing, unless the parts are acceptable for, and identified with, an official USDA Grade Mark. For example, if the bone of a part is cut short (i.e., medullary cavity exposed), but all of the meat yield associated with that part is not materially affected, then the part may qualify for a grade other than 'A' grade.

'B. Patella (kneebone). The patella (kneebone) may be included on either the drumstick or thigh.

'C. Skin and Fat. Skin or fat not ordinarily associated with a part may not be included unless stated on the label.

the horizontal work plate and the bottom of the polythene cones when in a raised position. A degree of skill was required by the operator when positioning joints into the anular clamps. A reduction in yield resulted if the joints were pushed too far into the unit because available meat was then positioned below the clamps and cutting jaws making it inaccessible for deboning purposes. All yield percentages for the Simon-Johnson system were attained by an operator who had undergone a two day familiarization procedure (Table 7.6). Yields gained by the Simon-Johnson unit were higher than those attained by manual methods.

The critical analysis of additional throughput achieved by the two systems was not specifically investigated. The use of a rotary cutter on raw thigh allowed throughputs in the region of 50 kg/h by trained operators in a working environment. Equally, cooked thighs could be manually stripped at rates in the region of 70 kg/h. The detailed appraisal of the operation characteristics for each system were the prime objective during trials but it was readily apparent that both units were capable of throughputs in excess of manual methods on a man hour basis.

The systems considered showed limitations when compared to hand deboning techniques because the technology available does not take account of the inter-joint variation to the same extent that human operators do. Prior sizing of feed materials is required for both units, more so in the case of the Protecon system. The applications for each unit are somewhat different. The PAD may be successfully employed to produce consistent products, at high volume, over long production periods. The Simon-Johnson system would appear to give a lower output than the PAD but is more flexible from both the point of view of location and feed materials.

In order to meet volume and price requirements imposed by the market, poultry processors should seriously consider the use of automated deboners.

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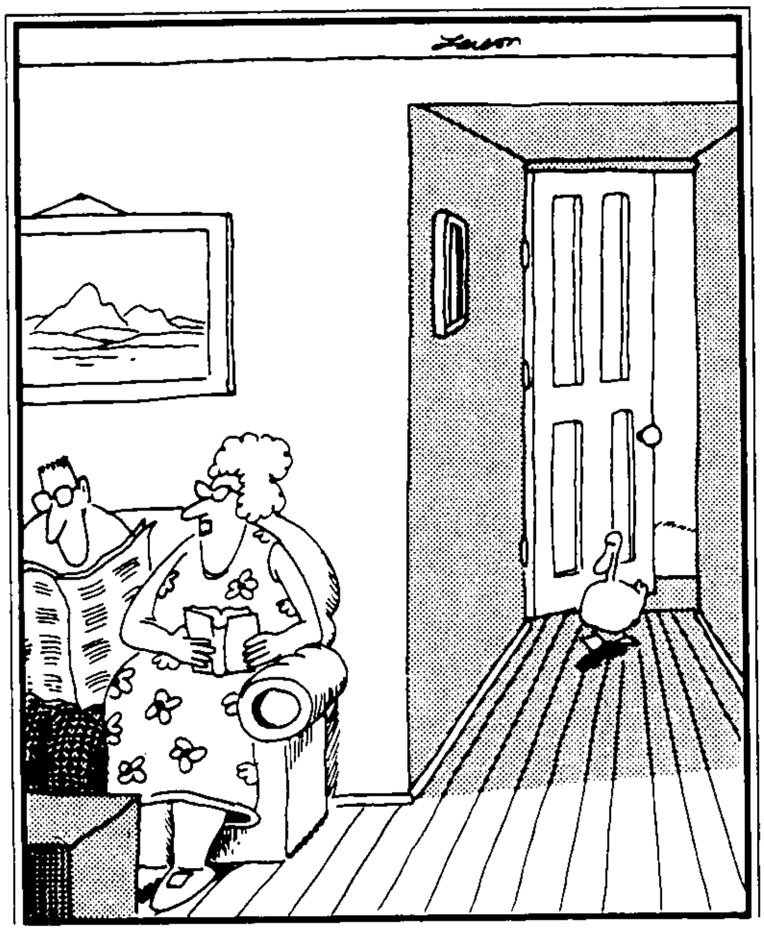

"Here he comes, Earl . . . Remember, be gentle but firm . . . we are absolutely, positively, NOT driving him south this winter."

ref # 4
Chap 2

PROCESSING OF POULTRY

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and downgrading is reputed to be 50% less than with conventional crating systems.

2.2. Transportation

With over 450 million broiler chickens, 37 million 'spent' hens, 30 million turkeys and 8·5 million ducks slaughtered annually in the UK alone in 1986, transportation from the rearing sites represents a massive logistical exercise.

The two critical aspects of transportation by open-sided vehicles are exposure of the birds to the prevailing climate and to high wind speeds (80 km/h). The protection offered varies from system to system, and several methods have been introduced for reducing the degree of exposure in adverse weather conditions, such as sheeting on the sides of vehicles.

In cold, wet conditions, wind increases the chill factor, whereas in hot, humid conditions, it will provide a beneficial cooling effect. The loss of this cooling effect, when the vehicle is stationary, can have severe adverse effects on the birds, which is why it is mandatory under the provisions of the UK Slaughter of Poultry (Humane Conditions) Regulations 1984 for the occupier of a slaughterhouse to ensure that any bird on the premises: 'is protected from the direct rays of the sun and from adverse weather and is provided with adequate ventilation'.

In warm weather, the numbers of birds placed in each crate or module should be reduced.

3. RECEPTION AND UNLOADING

The reception area, often referred to as the 'arrival area', is where the live birds are brought into the slaughterhouse for unloading. To comply with welfare requirements, the area should be under cover and of sufficient size to contain all the transport vehicles awaiting unloading. The ideal arrangement is one where vehicles enter the building at one side and leave at the other after washing, thus avoiding cross-contamination.

In warm weather, additional ventilation provided by fans is necessary and evaporative cooling devices are sometimes used to regulate the environment (Shakelford *et al.*, 1984). Good ventilation is not the only factor necessary to prevent the birds overheating. Control of relative humidity is also essential, and this should not be allowed to rise above 70%.

3.1. Unloading

The method employed depends upon the transportation system.

Loose Crates

The crates arrive at the slaughterhouse on the transport vehicle in stacks eight high. They are unloaded from the vehicle, one by one, and placed on a conveyor system, which carries them to the hanging station. Here the crates are opened, the birds removed and hung on the killing line. The empty crates are then washed and brought back to the vehicle. The crates are generally moved by a combination of driven belt-conveyors and roller track, but nylon chain conveyors are becoming more popular since they do not have to be tensioned and show very little wear.

An automatic crate-washer may be incorporated into the conveyor system. This is normally a three-stage operation. In the first stage, the gross debris is washed away using waste process water, such as the overflow water from the immersion chillers. Then, the crates are thoroughly washed under pressure in water containing detergent, which is re-circulated and filtered. The final stage is a rinse in potable water containing disinfectant.

Fully automated crate-handling systems have been developed to handle palletised stacks of crates. The stacks of crates are removed from the transporter by fork-lift truck and taken to a holding area. From there, they go to an automatic de-stacking point, from which they are conveyed, one by one, to the hanging station. After washing, the empty crates are conveyed to an automatic re-stacking machine and the stacks re-loaded onto clean vehicles. The big advantage of the fully automatic crate-handling system is the elimination of much rough handling of crates, resulting in less down-grading of the carcasses and fewer damaged crates. It also makes more efficient use of the vehicles, since unloading is rapid and there is a buffer stock.

Fixed Crates

For unloading the birds from fixed crates, a system comprising two vertically moving platforms is usually employed. The vehicle is driven between the platforms. The killing-line overhead conveyor extends along these platforms, moving up and down with them. The hangers standing on the platforms open the crates at the side, take out the birds and hang them on the killing line, which is behind them. An alternative is to station the vehicle on an hydraulic ramp, so that it moves up and down in relation to a fixed platform and stationary killing line.

Fixed crates have the advantage that no crate conveyor system is required but there is the major disadvantage that the crates are difficult to clean. In addition, the hangers have to turn through 180° every time a bird is removed and hung on the killing line.

Modules

Multiple floor module. These are unloaded without taking them off the transport vehicle. The birds are removed through hinged doors in the side in a manner similar to that for fixed crates. In common with the fixed crate systems, these modules are difficult to clean. The hanger has also to turn through 180° to shackle the birds on the killing line.

Metal drawer module. The Sun Valley module is designed so that the loaded modules are stacked on a lorry having a demountable bed. At the slaughterhouse, the whole bed, complete with modules, is removed and relocated on a mobile scissor-lift. This raises the modules hydraulically to a high-level unloading platform, so that the drawers are at the required level. The birds are taken from the open drawers and hung on the shackles by a 90° rotation of the unloading operative. It is also possible to unload direct from the lorry, using a vertically moveable platform of the type used for fixed crates.

Unrestrained plastic drawers. The Easyload module is removed from the transport vehicle by a fork-lift truck and fed into an automated system which presents it to a drawer push-out unit. This transfers the plastic drawers to a covered conveyor leading to the hanging station. The open drawer allows unrestricted access for the hanging operatives, greatly reducing bird damage and manpower requirements. The birds are hung directly on the killing line and are available to do so in front of the operatives.

Empty drawers are washed and disinfected in a custom-built unit. The module frames and vehicles are washed independently.

The Tamdev APS 5000 modules are automatically de-stacked after off loading onto a conveyor, and the birds hung directly on the killing line from the open trays. The empty trays then pass through a washer and are automatically re-stacked.

Dump modules. The Stork, Tamdev and Mola systems all transfer the birds from the modules onto conveyors. With the Stork system, the modules are unloaded with a fork-lift vehicle and placed on a supply belt which automatically transfers them to a weigh/tilting mechanism. Before the module is tilted, its gross weight is registered. When the module is tilted, the doors of the tiered cages are opened by the pressure of the birds against them. Broilers from the different tiers flutter down chutes of varying lengths to a wide conveyor, over which they are evenly spread. After tilting, the empty conveyor is weighed again to check the tare value. The empty module proceeds to an enclosed washing unit where it is cleaned and disinfected. After washing, the module doors are shut automatically and the clean modules are transferred for re-loading. The broilers transfer from the wide belt to a narrower one which takes them to a rotating table from which they are hung on the killing line. Hanging rates up to 2000 birds/h can be achieved, which is double that possible from the fixed-crate system.

The Tamdev APS 4000 system is similar except it is claimed that the design avoids dumping the birds, since the speed of descent is controlled by rotating conveyors (Fig. 5). High frequency vibration is also applied to encourage the birds to leave the module. Birds are again hung directly on the line and are available in front of the operatives. The conveyor has a return so that excess birds can travel round safely a second time to avoid the need for build-ups or stop-start conveyors.

The plastic crates of the Mola system have an unloading door, which opens outwards. The modules are unloaded onto a conveyor, which takes them to a tilting device. As the module is tilted, it is clamped to a series of slides, each emptying two tiers of crates. During tilting, the crate doors open by gravity and, as the angle increases, the birds slide gently onto a conveyor taking them to the hanging-on point. The module then moves across to a crate washer. The crates never leave the module.

3.2. The Killing Line

This is an overhead conveyor from which stainless steel shackles are suspended. The birds are attached, head downwards, to these shackles by both feet. One or more overhead conveyor lines serves the reception area. A low-speed extraction unit is frequently fitted above the hanging station to remove dust and feathers.

The conveyors travel at a prescribed rate which depends on the type of poultry being handled, its weight, the number of operatives on the

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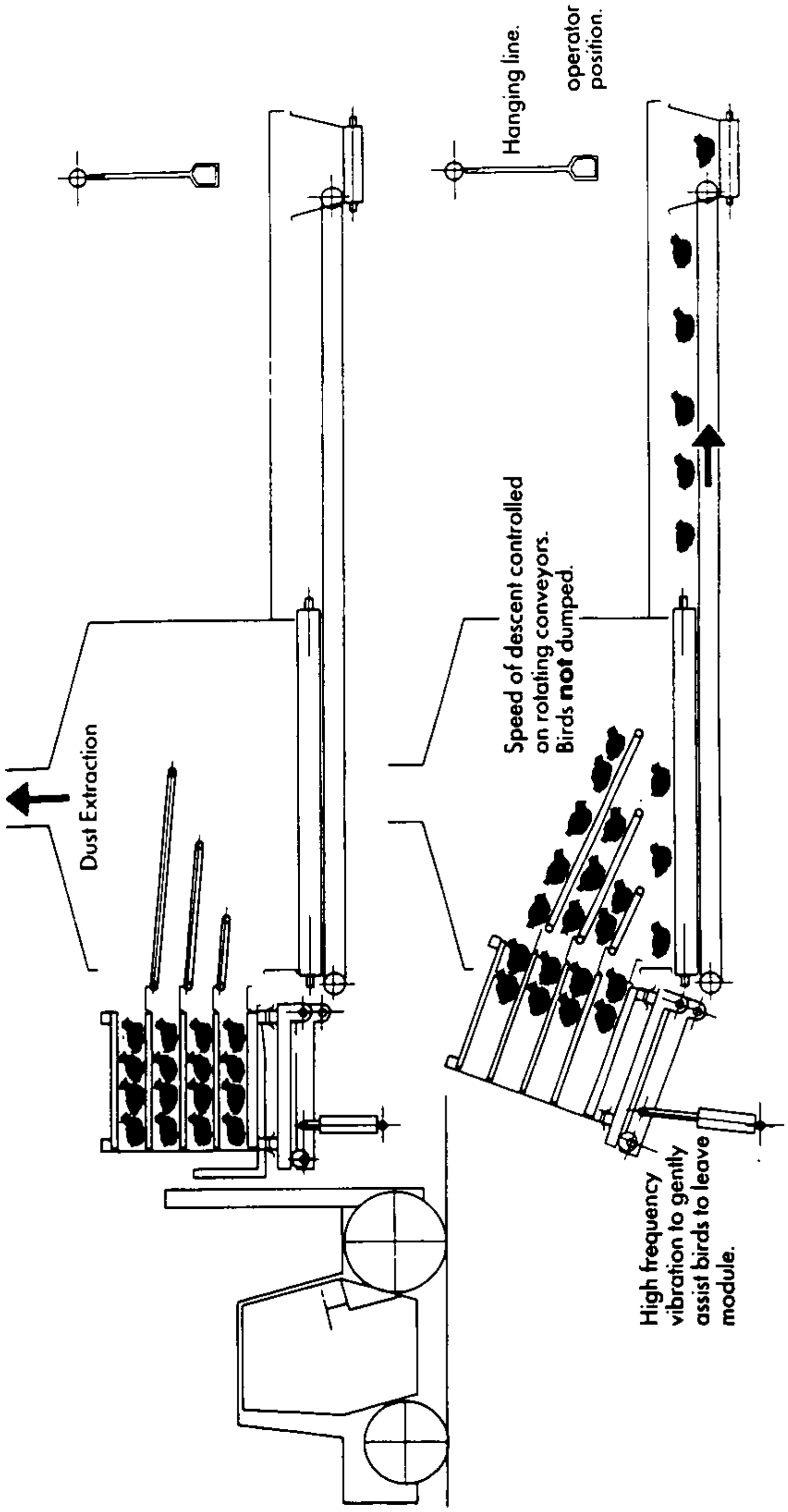

FIG. 5. Unloading the Tamdev APS 4000 module at the slaughterhouse. (Reproduced by kind permission of Tamnaharry Developments Ltd.)

processing lines or, in an automated plant, the capacity of the machinery.

Under the provisions of the UK Slaughter of Poultry (Humane Conditions) Regulations 1984, chickens must not remain suspended from the overhead conveyor for more than 3 min, or in the case of turkeys 6 min, before stunning. It is also a requirement of the same regulations that the lighting in the hanging-on area should be sufficient to enable staff to see the birds properly and identify any problems. However, it should not be bright enough to disturb the birds, and in some instances coloured lights are used since they appear to reduce stress. In the USA, the suspended birds sometimes pass through a darkened tunnel after shackling to calm them.

A strip of smooth plastic sheeting is occasionally installed in a position parallel to the overhead conveyor line, along which the breasts of the suspended birds rub. This is reputed to have a soothing effect on poultry.

4. STUNNING AND SLAUGHTER

Although the subject of stunning and slaughter has been comprehensively reviewed by Gregory in Chapter 2 of this book, there are some technological aspects that need emphasis.

4.1 Stunning

The provisions of the UK Slaughter of Poultry Act, 1967 make it mandatory to stun birds prior to slaughter, unless they are decapitated or have their necks dislocated. There is an exemption for religious slaughter methods.

Stunning is usually carried out in an electrically charged water bath by dragging the heads of the birds through water in which an electrode is submerged. The shackles of the killing line simultaneously touch an earth electrode, causing an electric current to run through the whole body of the bird. Effective stunning requires careful observation of the birds and adjustment of the equipment. The water level is critical and it is essential to avoid water flowing down the inlet chute causing a pre-stun shock, which may make the birds raise their heads, thus avoiding contact with the water of the actual stunner.

Less commonly used stunning instruments are the dry stunner, usually incorporating an electrically charged metal grid or plate, and hand-operated stunners.

4.2. Slaughter

Killing is either performed manually, by passing a knife across the side of the neck at the base of the bird's head, which should sever a jugular vein and carotid artery, or mechanically. Mechanical neck-cutting has been widely adopted for broilers. The bird's head is guided across a single, revolving, circular blade or between a pair of revolving blades. Accurate positioning of the head is essential.

If the cut is not made correctly, several subsequent stages in the process may be affected. When the oesophagus and trachea are severed, the automatic head-puller will not function properly, and the lungs may not be removed completely. If the cut is too deep, the bird may lose its head in the defeathering machines, and the automatic head-puller will not remove the trachea.

Where a mechanical killer is used in the UK, it is mandatory to have an operative present to carry out manual killing, should a bird by-pass the system (The Slaughter of Poultry {Humane Conditions} Regulations, 1984). The UK Animal Health and Welfare Act, 1984 requires operatives to be licensed to slaughter animals by the local authority.

Automated killing of turkeys has not yet been introduced because of the problems created by major variations in bird size (Parry, 1980).

The minimum time permitted for bleeding before birds enter the scald tank is specified in the UK Slaughter of Poultry (Humane Conditions) Regulations, 1984, and is 90 s in the case of chickens and 120 s for turkeys. The blood is collected in a tiled bleeding-tunnel or stainless-steel trough, and pumped to a holding tank at regular intervals.

In most slaughterhouses, an automatic, electronic bird counter is installed between the killer and the scald tank. Loaded shackles are counted, empty shackles are not.

5. SCALDING AND DEFEATHERING

5.1. Scalding

After bleeding, the birds are scalded by immersion in hot water or by spray-scalding. Scald tanks are much more widely used than spray-scald systems. Spray-scalding offers positive benefits for carcass hygiene (Lahellec *et al.*, 1977). However, high water usage and the reported occurrence of quality defects has inhibited its wider adoption commercially.

Birds are immersed for up to $3\frac{1}{2}$ min in the scald tank, depending upon the water temperature. Choice of the latter depends, in turn, on the way in which the birds are to be packed and distributed. For the fresh, chilled market, a 'soft' or semi-scald at 50–51·5°C is required because this permits retention of the cuticle, which is essential if severe discoloration and drying of the skin are to be avoided on air chilling. For the frozen market, a 'hard' or sub-scald at 56–60°C is used since retention of the epidermis is not necessary for a water-chilled product. At the higher temperature, feather removal is greatly facilitated, and the birds only need to remain in the scald tank for 2–$2\frac{1}{2}$ min. Also, fewer defeathering machines are required. Spray-scalders are operated at a water temperature of *ca*. 65°C.

With scald tanks, it is essential that the temperature throughout the tank is constant, and that the water level is correct to ensure total immersion of the birds. The water used to be heated by direct injection of steam. Today, indirect heating by means of heat exchangers is more common. These are fed with hot water or steam. The latest electronic control equipment is capable of maintaining the water temperature to within 0·1°C. The water is circulated continuously by means of pumps or agitators at the centre of the tank. The birds pass through the tank with their backs to these agitators. Since feathering is most dense on the back of a bird, this improves penetration of the water.

In the USA, there is a statutory requirement for an overflow from the scald tank of *ca* 1 litre/bird for hygiene reasons.

Scald tanks are usually fitted with a hood or canopy, which sometimes contains an extraction system to remove steam and odours. However, if steam extraction is used, the energy-saving benefits of steam condensation are lost. It is desirable to enclose the sides of the tank by sliding or hinged panels to reduce heat losses and prevent steam escaping. The latter would make the working environment unpleasant. Improvements in tank design have led to energy savings in excess of 40% (Schipper, 1981).

Various chemicals are available for addition to scald tanks, and these are claimed to assist feather removal by reducing surface tension and enhancing wetting of the feathers.

A subsidiary scald tank operating at 60°C is often used for treating the wings of semi-scalded turkeys, since the wing feathers are difficult to remove.

A potential, future alternative to scalding with water is the use of microwave energy to assist feather removal. Miller *et al.* (1982) have shown that this is a feasible concept. However, a method for reducing exposure of the extremities of the carcass to microwave energy is required, if the process is to become commerically viable, because of the need to prevent tissue damage. The benefits would be two-fold, not only could cross-contamination be eliminated but there would also be considerable energy saving.

5.2. Defeathering

Feathers are removed mechanically, immediately after scalding, by a series of on-line plucking machines. The numbers and types of machine used depend upon the species and size of the bird and the specific part of the carcass to be defeathered. The machines consist of banks of counter-rotating, stainless-steel domes or discs, with rubber 'fingers' mounted on them (Fig. 6). Rubber flails mounted on inclined shafts are sometimes used for 'finishing'.

The machines should be positioned close to the scald tank and adjacent to each other to avoid cooling of the carcasses. The number of machines and their length depend upon the line speed, that is the number of birds processed per hour. Generally, semi-scalded birds require *ca* 50% more defeathering capacity than sub-scalded ones.

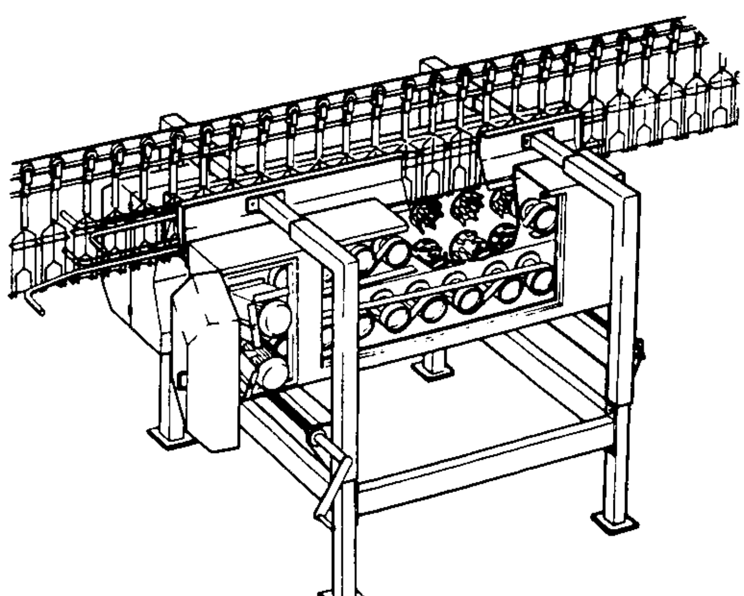

FIG. 6. Defeathering machine. (Reproduced by kind permission of Stork PMT B.V.)

The machines are adjustable for height, width and angle. Frequent adjustment is required to allow for variations in carcass size from load to load. Failure to attend to this can lead to an unacceptable level of mechanical damage to the carcasses.

Continuous water sprays are usually incorporated within the machines for flushing out the feathers. A fast-flowing water channel is normally situated beneath the machines to transport the feathers away from the defeathering area to a central collection point. Dry feather-transport systems are sometimes used. These utilise a conveyor belt in combination with a vacuum or compressed-air system to remove the feathers from the area.

Pin feathers are usually removed by hand. In the USA, the birds pass through an arc flame to singe the remaining fine hairs (filoplumes) and pin feathers. This is not a common practice in the UK.

Wax stripping is used by duck processors. The ducks are dipped in a bath of molten wax and then passed through cold-water sprays which harden the wax. The hardened wax is stripped from the birds by hand and, in the process, the fine feathers are removed. The wax is re-claimed for further use.

With all types of poultry, it is hygienically beneficial to pass the birds through a spray washer after defeathering.

The heads of the birds are removed by an automatic head and windpipe puller. By pulling the heads off rather than cutting them off, the oesophagus and trachea are removed with the heads. An advantage in removing the oesophagus and trachea in this way is that the crop and lungs are also loosened, so that their subsequent removal by the automatic evisceration machines is facilitated. The heads are removed by catching them between two guide bars which slope downwards in the direction in which the birds are travelling. Devices are incorporated to ensure that the heads travel at the same speed as the carcasses, so that they are removed by a straight pull.

The birds then pass through an automatic foot-cutter. In the UK, the feet of the broilers are cut off just above the spur by means of a rotating knife. Elsewhere, they are cut off at the hock joint. The severed feet remain on the shackles and are removed mechanically on the return line.

In the case of large turkeys, retention of the sinews is considered unacceptable. Instead of cutting off the shanks, an automatic sinew-puller is used, and this draws up to nine of the main sinews. The most common design employs two toothed discs, the lower of which is mounted at an angle of 30° relative to the upper. The upper disc engages the leg above the foot, the lower beneath the hock joint. As the discs rotate and move apart, the foot and shank, along with the sinews, are separated from the carcass.

The carcasses are re-hung on the evisceration line after removal of the feet. This can now be done automatically, using a transfer system available from several equipment manufacturers. In this case, the foot cutter and transfer device are combined in one unit.

The empty, returning, killing-line shackles pass through a shackle washer on their way back to the bird arrival area.

6. EVISCERATION

In the EEC, the evisceration area must be physically separated from the defeathering area (Council Directive 71/118/EEC).

Chickens are usually suspended from the shackles of the evisceration-line conveyor by engaging the hock joints: 'two-point' suspension. Turkeys, however, are commonly hung by a 'three-point' suspension, which includes the head as well as the legs. This presents the bird horizontally, making cutting and evisceration easier.

Hand evisceration is performed by first making a horizontal or J cut (a bar cut is customary in the case of turkeys) around the vent, through which the viscera can be drawn. A mechanical vent-cutter is sometimes used. This has a central pin, which is put into the vent. The vent is then sucked by vacuum and cut by a revolving, cylindrical blade. The connection with the intestine is not severed. The initial cut is enlarged with scissors to allow removal of the viscera.

The edible viscera, that is the heart, gizzard and liver, are separated and washed. The lungs and any other material remaining within the carcass are removed with a special hand-tool or by suction, using a lung gun. The neck is cut off, washed and retained for packing with the edible viscera (giblets). The gizzards require cleaning before packing. This entails splitting them, washing out the contents, peeling off the hard lining (skinning) and a final wash.

The entire operation can be performed mechanically by a gizzard harvester (Fig. 7). This machine separates the gizzards from the inedible viscera. It has two rollers, which bring the gizzards into the correct position to be received by a transport chain with sharp points. The chain moves the gizzards over a rotating knife, which splits them.

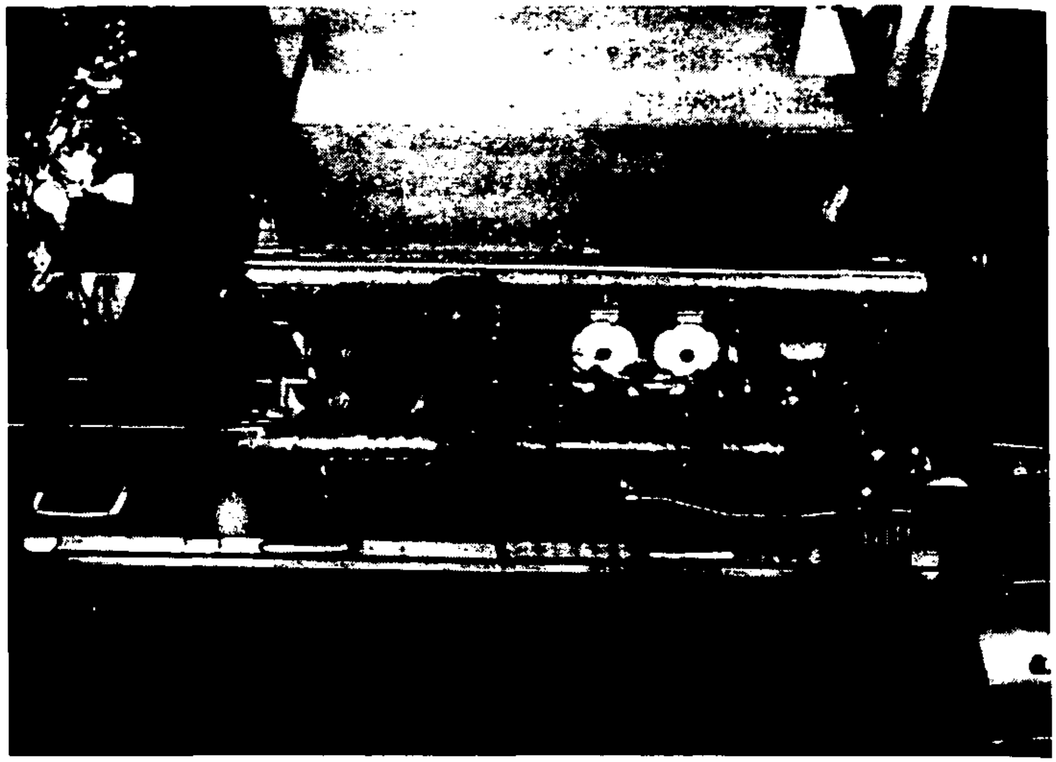

FIG. 7. Gizzard harvester in operation. (Reproduced by kind permission of Stork PMT B.V.)

A spreader bar opens out the gizzards and two brushes clean them before they are pushed onto two pairs of peeler rollers by a pressure wheel. The rollers remove the hard lining.

The giblets are transported in water via flumes, or pumped separately through overhead pipes to a central processing area, where they are sorted, chilled and packed. Chilling frequently involves the use of continuous water chillers, which are miniature versions of the screw-type counter-flow chillers used for carcass chilling. In the UK, giblets are generally wrapped in opaque polythene bags or heat-sealed in sachets of polythene. In other countries, paper pouches are more commonly used for packaging giblets.

The inedible viscera are usually transported in water troughs to a central collection area. To conserve water, dry offal transport by means of a vacuum or compressed-air system is sometimes used.

Automated evisceration has been a major innovation in the chicken industry, resulting in considerable labour savings. Unfortunately, size variability in turkey carcasses has delayed the development of similar equipment for turkeys (Parry, 1980), although some pieces of automated equipment, such as a neck-skin slitter, a neck remover, a gizzard harvester and an inside-outside washer, capable of handling birds up to 14 kg, have recently been introduced.

A single automatic evisceration line can handle up to 6000 broilers/h (Fig. 8). The standard layout comprises a vent cutter, an opening machine (these two machines may be combined), an eviscerator and a neck cracker, usually with a built-in neck-slitting facility. A final inspection machine, which removes by vacuum residual debris from inside the carcass, is often included.

Vent cutters have a cylindrical knife rotating about a centring pin. The knife makes a circular cut around the vent, and as it withdraws, pulls out the vent still attached to the intestines. The bursa of Fabricius, a gland between the tail and the vent, is cut and removed together with the vent. If the equipment is correctly adjusted, the intestines are not cut or broken, thus avoiding faecal contamination. The opening machine enlarges the opening made by the vent cutter, so that the viscera may be removed without damage.

The eviscerator, which locates the bird with its back to the machine

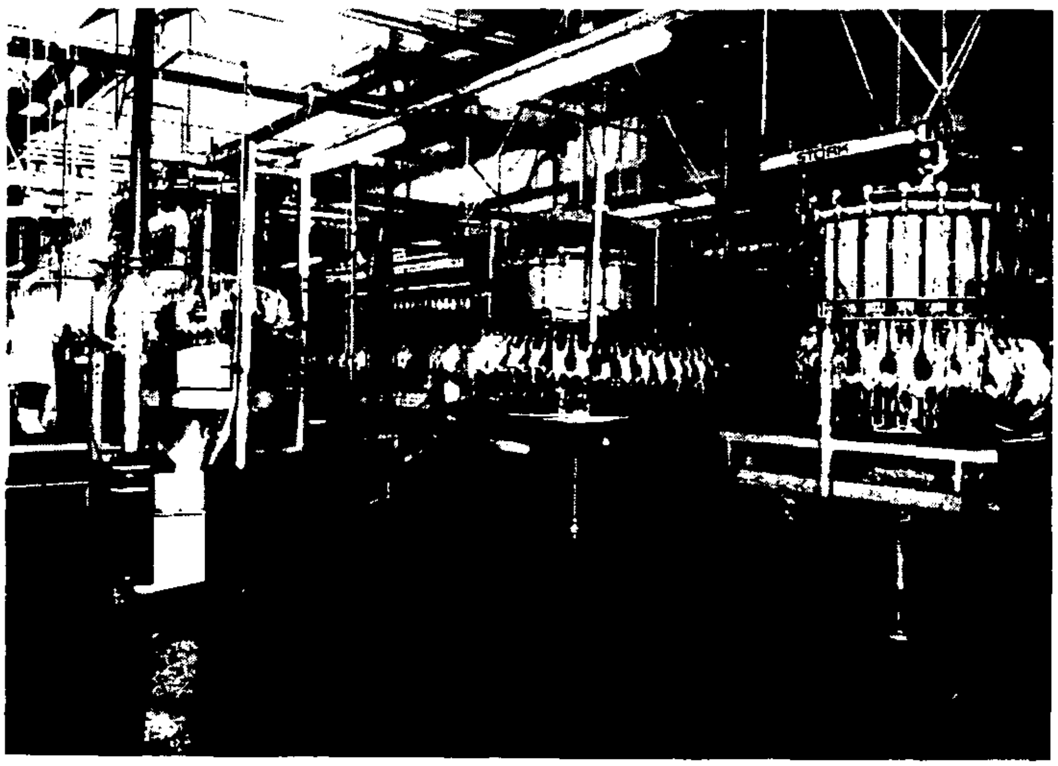

FIG. 8. Automated evisceration line. (Reproduced by kind permission of Stork PMT B.V.)

comprises up to 24 units, each of which has an eviscerating spoon that is inserted into the bird by sliding it down near the inside of the breast bone. When the spoon has reached the lowest point in the body cavity, the tip of the spoon is turned upwards. As it turns, the oesophagus is caught between the teeth of the spoon at a point between the gizzard and the crop, and the ball-shaped ends of the teeth are pressed against the ribs of the bird on both sides of the spine. The spoon is then withdrawn to lift the viscera and lungs out of the bird. The crop should also be withdrawn, since it is attached to the oesophagus, but this is difficult to achieve, unless the crop has already been loosened by the head and trachea puller. A new eviscerating machine, recently introduced by Stork PMT BV, locates the bird with the breast facing the machine. It achieves complete removal of the viscera and crop in one operation.

Another recent development has been the automatic cropping machine which is located after the eviscerator. This removes the crop, trachea and neck glands from the eviscerated bird. The neck has to be left on the carcass until after it has passed through the cropper, but the performance of the neck cracker is improved because the neck skin is no longer attached to the neck. This can increase the yield since virtually no neck skins are removed by the neck cracker. These machines eliminate the need for a head and trachea puller. A head cutter can be used instead, which can also increase yield.

The neck cracker separates the neck from the spinal column by a pressure arm fitted with a knife to slit the neck skin. The neck is then removed by guide bars, which allow the skin to pass through but direct the neck into a flume, to be collected with the edible offals.

A neck-skin trimmer, comprising a horizontally mounted, rotating, circular knife is invariably included in the line to trim the neck skin.

The last machine on the evisceration line is the final inspection machine, which has a suction head that is lowered into the body cavity to remove any residual tissues such as pieces of lung. The vacuum is not applied to empty shackles. In the processing of air-chilled carcasses, the final inspection machine is sometimes located after the final bird washer to dry the cavity.

A revolutionary, new range of evisceration equipment has been introduced by the Danish company, Atlas, and is called the ALEC 4000. This is a batch system which operates with the bird in a horizontal position, and is said to cause less carcass damage, such as skin tears, and to improve yield by >1·5%. The system is capable of handling 4000 broilers/h, with a dressed-weight range of 600–2000 g. Birds released from the killing line are automatically placed on their backs and firmly clamped to the transfer table, in groups of eight. After fixing of the birds, the table moves on, and a new transfer table comes into position for loading.

Following evisceration, the birds must be thoroughly washed both inside and out. In the UK, the washer must be fitted with a recording meter to measure water usage and comply with the Poultry Meat (Hygiene) (Amendment) Regulations, 1979. A range of mechanical inside-outside washers is available and these lower a spray nozzle into the body cavity, piercing the thoracic membranes to allow proper drainage of the cavity before chilling. Washing of the outside of the carcass occurs simultaneously. Mulder & Bolder (1981) investigated the effect of different types of bird washer on the microbiological quality of broiler carcasses in thirteen slaughterhouses, and concluded that the inside-outside washer does not guarantee better removal of organisms.

Processors of fresh poultry have recently begun to introduce carcass washers on the evisceration line in response to the work of Notermans *et al.* (1980), which indicated that, during evisceration, contaminating microorganisms become attached to the skin and cannot be removed by washing alone. However, attachment appears to be a time-dependent process and Notermans and his co-workers showed that washing at different stages during evisceration can be beneficial in reducing the numbers of coliforms and salmonellas on carcasses because there is insufficient time for attachment to occur. A suitable carcass washer comprises a small cabinet containing an appropriate arrangement of spray nozzles.

7. AUTOMATIC WEIGHING AND GRADING SYSTEMS

In recent years, mechanical scales have been replaced by on-line, electronically controlled weighing systems. These not only save labour but have improved the efficiency and flexibility of the packing department (Fig. 9).

After chilling, the birds are hung by one leg on the weighing line, which is an overhead conveyor with specially designed weighing shackles. Each bird is weighed as it passes over a weighing station, and the weight is transmitted to a central computer (Fig. 10), which

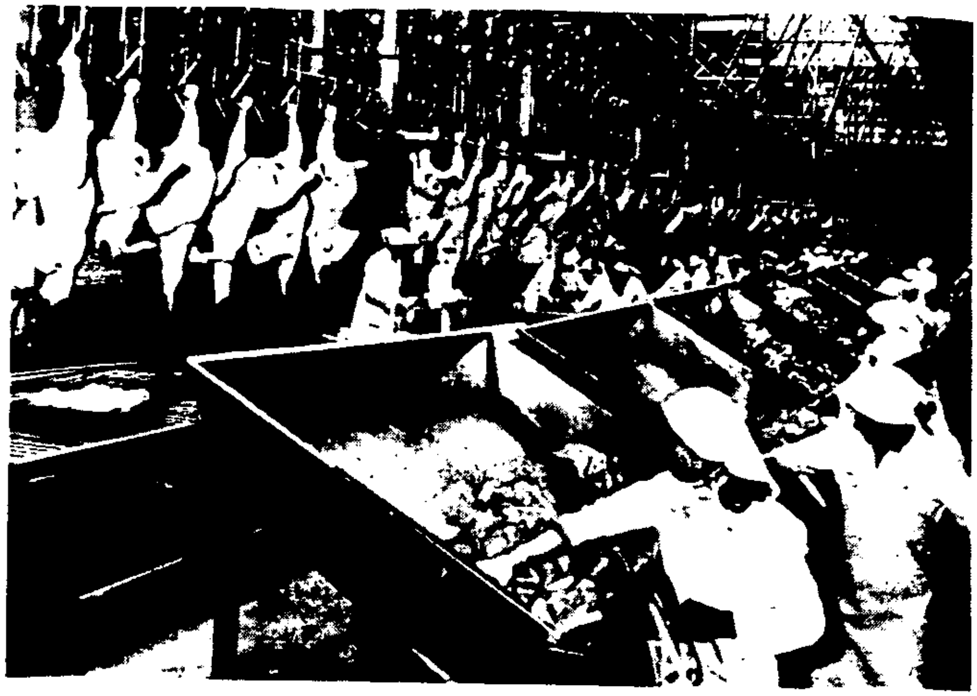

FIG. 9. The Chickway electronically controlled, on-line weighing system. (Reproduced by kind permission of Chickway Systems Ltd.)

FIG. 10. The Chickway central, computerised control system. (Reproduced by kind permission of Chickway Systems Ltd.)

decides where the carcass must be dropped, according to a pre-set programme. A recent innovation by Chickway Systems, Huddersfield, UK, is their 'non-contact' weighing method in which the birds are lifted clear of the conveyor during weighing, so that they are isolated from track-induced vibration, which can cause inaccuracies.

For water-chilled carcasses, an electronically controlled weighing line can be combined with the drip-line. The system can also be incorporated into on-line air chillers. Where carcases are being packed to average weight, these systems are especially valuable, since incorporated into on-line air chillers. Where carcasses are being packed to average weight, these systems are especially valuable, since in a code of practice published by the British Poultry Federation (1985).

The same electronically controlled conveyor system can be used for quality grading, as well as weighing. A trained operative sits at a quality-grading console and inspects the birds as they pass by on the conveyor. By pressing the appropriate buttons, the operative can instruct the computer on those birds that have been downgraded. The computer will assume each bird to be of A-grade quality unless otherwise informed.

8. CARCASS GRADING

The influence of live-bird condition on the quality of the processed carcass has been reviewed by Ziolecki (1985). He identified the various factors responsible for downgrading of broiler carcasses that occur prior to slaughter. Jones (1986) discussed the processing parameters influencing carcass and meat quality, particularly the causes of textural problems.

A push-button system for recording up to fifteen causes of downgrading, such as bruises and breast blisters, to permit rapid analysis of flocks, has recently been developed by Chickway Systems for incorporation into their post-chill weigh/grading line. The fifteen-button panel is located near the hanging-on position. Keys 1–8 are used to identify farm or catching faults and keys 9–15 to identify processing faults. The information is analysed by the central computer and can be used either by the poultry meat inspectorate or as a management tool.

The Economic Commission for Europe (ECE) Working Party on

Standardisation of Perishable Produce (1986) has produced the first internationally agreed set of grading standards for marketing poultry carcasses and portions. The document defines A-grade carcasses as follows:

> Poultry carcasses and poultry cuts in this category shall be of good quality. The flesh shall be plump; the breast well developed, broad, long and fleshy. On chickens, ducklings, turkeys and broiler geese, there shall be a thin, regular layer of fat on the breast, back and thighs. On cocks, hens, ducks and young geese, a thicker layer of fat is permissible. On fattened geese, a moderate to thick fat layer shall be present all over the carcass.
>
> Stubs (quill ends) and hairs (filoplumes) shall not be present on the breast or legs; however, a few may be present on the rump, foot joints and wing tips. In the case of boiling fowl, ducks, turkeys and geese, a few may also be present on other parts.
>
> Some damage, contusion and discoloration is permitted, provided that it is small and unobtrusive, and that the contusion or discoloration is not present on the breast or legs. The wing tip may be missing. A slight redness is permissible in wing tips and follicles.
>
> In the case of chilled poultry in this category, there shall be no traces of freezing and, in the case of frozen or deep-frozen poultry, there shall be no traces of freezer-burn, except those that are accidental, small and unobtrusive.

9. PACKING

After weighing and grading, whole carcasses produced in the UK are trussed prior to packing. This involves folding the wings behind the back and tucking the shanks into the opening of the body cavity. Elasticated bands are often used to secure the limbs. An automatic trussing machine has been developed for broiler carcasses and this folds the legs into a 'sleeve' of skin. One operator can truss 800 birds/h with this machine.

Water-chilled broiler carcasses are trussed with the giblets inserted in the body cavity, and are packed in polythene bags sealed by means of a clip or tape. Semi-automatic bagging machines exist for putting the bird through a conical chute into the bag, which is fed from a magazine and blown open by compressed air. The legs are folded at the same time. The filled bag is sealed by hand. There is also a number of fully automatic machines capable of packing up to 1200 birds/h.

Frozen turkeys are given a more sophisticated presentation, being placed in oxygen-impermeable, shrink-film bags, which are evacuated and passed through a hot-water shrink tunnel prior to freezing. Semi-automatic bagging systems are available for carrying out this operation.

Air-chilled broilers are usually packed, without giblets, on polystyrene trays and wrapped in transparent film. Alternatively, they may be bulk-packed in polythene-lined cardboard boxes, eight to 12 birds to the box, depending on carcass weight.

10. POULTRY PORTIONS

A decline in the sale of whole chicken carcasses in the UK in the 1980s has been counter-balanced by a steady increase in the sale of cut portions. In practice, a variety of cuts are marketed, and the principal ones have been defined by the ECE Working Party on Standardisation of Perishable Produce (1986), as follows:

Half: half of the carcass obtained by a longitudinal cut in a plane through the sternum and the backbone.
Quarter: a half divided by a transversal cut, by which the leg and breast quarters are obtained.
Breast: sternum and the ribs distributed on both sides of it, together with the surrounding musculature.
Leg: femur, tibia and fibula, together with the surrounding musculature. The cut shall be made at or near the joint.
Thigh: femur together with the surrounding musculature. The cut shall be made at or near the joint.
Drumstick: tibia and fibula, together with the surrounding musculature. The cut shall be made at or near the joint.

Halves and quarters are usually cut with a bandsaw or a rotating, circular knife. Individual portions are generally cut on a moving line by hand with a sharp knife.

Cutting up birds manually is very labour intensive, and a number of automatic portioning machines have been developed. The early machines were fed birds by an operative located at the front of the

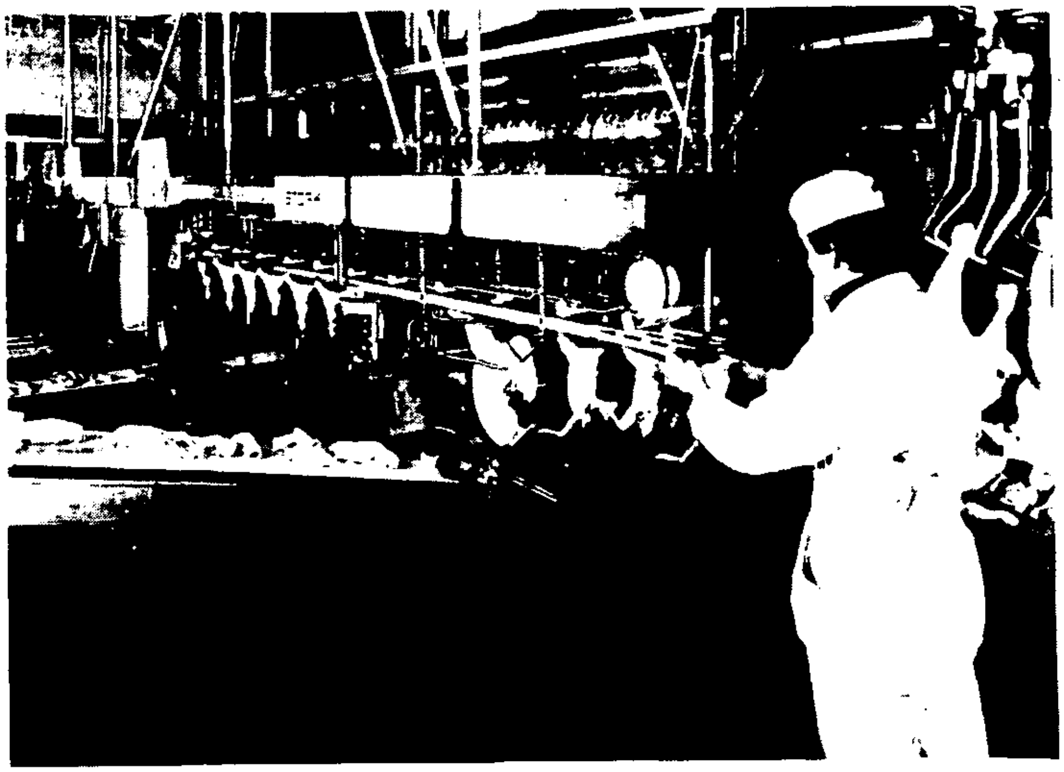

FIG. 11. Modular automatic portioning machine. (Reproduced by kind permission of Stork PMT B.V.)

machine. The cuts were, however, imprecise and led to yield losses and quality problems. In the past 2 years, a new range of highly effective portioning machines has been introduced by several manufacturers. These machines are constructed on a modular principle, and cut up birds automatically, on-line, at rates up to 2000/h (Fig. 11).

The usual sequence in which the modules are operated for the standard portion range is, first, removal of the neck skin, then the wings, followed by the breasts. The backbone is removed next, leaving the thighs, which may be separated from the drumsticks, if required. The only manual labour needed is for feeding carcasses into the machine and packing the portions.

11. CARCASS DEBONING

The spectacular growth in the sale of further-processed poultry products in recent years has placed a heavy demand on the production of deboned poultry meat. Traditionally, poultry meat has been removed from the carcass by hand with a sharp knife, another highly

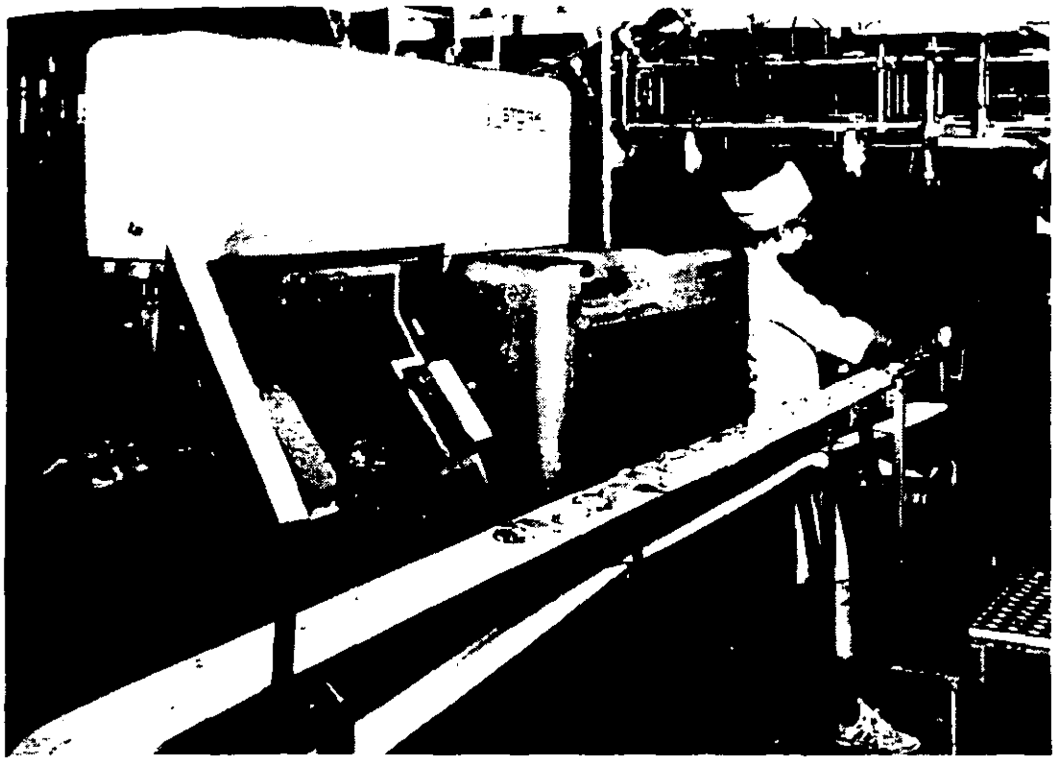

FIG. 12. The Stork-Protecon PAD 1000 thigh deboner. (Reproduced by kind permission of Stork PMT B.V.)

labour-intensive operation. The carcasses for deboning may be suspended from special shackles on a slow-moving line, or placed on a deboning cone which may be static or moving.

Several automatic deboning machines have been developed, and amongst the most successful are the breast-fillet removers. The earlier thigh and drum stick deboners tended to produce a lower yield than a manual system and still required manual trimming of the meat. Later machines have largely overcome these problems. An innovative system, the PAD-1000 thigh deboner, introduced by Stork-Protecon (Fig. 12) compresses the portions while held in a specially designed mould capable of containing two thighs, squeezing the meat away from the bone. A rate of up to 2000 pieces/h is claimed, and the deboned meat retains its structure.

12. MECHANICALLY RECOVERED MEAT

Mechanically recovered poultry meat of good quality has found a ready market in recent years, and is widely used in a variety of white and red meat-products, such as frankfurters, sausages and burgers. The process has been reviewed in detail by Froning (1981). A variety of machines is available for the separation of meat from bones. Many of these machines have been described in detail by Newman (1981, 1983).

Two basic systems are used. The older system operates on an auger principle, pressing the meat and bone against a perforated, cylindrical screen or microgrooved cylinder, through which the meat passes, leaving the bone. Early models generated considerable heat (up to 10°C) during operation and required pre-grinding of the bones. Considerable advances in design, particularly of the separation head exemplified by the Lima, Poss and Stork-Protecon MRS 1500R machines, have resulted in minimal temperature rises during operation, and a texturally more attractive product. Pre-grinding of the bones is not necessary with these machines.

The alternative system is a hydraulic, 'press-type' design, of which the Stork-Protecon machines are the most popular examples. These operate on the principle of compression of the bones, which do not need to be pre-ground, by means of a hydraulically powered ram at pressures between 15 and 45 MPa. The residual meat and soft tissues are squeezed through a series of coaxial, stationary filter rings. Extracted bone is discharged in a compressed form. Absence of rotating parts ensures very low rises in temperature and little machine wear. The system is a batch one, and yields are less than those obtained with the auger machines, which achieve 70–80% yield, depending upon the type of raw material. However, calcium and bone contents are appreciably lower, a major advantage in the light of pending legislative restrictions in some countries. The hydraulic systems give a product of poor textural quality, lacking fibrous structure.

Mechanically recovered meat can be held chilled at 2°C for use within 48 h, or frozen in shallow layers in a plate freezer.

13. CONTROL OF PROCESS YIELD

The reductions in processing costs resulting from the many technological improvements in slaughtering that have taken place over the past 25 years, have been accompanied by an awakening interest in process yield. The yield of an operation is calculated by weighing the bird live (prior to slaughter) and again before and after the operation (Veerkamp, 1981):

$$\text{Yield} = \left(1 - \frac{\text{input weight} - \text{output weight}}{\text{live weight}}\right) \times 100$$

Veerkamp (1983) proposed the measurement of yields against a standard and suggested that the various yields should be based on the live-weight of the birds. He made the following recommendations: (a) the live weight (just prior to slaughter, after a fasting period of at least 4 h) must be established as the basis for calculation of yields; (b) standard procedures for the processing, cutting and deboning operations must be adhered to; (c) detailed descriptions of the ways of separating the various physical components of the bird must be made.

Standard yields can be calculated by analysis of data from multiple samples (Tables 3 and 4). Most yield standards increase with increasing weight and decrease with increasing age. The contribution of weight to the yield is generally greater than the contribution of age. The ratio between the actual yield and the standard yield is the efficiency factor of the operation. A computerised system of process control, based on measuring product weights for calculating yields and efficiencies has

TABLE 3

YIELD STANDARDS FOR 48 SAMPLES (15 MALES AND 15 FEMALES EACH) OF COMMERCIAL BROILER FLOCKS (Veerkamp, 1983)

Processing yield standards	*Average (%)*	*Coefficient of variation (%)*
1. Bleeding/plucking	91·8	0·47
2. Head cutting	96·9	0·18
3. Feet and shanks cutting	94·8	0·23
4. Total of slaughterline	83·6	0·66
5. Evisceration[a]	84·6	1·10
6. Carcass[b]	68·1	1·72
7. Carcass including giblets	74·8	1·34
8. Giblets[c]	6·7	7·35

[a] During evisceration the following are removed: oesophagus, trachea, neck, gizzard, heart, liver, lungs, and intestines.
[b] The carcass includes: abdominal fat, kidneys, oil gland, neck skin and wing tips.
[c] Giblets include: neck (up to the 9th vertebra), gizzard without fat and lining, liver and heart.

TABLE 4

YIELD STANDARDS FOR 48 SAMPLES (15 MALES AND 15 FEMALES EACH) OF COMMERCIAL BROILER FLOCKS (Veerkamp, 1983)

Yield standards of parts	*Average (%)*	*Coefficient of Variation (%)*
1. Wings	8·61	3·14
2. Breast meat	12·80	4·69
3. Legs[a]	24·30	2·06
4. Heart	0·65	7·69
5. Liver	1·88	14·36
6. Gizzard	1·72	26·16
7. Neck	2·43	7·82
8. Skin and fat[b]	7·70	7·40
9. Back[c]	12·90	2·02

[a] The legs include pelvic meat and *M. gluteus*, with the skin covering these parts.
[b] The skin and fat contains the abdominal fat and the skin with underlying fat layers. The skin of the legs and wings is not included.
[c] The back includes the tail but not the skin, fat, breast-bone (sternum), wings, legs or breast meat which have been removed.

been developed at the Spelderholt Institute for Poultry Research in The Netherlands (Veerkamp, 1983).

14. CONSERVATION OF ENERGY

Escalating fuel costs in recent years have focused attention on the need to conserve energy in industry, and energy audits are becoming a commonplace feature of financial planning. Within the poultry industry the theoretical considerations of energy conservation have been thoroughly examined by Erdtsieck (1980, 1981).

The scald tank is one piece of equipment where substantial energy savings have been achieved by improved design and temperature control. Energy is required to heat the water initially, maintain the temperature, and heat the water required to replace that taken out by the birds or, in the USA, to comply with the statutory overflow requirement. Heat is also lost by convection, radiation and evaporation. Radiation losses are negligible, and insulation of the scald tank walls is not cost-effective. However, the provision of a hood and side panels to reduce evaporation losses, which can be substantial, is highly effective. Some of the energy in the overflow water can be reclaimed by using plate heat-exchangers.

Marion (1981) presented a review of practical approaches to energy conservation, based on research and development in the USA. He explored the concept of energy management, as opposed to energy conservation, as a more positive approach to the energy crisis.

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3.2. Soil Pollution

Standards are usually set for the discharge of effluents onto the land. These are needed to ensure that applications are controlled in volume and pollutant loading-rate, to a level that will allow the soil microorganisms to degrade the effluent. This avoids pollution of water by surface run-off, discharge into land drainage systems or, by deep percolation, into aquifers and underground water systems.

The usual parameters that are controlled are the BOD_5, SS, TS, NH_4–N, NO_3–N, and levels of the following: phosphate, P_2O_5, potassium salts, K_2O and, where applicable, toxic metals, phenols and any other substance that may cause damage to the environment.

3.3. Air Pollution

Poultry processing plants are unlikely to pollute the air other than giving rise to unpleasant odours. The measurement of odours is at present entirely subjective, and controls are therefore of an arbitrary nature and related to the effect the odour has on the public, i.e. the degree of 'nuisance'. A review of the sources of odours from processing plants and their control has been made by Sullivan (1978), while Griffiths (1981) has identified thirty odorous compounds that together constitute a typical processing odour.

4. PROCESSING AS A SOURCE OF POLLUTANTS

4.1. Bird Reception

The types of waste and by-products at different stages of processing are shown in Table 1. A processing line starts with the reception of the birds which are unloaded and placed on an overhead conveyor line to be slaughtered. There is a relatively fixed rate of processing so that, after arrival, the birds may be held for varying periods at the unloading bay. If the period of starvation has been inadequate, the longer they remain there, the greater the amount of droppings and feathers. The load on the waste-treatment system will mainly depend upon bird throughput and the degree of dry cleaning (brushing and removal of droppings, without water) that takes place. Dry cleaning is labour intensive and therefore expensive. The amount of water used to clean the crates, the lorries and the unloading area adds significantly to the ultimate volume of effluent to be treated. Waste water from the washing of poultry crates at a medium-sized plant can be 12·7 m^3/day,

TABLE 1

TYPES OF WASTE AND BY-PRODUCTS AT DIFFERENT STAGES OF PROCESSING

Processing stage	*Type of waste, by-products*
Reception	Manure, feathers, cleaning water
Slaughter	Blood (by-product), blood/grease, cleaning water
Scalding-defeathering processes	Feathers (by-product), blood/grease, cleaning water
Evisceration	Viscera (by-product), blood, grease, small pieces of flesh, cleaning water
Chilling	Wet chilling—grease, blood, flesh debris and water
	Dry chilling—cleaning water from chilling area
Grading and packing	Cleaning water
Total plant	Cleaning water

with a BOD_5 of 11·3 kg/day and a concentration of 900 mg/litre BOD_5 according to Dart (1974), who quotes reductions in the BOD_5 load of 25% when dry cleaning is practised. However, at plants processing more than 5000 birds/h, it may not be practicable to dry-clean. In this case, the crates and vehicles are usually washed automatically at specially prepared bays.

4.2. Slaughtering

The method of electrical stunning appears to determine the required bleed-out time (see also the chapters by Gregory and Jones & Grey). Kuenzel *et al.* (1978) describe the effects of currents with different frequencies and voltages on bleed-out time. It was found that with DC circuits and increasing the bleed-out time from 60 s to 90 s, twice as much blood could be collected. Generally, however, an AC stunner (60 Hz, 50 V) was the most economical to operate. In the UK, there are regulations (Anon., 1984) requiring broilers to be bled for at least 90 s and turkeys for 120 s.

At the slaughter stage, blood is collected and removed for processing because it is an important by-product and has significant value as a feed component or fertiliser. The amount of blood collected has been given as 40–55 g/1·4 kg bird (Kahle & Gray, 1956), whereas Wadhams (1961) estimated 28 g/bird and Kuenzel *et al.* (1978) quoted mean values of 58·8 ml for 1·6 kg body-weight birds to 70·7 ml for 2·0 kg birds. Porges (1950) estimated the amount of blood to be 8% of body-weight, of which not more than 70% will drain out. Hrudey (1984) states that blood is 6–8% of body-weight.

Blood has the highest BOD_5 value of any type of poultry waste and Struzeski (1962) found that it contained 92 000 mg/litre BOD_5, which produced 7·0 kg BOD_5/1000 birds processed. Riley & Nielsen (1974) quote a range of values, from 80 000 to 120 000 mg/litre BOD_5. Because blood is such a highly polluting substance, effective removal and recovery will greatly reduce the total waste-load from the processing plant, and help to optimise the financial return. Dart (1974) found that a processing unit operating an efficient blood recovery system will probably have a 40% lower polluting load than one which allows blood to flow to waste. Not all of the blood can be collected separately from other waste. Limitations include the length of the blood collection line and the speed of the conveyor, which rarely allow complete drainage to take place. Inevitably, some further blood loss occurs in the scalding tank, and there is often a contribution to the pollution load from the cleaning of the collection channel and surrounding area. In more recent systems, the cleaning waters of the blood-collection channel are recovered with the blood, thus reducing the pollution load significantly.

4.3. Scalding and Defeathering

In scalding birds to loosen the feathers, temperatures are maintained and wastes partially removed from the tank by a constant flow of hot water. The volume of top-up water varies, and ranges from 1 litre/bird (Riley & Nielsen, 1974; Woodward *et al.*, 1977) to 5 litres/bird (Hamza *et al.*, 1978) and 8 litres (Hrudey, 1984). High flow-rates, above those necessary to maintain temperature and remove some of the suspended solids, blood and grit, are wasteful in terms of energy utilisation. However, recycling of heat can be achieved, and methods are described by Coombes & Boykin (1981).

The pollution content of the scald-water overflow ranges from 978 mg/litre BOD_5 (Hamza *et al.*, 1978) to 1560 mg/litre (Dart, 1974). Hamza *et al.* (1978) also measured COD and obtained a mean of 1330 mg/litre and a TS of 1556 mg/litre. The degree of pollution depends upon the cleanliness of the birds, the adequacy of prior blood collection and the amount of top-up water used.

The scalded birds pass directly into the plucking machines (a wet process), where the feathers are removed by rapidly rotating rubber fingers. Usually, the feathers are transferred from this area by a water flume, and are collected on rotary or inclined screens. The feathers will contain dirt and grit, as well as some of the blood from the flume water. Feathers are estimated to be 3–5% of the live-weight of the birds and range from 40 to 70 g/broiler (Riley & Nielsen, 1974). When recovered from the screens, feathers contain between 75 and 80% water. Feathers are a valuable by-product, and are usually cooked, diced and ground to form a high-protein meal for use in feeds.

The plucking flume is usually made up of the scald-water overflow and recycled, screened effluent from the system as a whole. Hamza *et al.* (1978) indicate that, when clean water is used instead of the recycled effluent, the additional volume is about 4 litres/bird. These authors state that the BOD_5 content of separate feather flumes is at least 937 mg/litre, whilst a level of 1825 mg/litre is indicated by Dart (1974).

Filoplumes (thin, hair-like structures) and some of the pin feathers remaining after plucking are sometimes removed by singeing. However, some hand finishing is usually needed, especially in the case of turkeys, ducks and geese.

4.4. Evisceration and Spray-washing

Large processing plants use automatic evisceration for broilers and, at this point, any signs of abnormality result in rejection of the carcass by a qualified poultry meat inspector. The edible offal, comprising heart, gizzard and liver, is removed from each bird, either in the dry state by vacuum conveyor or by a flow-away system, and processed separately. In smaller plants, the viscera are removed entirely by hand, the gut being taken by a flow-away system or dropped into the barrels. At this stage, the head and neck are also removed automatically. Usually, the neck is packaged with the edible offal, for sale with the bird, or kept separate for use in animal feed.

The head, feet and guts of chickens and turkeys are collected separately as inedible offal. In the larger plants, inedible offal is collected either in the dry state by vacuum conveyor or pipelines, or by a flow-away system. Flow-away systems separate out the solids by means of rotary screens. In smaller plants, offal is collected dry, in bins, thus reducing the water requirement.

After evisceration, the carcasses are washed to remove blood and particles of tissue before passing on to the next stage of processing. Water usage during evisceration is given as 2 litres/bird by Hamza *et al.* (1978).

Evisceration increases considerably the pollution loading of the plant, and is reported to contribute about one third of the entire load. After screening to remove the larger pieces of flesh and fat, the waste water will still contain small amounts of tissue, grease, grit, sand and blood residues.

The pollution load from the waste offal flume ranges from 1678 mg/litre BOD_5 (Hamza *et al.*, 1978) to 2640 mg/litre (Dart, 1974). The load from the edible offal flume ranges from 78 mg/litre (Dart, 1974) to 1156 mg/litre (Hamza *et al.*, 1978). The waste loading for every 1000 birds processed is reported by Hrudey (1984) to range from 3·0 to 22·9 kg BOD_5, with a mean of 6·0 kg BOD_5. Dry handling of offal by vacuum transportation will eliminate this pollution load and is now used in many of the larger plants.

4.5. Chilling

This is a most important stage in the process in that the carcass temperature is reduced by immersing the birds in static slush-ice, by a blast of super-cooled air or by passing them through continuous immersion chillers. Chilling serves two purposes: to retard the growth of bacteria likely to cause spoilage of the product and to prevent the growth of pathogenic bacteria such as salmonellas. In the case of continuous immersion chillers the water usage is an important factor in preventing a microbial build-up. Water chilling is normally a two-stage process to increase the efficiency of heat transfer and reduce the opportunities for cross-contamination. The amount of chill-water required in the European Economic Community ranges from 2·5 to 6·0 litres per bird. This method of chilling is the most widely used in the USA but air chilling has gained popularity in other countries. Currently, more than 50% of birds are dry chilled in the UK (Anon., 1987).

During wet chilling, organic matter, body fluids, fats and grease will continue to be washed off into the chill-water. The pollution load is relatively small, however, and the water overflow is often re-used in the initial stages of processing and, in the USA, recycled from the second to the first chiller unit.

The chilling process may add up to 8% of the total BOD_5 load, and can contribute significantly to the grease load.

Hamza *et al.* (1978) quote mean values for both stages of chilling as follows: first stage, 956 mg/litre BOD_5, 1193 mg/litre COD, 270 mg/litre grease; second stage, 758 mg/litre BOD_5, 884 mg/litre

COD and 239 mg/litre grease. Hrudey (1984) gives a range of BOD_5 values, from 0·7 to 4·3 kg/1000 birds.

4.6. Processing Losses

Processing losses are caused by bleeding, plucking and removal of the viscera. Losses will vary according to the type of process used, and hence will differ from plant to plant. The loss also depends upon the type of stock and its initial weight. In broilers, the loss has been estimated at 20–22% (Porges, 1950), 30% of live-weight (Kahle & Gray, 1956) and 22% (Erdtsieck & Gerrits, 1973). To some extent, this loss can be compensated by the uptake of water by carcasses during immersion chilling. In contrast, air chilling of carcasses results in evaporative losses; however, the process represents a considerable saving in water usage and thus reduces the pollution load. The processing of blood and feathers, and the use of offal to produce protein-rich meals for animal feeds, also help to offset the loss of weight and costs of production.

4.7. Further Processing

Cooking and other further-processing procedures will add to the pollution load because of the additional preparation of the meat and cleaning of utensils and equipment. For example the take-away, fried-chicken trade, requires the birds to be cut into a number of portions. This process produces considerable quantities of very small pieces of tissue, releases fat and involves regular cleaning of the equipment.

4.8. Washing and Cleaning of Plant Equipment and Premises

The waste load from the plant clean-up will vary widely, depending upon blood recovery, the degree of dry cleaning possible and the amount of cleaning water used. It is important that the power hoses used are of correct specification; this should include the diameter of the hosepipe, the diameter of the jet and the water pressure. Hoses should be used to flush surfaces and remove debris; high pressures and small jet-orifices cause splashing and can extend the cleaning time. It is also important to use detergents and sterilising agents that are biodegradable and will not interfere with treatment of the waste-waters. Hypochlorites and some quaternary ammonium detergent sterilisers react with organic matter to form inactive substances. Dart

(1974) gives a BOD_5 for washing-down water of 2440 mg/litre and a flow of 4·5 m^3/day.

Wash-down and clean-up take place after the day shift, and usually continue for most of the night. This helps to balance the flow of effluent and hence treatment-plant loading.

4.9. Total Processing Waste-water Load

The amount of water used per bird varies from plant to plant, depending upon the following factors:

1. The degree of dry handling of viscera. This is mainly related to the scale of the processing system.
2. The extent to which dry cleaning is practised, especially the brushing and collection of solid wastes at the bird reception area and during clean-up of the plant.
3. The management and control of water throughout the plant. This involves correct pressures and pipe diameters, ease of stopping the supply and the re-use of water e.g., using chilling water to augment the amount of scald water.
4. Whether or not water is needed to cool the carcasses. Table 2 shows a range of water usage according to various authors, often with no indication of the extent of water recycling within the plant.

   In small processing plants, where flow-away systems are not used, and in those that use dry, vacuum removal of offal, less water is required and a usage of 9–21 litres/bird can be achieved.
5. Whether or not carcasses are further processed.

TABLE 2
WATER USAGE IN PROCESSING

Water/bird (litre)	*Reference*
26–44	Erdtsieck & Gerrits (1973)
10–45	Hopwood (1977)
10–55	Brolls & Broughton (1981)
31·5 (some re-usage)	Hamza *et al.* (1978)
26·5 (some re-usage)	Wesley (1985)
34·4	Hrudey (1984)

4.10. Characteristics of the Pollution Load

Complete information on the characteristics of poultry processing waste-water is not readily available. This is because processing plants generally differ from one another with regard to the types of poultry and products being processed and the nature of the processing operation. In addition, there are other factors, such as the amount of waste-water recycled, the effectiveness of collecting and separating highly polluting wastes, and the degree of dry handling of solid and semi-solid waste materials. Decisions on the procedures to employ in dealing with waste materials will depend on the type of bird being processed, relevant hygiene regulations and economic considerations such as disposal charges.

For a particular installation, the pollution loading-rates, described above for the separate parts of the processing operation, can be used as a general guide. Tables 3 and 4 indicate the type of total load that is likely to occur. The literature on this subject gives different units of measurement, including the pollution load per 1000 birds processed and the load per 1000 kg of poultry (live weight). Neither of these measurements is very helpful, because the birds being processed vary in size and the live weight is difficult to relate to the number of birds processed in a day. A more rational approach would be to measure the pollution load as kg of pollutant/m^3 of waste water, and to relate this to daily volumes and bird throughput.

It is interesting to note that much of the literature quotes only BOD_5, there are few references to SS, and even fewer to grease/fat content, COD, TS or VS. The most useful and comprehensive characterisation of poultry processing waste-water is that given by Hamza *et al.* (1978).

TABLE 3

CHARACTERISTICS OF PROCESSING WASTE-WATER (WEIGHT/BIRD)

Pollutant (g/bird)			*Reference*
BOD_5	*SS*	*Grease*	
10·2	—	—	Erdtsieck & Gerrits (1973)
29·0	15·0	12·0	Woodward *et al.* (1977)
13·0–23·0	—	—	Hopwood (1977)

For abbreviations, see pp. 362–5.
—, data not given.

TABLE 4
CHARACTERISTICS OF PROCESSING WASTE-WATER (AMOUNT/UNIT VOLUME)

Pollutant (mg/l)					Reference
BOD_5	SS	COD	TS	Grease	
150–2 400	100–1 500	200–3 200	—	—	Struzeski (1962)
225–2 725	125–1 215	—	597–1 836	—	Singh *et al.* (1973)
450–950	—	—	—	—	Whitehead (1979)
1 265	—	—	—	572	van Staa (1981)
2 110	1 295	—	—	—	Litchfield (1984)

Key: as for Table 3.

5. TREATMENT OF POULTRY PROCESSING EFFLUENTS

The objective in treating poultry processing effluents is to enable the end-products to be introduced into the environment, without giving rise to pollution, and at a cost that is commensurate with the profitable operation of the processing plant. Various options are available, not all of which will be practicable or even possible at any one site, but consideration should be given to each, including the cost of operation.

The methods of disposal are (i) disposal to a public sewer; (ii) treatment on-site and disposal to a water course or to land. The choice of disposal systems is indicated in Fig. 1. Whichever system of disposal is finally selected as the most suitable and cost-effective for the site in question, permission to discharge is still needed. In the UK, the water authorities are responsible for issuing a discharge consent, and they will impose a wide range of standards. These are likely to include controls on the polluting concentration of the effluent, BOD_5, COD, TS, SS, ammonia, ammonium salts, nitrates, chlorides, possibly various elements and chemical sterilants, as well as colour, turbidity, temperature, total volume and hourly flow-rates.

Most processing plants operate on a 7·5- or 8-h day, 5 days a week. This causes two major fluctuations in the volume of effluent, producing a daily peak and a weekly cycle, with virtually no discharge at weekends. Both treatment systems and disposal to sewers require an even flow throughout the day, because biological treatment is at a relatively constant rate. To obtain the most economic treatment and full use of equipment, the plant must be operated at optimum capacity

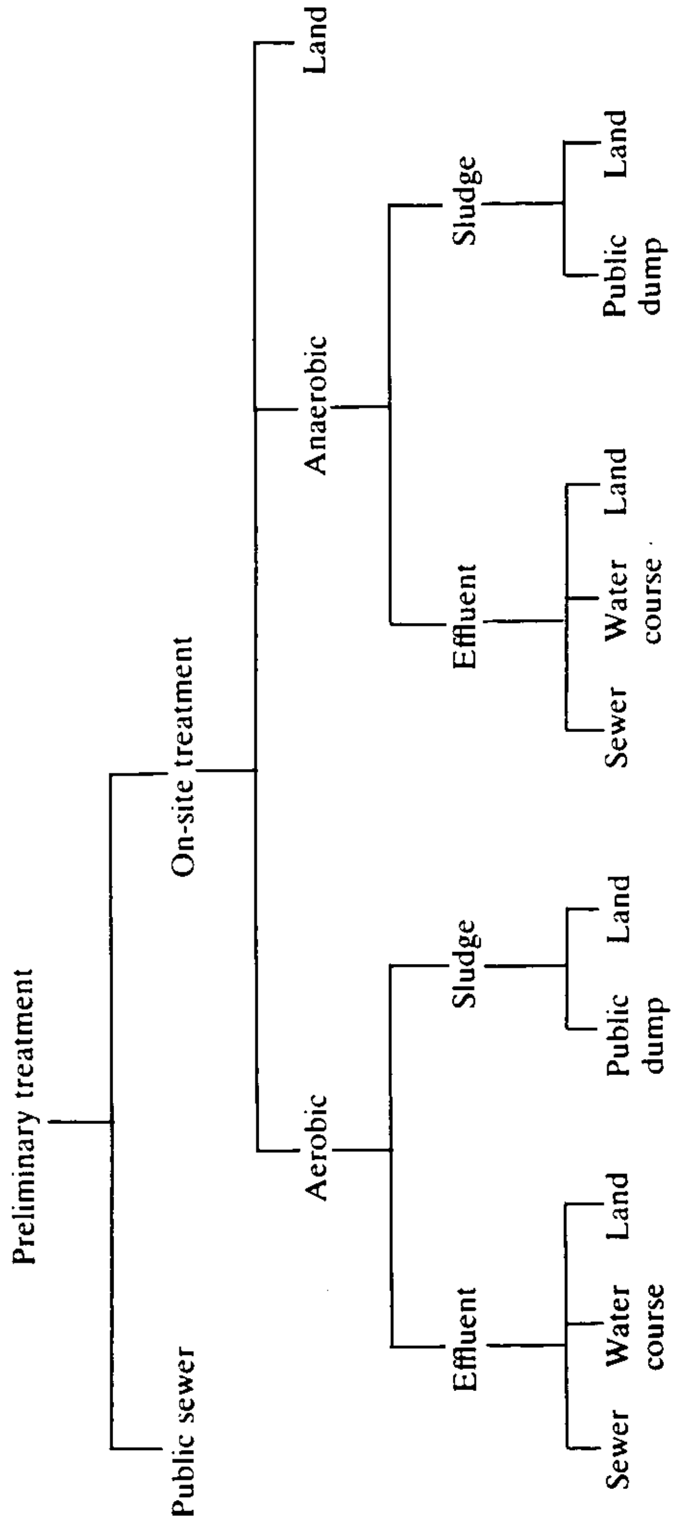

FIG. 1. Options for the disposal of processing waste effluents.

period. This, like heavy rainfall, will require a storage period until the land thaws. Long periods of freezing increase costs of storage and may make land application less cost-effective than full biological treatment.

Wind direction and speed. Reference has already been made to odour and spray-drift from a land treatment site.

Waste-specific Factors

These factors include the amount of material to be applied both daily and yearly, the loading rate of the most important constituents, again as a daily and yearly rate in kg/ha. The characteristics of the effluent to be applied can be controlled by the amount of pre-treatment given. There is an economic balance between necessary pre-treatment and the area of land required. For example, effluent which has only received treatment for coarse separation of solids will still contain high concentrations of BOD_5, SS and fats, oils and grease. The last are slow to degrade in soils, and can only be applied at low rates that require a relatively large area of land. When pre-treatment includes dissolved-air flotation of fats and finely suspended matter, the resulting effluent will be much less polluting and require a smaller area of land.

In conclusion, land spreading of effluents can have a financial advantage over full biological treatment, but the site, soil, climate and amount of pre-treatment required need to be properly investigated and evaluated before adoption.

5.4. Preliminary Treatment

There are three essential stages in the preliminary treatment of poultry processing effluents, as indicated in Table 5. The first stage of any effluent disposal system is the removal of coarse solids. These, if left, will block pump inlets and pipelines. The solids also tend to break up during passage through the treatment system, thus increasing the dissolved BOD_5 load and amount of suspended solids. Coarse solids are removed by screening. The size of the screen varies, depending upon the size of the solids to be removed. The aim is to remove all solids above 1 mm in size (Brolls & Broughton, 1981). Dart (1974) suggests screen-sizes ranging from 3 to 6 mm, while Hopwood (1977) found that screens below 1 mm in size can be used, but they block easily and must be self-cleaning. Fat and gelatinous mucous substances were the main cause of blockage. It was also found that efficient screening could remove up to 50% of the BOD_5 and suspended-solids content.

TABLE 5

STAGES IN PRELIMINARY TREATMENT OF PROCESSING WASTES AND TREATMENT OPTIONS

Stage	*Options for treatment*
Coarse separation	Stationary or inclined screens Rotary cylindrical screens Brushed screens Vibrating screens
Removal of fats, grease and fine solids	Fat traps Dissolved air flotation Dissolved air flotation with chemical flocculation Chemical flocculation
Balancing tanks	

There are several screen designs which can be used to remove coarse solids; these can be grouped as follows: (i) stationary or inclined screens; (ii) rotary, cylindrical screens; (iii) brushed screens; (iv) vibrating screens.

Stationary Screens

The most commonly used system in treating poultry-processing effluent is the inclined screen. The effluent enters a collecting box at the top of the screen by gravity. The collecting box or channel runs the entire length of the top of the screen, and effluent flows over a weir, evenly throughout its length, onto the surface of the screen.

The screen is composed of stainless steel V-shaped wires, running in parallel rows across its surface. For this reason, it is often called a wedge-wire screen. The space between the V-shaped wires ranges from 0·25 mm to 1·5 mm. The slope of the face of the screen varies, being very steep at the top for about 600 mm, then levelling out with a near-horizontal stretch at the base. The mode of operation is that effluent overflows along the entire face of the screen, falling rapidly down the first slope. During this process, free water passes through the screen. The second face allows solids to slide more gently, thus causing a skin of solids to form, the weight of which leads to a pressing action that removes further liquid. The final phase accentuates the build-up of solids and helps to press out even more liquid. Solids then slide off by gravity into collecting vehicles situated below. The liquid is collected in a trough behind the screen, and flows by gravity to the next stage. These screens do not work well where there are high concentrations of fat and grease. It is possible to degrease the screen by steam jets, but this is a labour-intensive operation, and difficult to carry out.

Rotary Cylindrical Screens
Rotary cylindrical screens consist of a cylinder that is covered by a screen-mesh of stainless steel. The openings are 0·4 mm in diameter and there are 16 holes/cm. The screens can be fed either internally or externally. Internally fed screens are less useful, because it is difficult to de-water the collected solids. Externally fed screens operate by allowing the separated effluent to flow through the screen for collection, whilst the solids adhere to the outside, and are scraped off by a fixed blade. 'Blinding' of the screen can be prevented by recycling the separated effluent onto the screen, after the solids have been removed. Externally operated screens are useful in that the pressure of solids against the blade aids de-watering, producing solids of 12% dry matter.

Brushed Screens
These are used frequently in sewage works to remove coarse solids. They consist of a half circular drum, lined with a perforated, stainless-steel screen. The hole size and number per unit of surface area depend upon the material to be screened. A rotating pair of brushes on arms sweep the screen surface constantly, lifting the solids up over the end of the screen, to fall by gravity into a collecting vehicle. The effluent flows through the screen into a receiving channel, to be piped away to the next stage of treatment (Patel, 1976). Where solids with a higher proportion of dry matter are required, the screen can be doubled, the solids being scraped into a second screen, which is brushed and pressed alternately by sets of rotary brushes and roller presses (see Pain *et al.*, 1978).

Vibrating Screens
These are very successful in removing coarse solids and, due to the action of the screen, 'blinding' is most uncommon. There are various configurations and methods of providing the vibration. Perforations of 0·8–13 mm diameter are used (Hrudey, 1984), and the screens are

usually made of stainless steel. The systems operate by allowing the effluent to drop onto one side of a square or rectangular screen, or into the centre of a circular screen. The screen's shape and the vibrating action cause the effluent to pass through, while the solids are propelled towards the end or a side outlet, to fall by gravity into a container. The gauge of the perforations is very important, and the most effective size may need to be found by trial and error. These screens are more sensitive to variations in effluent flow-rate and solids content. High levels of total solids, in excess of 2·5–3·0% are likely to cause 'blinding'.

5.5. Fine Solids, Fats and Grease

After the removal of coarse solids, the effluent stream still contains finely suspended solids, fats and grease. These have high BOD_5 values and form a floating scum, which adheres to the sides of tanks and pipes. The scum causes blockages in pipelines, reduces the efficiency of aeration and blocks the small-bore irrigation outlets on filter beds. Details of the effects on sewage systems are given by Banerji *et al.* (1974). Thus, it is essential for the efficient running of treatment plants that this material is removed at the beginning of the process.

Fine solids, fats and grease have a financial value in that the scum can be skimmed off and utilised as an animal feed, or processed as a raw material for soap and cosmetics manufacture.

There are a number of methods of removing this material, the choice depending on whether sufficient material can be collected to make it financially worthwhile to install one of the more complex systems. Various factors can affect the amount of fatty material collected and its usefulness. Grant (1981) classifies the material as total fatty matter, made up of separable and non-separable fractions. The distinction between the two fractions is related to the method of handling the effluent. High-powered, pressurised pumps will cause much of the fatty matter to become emulsified, so that it will not settle out by gravity. The addition of detergents and emulsifiers will have a similar effect. It is normally helpful to divert plant cleaning-water containing detergents and emulsifiers away from gravity settlement tanks (fat traps).

The method of removing fatty matter depends upon the amount produced and its quality. For small quantities of low-grade material, a simple fat trap is all that is necessary. For large volumes of effluent and a high-grade fatty waste, a more efficient method is worthwhile.

The available methods are: (i) fat traps; (ii) dissolved air flotation; (iii) chemical treatment.

Fat Traps

These work on the principle of gravity separation, by the provision of a minimum-turbulence, flow-through tank. In this, settlable solids can remain long enough to settle out on the bottom of the tank, while grease and fine solids rise to the surface. Continuous sludge removal and skimming of the surface to remove scum are essential. The design criteria are described in detail by Patel (1976). The essential factors are the overflow rate to remove the scum and the retention time, functions of the capacity of the fat trap and the flow-rate of effluent through the tank. Retention times vary from 20 to 40 min, and a recovery efficiency of 60–70% can be achieved (Patel, 1976).

Fat traps are generally rectangular in shape, with a preferred length-to-width ratio of more than three to one, a recommended maximum width of 3·3 m and maximum depth of 2 m (Hrudey, 1984). Recommended surface loading-rates range from 30 to 60 m^3/m^2/day. This should remove 30–50% of suspended solids and 30–60% of the fat/grease. Grant (1981) indicates that the amount of fatty matter removed is related to the influent concentration; for example, an inlet value of 2274 mg/litre was reduced by 62%, while a value of 1721 mg/litre was reduced by 84%.

The system is relatively cheap to build, and the scum removal can be either by means of surface flow or a simple surface skimmer/scraper device. De-sludging is essential to prevent the development of anaerobic conditions. With large daily flows, the tanks may need to be of considerable size. Separation is then relatively inefficient and requires management to maintain good performance.

Dissolved Air Flotation

This is a successful method of removing suspended solids, fats and grease, and is particularly useful when disposal is to a sewer. Brolls & Broughton (1981) list the advantages for its use as: (i) capital costs are low; (ii) the system is compact, requiring little space; (iii) it can accept variable loading rates; (iv) aeration by the compressed air prevents odours; (v) maintenance requires little operator time.

When the system is combined with chemical flocculation, which will be described later, the cost of the necessary chemicals raises the cost of operation, but increases the efficiency of separation.

The method of operation is a physical separation of suspended matter, fats and grease by the production of micro-bubbles of air that attach themselves to the suspended material, lifting it to the surface to form a scum, which is removed.

There are three methods of using dissolved air flotation (Patel, 1976). These involve recycled flow pressure, full flow pressure or partial flow pressure. In the food processing industry, the most successful method has been recycled flow pressure. This involves recycling part of the contents of the flotation tank to provide the liquor for the dissolved air. The method causes least damage to the flocs, and avoids the break-up and emulsification of fats and greases, which would reduce the efficiency of the system. Full flow pressure and partial flow pressure systems are designed to force the influent into the system under pressure, and are unsuitable for poultry processing effluents.

The principle of dissolved air flotation, described by Patel (1976), depends upon the capacity of a liquid, when pressurised to 3–4·5 bar, to retain a greatly increased quantity of dissolved air. When air and pressurised liquid are mixed in a retention tank at 5–6 bar for a period of 1–3 min, the process is completed. Eckenfelder (1966) states that *ca* 35–40% of the air will be dissolved in the recycled liquor. The pressurised liquor is then forced out through a non-return valve into the flotation tank, which is at atmospheric pressure. This causes the release of millions of micro-bubbles, which range in size from 70 to 90 μm (Nutt, 1978), and results in a milky-white appearance.

The complete system involves a flotation tank, the size of which is determined by the daily flow-rate. Hrudey (1984), gives loading rates ranging from 30 to 60 m^3/m^2/day. Brolls & Broughton (1981) state that the tank should not be more than 2·5 m deep and have a retention time of 20–45 min. With the recycled flow system, liquor is pumped under pressure from the flotation tank, and Patel (1976) recommends that between 25 and 60% is recycled. The actual amount depends upon the suspended-solids content of the influent, and is usually determined by trial and error.

Air is fed into the suction side of the liquor recycling pump under pressure, or directly into the pressurised retention tank. This tank is designed to hold enough liquor to provide a retention time of between 1 and 3 min, before the liquor is released back into the flotation tank. The supernatant liquor from the flotation tank is taken off just below the surface to be discharged, whether directly into a sewer or for further treatment. The floating scum is removed continuously by gravity overflow over a weir, or by mechanical scrapers or a screw device. The scum is rich in fats and proteins and has commercial value for use in animal feeds or for fat extraction.

Dissolved air flotation is more efficient than separation by fat traps, and requires less space. Grant (1981) found that the method could remove 79–94% of the total fatty matter present. He also showed that the initial loading rate affected performance; for example, a loading rate of 2116 mg/litre was reduced by 79%, while a loading rate of 1721 mg/litre was reduced by 94%.

Hopwood & Rosen (1972) suggest the removal of 70–90% of BOD_5 and 80% of the SS present in the influent.

Recently, the system has been improved by addition of chemical flocculants, which help to ensure that separation takes place over a wide range of flow-rates and concentrations of polluting matter. A number of such systems is available.

Dissolved Air Flotation with Chemical Flocculation

The addition of chemicals that aid flocculation is useful because the process is easier to control automatically and, when operated correctly, produces effluent of a more consistent quality.

A large range of suitable chemical flocculants is available, the most common of these being ferric chloride, ferric sulphate, ferrous sulphate, aluminium sulphate (alum), sodium carbonate (soda ash), calcium carbonate (lime), lignin sulphonic acid and sodium lignosulphonate. Table 6 gives the results of trials with some of these flocculants.

The chemical flocculation stage varies with the system. In most cases, it is either a separate stage before the flotation tank, or the flocculant is bled into the effluent flow-line before entry into the flotation tank. Brolls & Broughton (1981) recommend that flocculation is carried out before entry into the dissolved air flotation tank, for the following reasons: (1) Retention and mixing times can be properly controlled to ensure optimum flocculation. (2) Floc formation tends to be disrupted if the treated effluent is subjected to high-pressure pumping. (3) A separate chemical treatment tank allows a visual check on floc formation, and steps can be taken to remedy failure.

Grant (1981) found that the addition of iron or aluminium salts over the pH range of 5·0–6·5 gave good results and produced stable flocs. Ten Have (1981) found that ferric chloride, 160 mg/litre plus an

TABLE 6

THE TREATMENT OF POULTRY PROCESSING EFFLUENTS, USING VARIOUS FLOCCULANTS AND DISSOLVED AIR FLOTATION

Flocculent	*Effect of the treatment:*						*Reference*
	BOD_5		*SS*		*Total fatty matter*		
	% removed	*Concentration remaining (mg/litre)*	*% removed*	*Concentration remaining (mg/litre)*	*% removed*	*Concentration remaining (mg/litre)*	
Lime (concentration not given)	64				91		Grant (1981)
Ferric chloride, 160 ppm + polyelectrolyte	80						Ten Have (1981)
Alum, 75 mg/litre; Soda ash, 75 mg/litre; Polymer, 2 mg/litre	74–98	18–294	87–99	4–98	97–99	2–51	Woodward *et al.* (1977)
Lime, 100 mg/litre	57		81				Steffen (1973)
Alum, 300 mg/litre	33		94				
Sodium lignosulphonate, 40–400 mg/litre	90		85				Hopwood & Rosen (1972)
Lignosulphonic acid, 140 mg/litre	75		80				Crocco (1975)
Lignosulphonic acid (concentration not given)	65–90		65–90				Dart (1974)

anionic polyelectrolyte 3·5 mg/litre produced a scum sludge with a total solids content of 5–10%. It was found that the yield of scum sludge was 0·15 m^3 at 7% total solids per 1000 broilers processed. The scum sludge was heavily contaminated with *coli-aerogenes* bacteria (10^7/g) and salmonellas (10^2/g). The total counts were so high that the scum sludge deteriorated after 2 days' storage. It could be kept longer by the addition of 1% formic acid, which also reduced all bacterial counts by 3–4 $\log_{10}$ units in two days.

Woodward *et al.* (1977) monitored a commercial plant and provided details of its operation and loading, which was 160 m^3/m^2/day. This particular plant operated satisfactorily when 20% of the contents of the flotation tank were recycled through the retention tank. The results given in Table 6 indicate the range of treatments found.

Several studies were based on the use of lignin sulphonic acid as the flocculant. This substance is very successful in flocculating proteins at pH 3. Dart (1974) gives protein recovery as 65–90%, with a total solids content of the scum sludge of 5–15%. The disadvantages of this treatment are the need to maintain the low pH and the difficulty of utilising the potential value of the scum sludge. Hopwood & Rosen (1972) report the use of sodium lignosulphonate at rates of 40–400 mg/litre at pH 3 (see Table 6). Crocco (1975) obtained similar results with 104 mg/litre of lignosulphonic acid.

Commercially, the most widely used method consists of a flocculation stage involving alum and polyelectrolytes, and made to flow by dissolved air flotation, using the recycled flow pressure system. The scum sludge is removed by mechanically operated scrapers, while the supernatant liquor is discharged continuously either to a sewer or for further biological treatment.

Chemical Treatment

Both Grant (1981) and Patel (1976) describe the principle of the process which is based on the fact that the stability of most emulsified systems is determined by the electrostatic charges carried by the particles. Fatty and proteinaceous materials from poultry processing wastes are usually negatively charged, resulting in repulsion of particles, which prevents coagulation. The emulsified system can be destabilised by adjusting the pH value, by the addition of ions of opposite charge, or by both processes. Iron, aluminium (alum) and lime are frequently used for this purpose; more recently, lignosulphates (waste products from paper-making) and polyelectrolytes have also given good results.

The theoretical aspects of coagulation by aluminium salts have been considered by Dentel & Gosset (1987), to determine dosage rates. At pH 5·0–6·5, alum dissociates in water to yield positively charged complexes, which neutralise the negatively charged colloidal fat particles. In the presence of polyelectrolytes and alum, large flocs are formed and these can be separated by flotation or sedimentation (Grant, 1981).

Nutt (1978) emphasises that the following points are important in choosing the correct system: (1) The choice of coagulant must take account of the ultimate disposal of the sludge/scum produced. Some chemicals are highly toxic, and will render the product useless for animal feeding. (2) The coagulant must be mixed rapidly and uniformly, but gentle mixing is required to avoid destruction of the flocs. (3) There must be sufficient contact-time to ensure floc formation.

A number of papers describe successful systems of treatment. Patel (1976) tabulates the results of various chemical treatments, while Mihaltz & Czako (1984) provide details of a treatment which reduced COD values for the effluent by 85–87%. Tookos (1984) showed that there are three ranges of pH values in which chemicals operate successfully; pH 3·2–3·4, using lignosulphonic acid, 5·2–5·6 for ferrous and aluminium salts, and >10 for lime. It was found that the best results for poultry processing effluents were at pH 5·2–5·6, using ferrous salts or alum, with the later addition of lime. This treatment reduced the COD of the effluent by 80–90%, leaving a COD between 200 and 500 mg/litre.

Chemical flocculation can be combined with dissolved air flotation, and a number of commercial systems are in use. Chemical treatment on its own is usually limited to the separation and recovery of particular substances, such as protein and fat, from the sludges and scums already collected by dissolved-air flotation systems.

There are other methods of separating fine solids and fatty matter from processing effluents, and these include electro-flotation, ion-exchange resins, reverse osmosis and ultrafiltration. None has achieved the level of uptake by industry that has occurred with dissolved air flotation plus chemical flocculation; future developments may change this situation.

5.6. Choice of Preliminary Treatment

Preliminary treatment is an essential first stage in the treatment of poultry processing wastes and the correct choice of equipment and systems will significantly reduce the pollution potential of the effluent before discharge or further biological treatment. The cost of the equipment and its running costs will be significantly less than discharge of the untreated effluent to a sewer.

The choice of equipment will depend upon the amount and type of coarse solids to be removed and the amount of effluent to be processed.

The choice of coarse-solids separator will be decided by the amount of solid matter present. A level of more than 3% will require a rotary or brushed-screen separator, where 'blinding' is prevented by brushing or scraping. For the removal of finer and less concentrated solids (<3% total solids), the choice will be between a stationary or a vibrating screen. Vibrating screens usually produce higher levels of dry-matter solids than stationary screens, but they require closer control of the volume of effluent flowing onto the screen.

The choice of method for fine-solid and fatty-matter separation will depend upon the size of the plant and volumes of effluent to be handled. For larger plants, the most efficient and economic system is one which combines chemical flocculation with dissolved air flotation. Fat traps are only economically viable for small plants, with low daily effluent flows. Both systems have a built-in retention time and, for most situations, the storage capacity can be used to even out fluctuations in effluent flow, thus avoiding the need for a balancing tank. Balancing tanks are only necessary where very strict control of hourly and daily flow rates is required.

6. SECONDARY TREATMENT: BIOLOGICAL TREATMENT SYSTEMS

Biological treatment involves maintaining under controlled conditions a mixed culture of microorganisms, which utilises the continuous supply of organic matter present in the effluent to synthesise new cells. By-products of the process are simple substances, such as carbon dioxide, methane, water and salts. There are two approaches—anaerobic digestion and aerobic treatment. Anaerobic digestion requires the absence of free oxygen, while aerobic treatment is carried out in the presence of free oxygen. Both systems are used extensively to treat waste effluents, the choice being influenced by the initial strength of the effluent, as measured by BOD_5, COD, SS and total-solids content. Other factors affecting choice are the initial capital cost, the cost of energy used to operate the system, the volume of effluent to be treated and the availability of suitable disposal facilities.

6.1. Anaerobic Digestion

This type of biological treatment is carried out in the absence of free oxygen. Hence, the systems used are totally enclosed to prevent the entry of air. The microorganisms involved are able to utilise suitable organic substrates, and the system operates as a two-stage fermentation process. Both stages occur simultaneously within the digester. During the first stage, bacteria break down complex organic substances into simpler compounds, the most important being volatile fatty acids (VFA). Carbon dioxide, water, hydrogen gas, hydrogen sulphide and ammonia are also produced. In the second stage, methanogenic organisms utilise the VFA to yield methane and carbon dioxide. It is believed that other organisms also form methane from carbon dioxide and free hydrogen. The second-stage process is strictly anaerobic, and the organisms concerned are very sensitive to oxygen.

Maintaining a suitable pH value is a very important factor in the process; the usual range is 7·0–7·2. Over-production of VFA will lower the pH value and stop the process; the latter can be difficult to re-start.

Temperature also plays an important part, and, for the economic production of methane in temperate climates, the mesophilic range of 30–35°C is most commonly used. Higher temperatures, e.g. 55–70°C, may be utilised in hot climates.

These systems require balanced substrates to provide optimum gas yields. Poultry processing effluents are high in protein and low in carbohydrates and, therefore, are not ideal substrates. The protein will break down to yield amino acids and eventually ammonia. Concentrations of ammonia in excess of 3000 mg/litre will affect digester performance (Hobson *et al.* 1981).

Anaerobic digestion operates efficiently at total solid contents >4%. Hawkes (1979), has shown that, below this concentration, insufficient gas is produced to have an energy surplus after heating the digester.

With conventional digesters, retention times vary from 10 to 40 days. However, recent developments, in which the sludge concentration is maintained within the digester by return systems similar to those used with activated sludge, have reduced retention times to hours instead of days. Two such systems have been developed: upward flow, with sludge return and contact, in which the activated, anaerobic biomass is attached to a totally submerged plastic medium, similar to that used in high-rate filters.

So far, neither system has been used commercially to treat poultry processing effluents. A recent survey of biogas plants in Europe by Demuynck *et al.* (1984) failed to identify a single anaerobic digester of any design treating processing effluents. The reason for this is that the disadvantages appear to outweigh the advantages and the substrate (effluent) is not well balanced. Other factors are the high costs of installation, the need for skilled operators, and the fact that surplus treated effluent requires further treatment (aerobic) before it can be discharged into water courses.

The advantages of these systems are low energy input, surplus biogas, high total-solids effluents and elimination of the need for pre-treatment systems. However, while the general principles are universal, account must be taken of local climatic conditions and water quality regulations.

6.2. Aerobic Treatment

In this type of treatment, the dissolved organic matter, colloidal residues and fine solids are utilised by the mixed culture of microorganisms (biomass), as a substrate for growth. This process takes place in a vessel (the reactor), in which a continuous supply of dissolved oxygen is maintained by artificially introducing air or pure oxygen into the effluent. There are several factors affecting aeration of the reactor, and these are: (i) the concentration of dissolved oxygen; (ii) the hydraulic retention-time and substrate-loading rate; (iii) pH value; (iv) temperature; (v) toxic substances.

The objective is to maintain the culture at peak activity and performance, at least cost.

Aerobic treatment results in oxidation of the substrate to carbon dioxide and water. Proteins are broken down into nitrates and sulphates. The major product of the process is new cells (biomass); 0·57 kg of new cells are produced from 1 kg BOD_5 (Patel, 1976). The biomass, together with material which has resisted biodegradation, is separated out from the treated effluent in settling tanks (clarifiers). The supernatant liquor from the clarifier is discharged over a weir for disposal or further treatment, if this is required. The biomass and debris settle out as sludge at the base of the clarifier. A proportion of the sludge is returned to the reactor vessel to maintain the critical concentration of biomass. The remainder is drawn off to be concentrated, and may require further treatment before disposal.

Aeration

This is the process by which the dissolved-oxygen content of the reactor is maintained. Oxygen is adsorbed instantaneously at the air–water interface. To achieve a high rate of adsorption, it is necessary to mix the contents of the reactor continuously to ensure even distribution of the air. In addition to the area of the interface, the amount of oxygen dissolved is related to temperature, the optimum being 10°C. The salinity of the effluent also affects oxygen transfer, as does the amount of oxygen already present in solution. To achieve the maximum degree of oxygen transfer, the input of biodegradable material in the influent should match as closely as possible the oxygen input of the aerator. Usually, aeration vessels operate at 2–3% saturation. Completely saturated water contains 10 mg/litre of oxygen at 10°C. As the contents of the reactor near saturation, the efficiency of oxygen transfer is reduced. This affects the performance of the aerator in that less oxygen is dissolved per unit of power, which, in turn, increases the cost of aeration.

Aerator performance is measured by the efficiency with which dissolved oxygen measured in kg can be produced per unit of energy used (kW) per unit of time (h). Tests are usually carried out with unsaturated water held under controlled conditions of temperature and salinity and taking account of the volume and shape of the aeration vessel. A review of the factors affecting oxygen transfer in farm slurries has been made by Cumby (1987*a*). The factors for this type of material are essentially similar to those affecting concentrated effluents such as poultry processing wastes. The review indicates the very complex relationships between the various chemical and physical factors which influence oxygen transfer.

Most aerators achieve between 1 and 2 kg O_2/kWh. Aerators performing below 1 kg O_2/kWh are considered to be inefficient and costly in terms of energy use. Some manufacturers claim much higher efficiencies, quoting 6–8 kg/kWh; however, these figures must be related to the conditions under which they were obtained.

The other approach to measuring aerator performance is to determine the ability of the equipment to mix the complete contents of the aeration vessel. There are several methods in use and these are described by Cumby (1987*b*). The most useful involves measuring the specific power input (W/m^3) of the vessel contents. A range of such values is given by Cumby (1987*b*) for various typical effluents. The value normally applicable in treating poultry-processing effluents is in the range 5–20 W/m^3, which is similar to that of most activated-sludge plants.

Aerators

There are two distinct methods of mixing air with an effluent to achieve a supply of dissolved oxygen. The first method involves forcing air and water to mix, for which there are five different types of aerator. The second method is to mimic the natural forces that occur in water courses, where all the surfaces of materials in contact with the water are covered with a thin layer of microorganisms, these being supplied with a constant flow of nutrients and dissolved oxygen. Examples of this method are aggregate trickling filters and high-rate biological filters.

Mechanical Aerators

The various types of aerator have been classified by Cumby (1987*c*) into five groups. viz, (i) compressed air type; (ii) mechanical surface type; (iii) mechanical sub-surface systems; (iv) compressed air and mechanical systems combined; (v) pumped liquid type.

Compressed-air aerators. Air is forced by a compressor into a network of pipes on the bottom of the tank to be released, either through rows of perforations in the pipes or by outlets feeding into diffusers. Diffusers are usually made of porous ceramic material. Whatever method is used, the objective is to create very small bubbles of air which then rise slowly to the surface. This has the effect of creating a large interface between the air and the effluent. Deep tanks, typically 3·5–4 m deep, lengthen contact time. According to Cumby (1987*c*), efficiency ranges from 1·8 to 2·8 kg O^2/kWh.

Mechanical surface aerators. The objective is to stir the surface of the effluent vigorously, so that there is a continuous change of the air–liquid interface. The stirring action is also designed to mix the contents of the tank and disperse the entrained air to increase contact. Aerators are simple, robust machines consisting of an electric motor driving, through gearing, a shaft, at the base of which is a circular disc with bars or a cylinder to which is attached a series of fins. Either the aerator is fixed and the level of effluent maintained, or the machine is suspended on floats so that it rises and falls with the level of effluent. The aerating action tends to cause foaming and cooling of the effluent, but good performance is possible.

Aeration efficiency ranges from 0·95 to 1·9 kg O_2/kWh (Cumby, 1987*c*). Aeration systems using this type of approach must match the aerator to the aeration vessel. Tank depth is usually not greater than 3 m.

Mechanical sub-surface aerators. These draw air down a shaft and disperse it into the effluent by an electrically powered turbine. Usually, the drive-shaft is hollow, and doubles for the air-shaft. The action of the turbine causes the depression in pressure, which draws in the air. Many of these machines are mounted on floats. They are kept in place by three cables attached to the sides of the aeration vessel. Often, there is a cone set around the shaft, with the apex of the cone terminating just above the turbine. This device acts as a very efficient method of foam control. Sub-surface operation tends to retain the exothermic heat produced by the biomass.

Aeration efficiency ranges from 0·50 to 3 kg O_2/kWh; however, 1 kg O_2/kWh is most likely.

Combined compressed-air and mechanical aerators. This system combines the advantages of compressed air, which is released at the base of deep aeration vessels, with mechanical mixing, which breaks up the bubbles and finely mixes these with the tank contents. Overall performance is very similar to that of surface aerators but has the disadvantage of needing two motors and drive systems. It has been used in very large industrial treatment installations.

Pumped-liquid aerators. There are several designs, the basis being the effect of drawing air into a jet of effluent, or bleeding air into the jet by the Venturi principle. The force of the jet returning the effluent to the tank induces mixing. Usually, oxygen transfer is good, as long as foaming is controlled.

Oxygen transfer efficiencies for plunging jet aerators range from 0·8 to 4·0 kg O_2/kWh (Cumby, 1987*c*).

Venturi jet efficiency in water is poorer and often less than 1 kg O_2/kWH (Cumby, 1987*c*).

With regard to operating efficiency and the range of machines that has been well tested over many years, the choice will usually be between compressed-air systems and surface aerators. Test reports are essential to evaluate performance.

6.3. Biological Filter Systems

There are two systems in use, the high-rate biological filter and the low-rate trickling filter. The principle of operation has already been described.

High-rate Biological Filters

These are used in the treatment of strong, high-content BOD effluents. The filters are made of lightweight plastic media, which have a high ratio of surface area to void space. The medium may be manufactured in blocks, which can be built up like brickwork and surrounded by a skin of metal mesh or plastic sheet. Alternatively, it can be made of small rings fitted with radial spokes and randomly packed into cylindrical containers, usually between 6 and 12 m high. The effluent is applied by a fixed grid and splash plates or a circulating set of dribble bars. The aim is to obtain continuous wetting of the entire surface area. The microorganisms become attached to the medium and use the thin film of effluent as the substrate for growth. The chimney effect of the structure encourages an upward air-flow, thus providing oxygen. Usually, the effluent is recycled by continuous pumping from a sump, which is recharged by incoming untreated waste-water. The holding time is normally 3–4 h. Jank & Guo (1978) report loading rates of 1·0–2·2 kg BOD_5/m^3/day and hydraulic loading rates of 10–30 m^3/m^2/day. Treatment results in 50–70% reductions in BOD_5 and SS. Sludge sloughs off continuously, and is removed from the base of the sump.

The main operational problems associated with the filters are odour production, the presence of flies in summer and freezing in winter. Siting of filters well away from residential areas is usually very desirable. Freezing can be overcome by enclosing the system, but care must be taken to allow adequate ventilation in order to maintain the necessary dissolved-oxygen concentrations.

Low-rate Trickling Filters

These systems are usually 2–3 m high and constructed of rock, coke or iron slag. Because of the weight of material, they are set on a concrete base, which is designed to allow the effluent to fall towards an external collection channel at a lower level than the base.

Low-rate filters are often used as a final treatment for waste-waters and can reduce BOD_5 levels to <10 mg/litre, whilst reducing nitrates to concentrations acceptable to statutory authorities before the effluent is discharged into a water course. The filters are expensive to build, but simple to operate and maintain. The treatment encourages the sewage fly to breed and, as mentioned previously, this may cause problems in summer. Jank & Guo (1978) propose design criteria as follows: 0·1–0·2 kg BOD_5 m^3/day; hydraulic loading rates are 1·5–3·0 m^3/m^2/day. There should be no recycling of effluent. Sloughing is intermittent, and only small quantities are produced.

6.4. Factors Affecting Biological Treatment

Hydraulic Retention Time and Nutrient Balance

The retention time is the period during which the untreated waste-water remains in the treatment vessel. There are two systems in use, the batch system, whereby there is a known volume of influent, which replaces a similar amount of treated waste-water on a fixed-time basis and the more common alternative, the continuous-flow system. In this case, a known, total volume of influent enters the reactor at a controlled, constant rate, over a predetermined length of time, while there is a continuous discharge of treated effluent.

Within the reactor, microbiological breakdown of degradable products in the waste-water takes place. The treatment process is dependent upon a number of factors, which can be controlled to achieve the standard of treatment required. These include the growth activity of the microorganisms and it is usual to try to establish a balance such that the flow of substrate supports maximum growth of the microorganisms but is not in excess. When this is achieved and settling allowed, the microorganisms clump together to form flocs. This takes place when the treated liquor enters the clarifier settlement tank. If the microorganisms become old and start to die off, the biomass fails to form flocs and separation becomes difficult. The stage of growth of the biomass is controlled by the concentration of organisms in the reactor, the substrate loading-rate and the flow-rate of waste-water.

The concentration of biomass is controlled by the volume of recycled sludge from the settlement tank. This usually varies from 25 to 50% of the volume of the influent flow (Hrudey, 1984). The returned activated-sludge and the suspended-solids of the influent are mixed in the reactor to form the mixed-liquor suspended solids (MLSS) and the level present is regarded as a measure of the biomass. Usually values range from 2000 to 4000 mg/litre (Jank & Guo, 1978).

The substrate loading-rate is determined by the BOD_5, COD, SS and TS content of the incoming influent, the volume of waste-water and the aeration system used; for example, the rate varies from 0·05 kg BOD_5/kg MLSS/day for extended aeration systems to 0·2–0·5 kg BOD_5/kg MLSS/day for activated-sludge systems.

The flow-rate of the waste-water controls the hydraulic retention-time which usually varies, in an activated-sludge plant, from 4 to 12 h and, with an extended aeration system, from 1 to 3 days.

pH Value

The optimum pH range in aeration systems is 6·5–8·5. High pH values indicate the presence of high concentrations of ammonium salts, which are associated with the breakdown of proteins and the presence of urine from livestock manures. The pH of an aeration system drops as the hydraulic retention-time is increased, allowing the oxidation of ammonium salts to nitrates. These lower pH values are likely to occur in extended aeration systems and in effluents from trickling filters.

The effluents from poultry processing plants contain a wide variety of organic residues and are normally well buffered. This is usually sufficient to balance the effects of fluctuating pH values, due to the release of cleaning agents, etc.

Temperature

There are groups of microorganisms adapted to growth at particular temperatures; psychrophiles grow best below 20°C, mesophiles between 20 and 45°C and thermophiles above 45°C. Some organisms can grow below 0°C, while others are found in hot volcanic streams. Most treatment systems in temperate climates operate between 5 and 30°C, according to the time of year.

In very cold climates, treatment systems must be protected from freezing. It is usual to design systems in accordance with mean winter temperatures.

The aerobic breakdown of organic matter is exothermic. By using appropriate aeration equipment to reduce the cooling effect of adding air to water and insulating the reactor vessel, temperatures within the system can be maintained at 25–30°C (Baines *et al.*, 1985).

Toxic Substances

Biological treatment-systems are very sensitive to the presence of toxic substances and, in the case of poultry processing waste-waters, there is a constant danger that these substances will gain entry into the system.

The reason this hazard occurs is the need to maintain hygiene standards within the processing plant. The entire plant is cleaned after each day's processing, using sterilising agents to disinfect the conveyor lines and processing equipment. The proper use of suitable disinfectants at correct concentrations will ensure that the residual levels are sufficiently low to avoid damage to the biomass in the treatment plant. Care must be taken to avoid using chemicals that persist and do not break down during the cleaning process. Compounds such as phenols, toxic metals such as copper, zinc and nickel, which are often used to protect steel and iron-work, can all cause treatment-plant failure. Routine monitoring for the presence of these substances in the raw waste helps to indicate a build-up before a problem develops.

7. AEROBIC TREATMENT SYSTEMS

7.1. Activated Sludge

The term refers to the recycled sludge from the clarification tank, which has been maintained under peak conditions for rapid growth of the microorganisms. Hence, the sludge consists mostly of living cells in a highly active state. At this stage, the organisms can clump together to form flocs, when they are removed from the aeration tank into the slow-moving mass of water in the clarification tank.

The activated sludge is returned, to be mixed with the pre-treated influent, at a concentration that ensures removal of all the biodegradable organic matter present.

Activated sludge is one of the most frequently used aerobic systems for treating both human sewage and industrial wastes. The process can be operated either as a batch (plug-flow) system, or as a continuous system. The batch system requires an even flow and concentration of the organic matter. It is, therefore, of little use for poultry processing wastes, the production of which is frequently tied to fixed operating times.

The continuous-flow system involves a constant supply of effluent that has been pre-treated. This is mixed with a pre-determined amount of activated sludge. The joint flow enters the aeration tank. Here, the mixture of sludge and organic matter (MLSS) is monitored and used to gauge the state and activity of the system. The retention-time of effluent in the tank (hydraulic retention-time) is controlled to allow the treatment to take place. The aeration tank is continuously mixed and

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