Preface

The aim of The Science of Poultry and Meat Processing book is to provide students and industry personnel with a comprehensive view of the modernized primary poultry meat industry and further processing of both red meat and poultry. An emphasis is placed on basic concepts as well as recent advancements such as automation (e.g. increasing poultry line speed from 3,000 to 13,000 birds per hour over the last 40 years) and food safety (e.g. HACCP in primary and the further processing areas). The book also includes chapters explaining basic muscle biology, protein gelation, heat and mass transfer, microbiology, as well as meat colour and texture to help the reader understand the underlying scientific concepts of meat processing. The Science of Poultry and Meat Processing book is based on over two decades of university teaching experiences, and is designed to be used as a course textbook by students, as well as a resource for professionals working in the food industry. The book is available online, at no cost, to any interested learner. Using this format has also allowed me to include many colour pictures, illustrations and graphs to help the reader.
The book is dedicated to my past and current students who have inspired me to learn more and conduct challenging research projects. I see this as an opportunity to give back to the field that I have received so much from as a student and as a faculty member. Looking back, I have learned a great deal from my MSc and PhD advisor, Dr. A. Maurer, who was the student of Dr. R. Baker - the father of poultry processing in North America. I would also like to thank Dr. H. Swatland with whom I worked for almost 20 years, for the many challenging scientific discussions.

Writing The Science of Poultry and Meat Processing book was a long process, which also included having all chapters peer reviewed. I appreciate the help of my colleagues, but I still take responsibility for any inaccuracy in the book. If you have comments or suggestions, I would appreciate hearing from you (sbarbut@uoguelph.ca), as I am planning to revise and update a few chapters on a yearly basis.

I would like to thank the many people who have helped me during the writing process. To Deb Drake who entered all of the material for the book, to Mary Anne Smith who assisted in editing, and to ArtWorks Media for the design and desktop publishing of the book. I greatly appreciate the help of my colleagues who reviewed chapters and provided useful discussions. They include Mark B., Ori B., Sarge B., Gregory B., Joseph C., Mike D., Hans G., Theo H., Melvin H., Myra H., Walter K., Roland K., Anneke L., Massimo M., Johan M., Erik P., Robert R., Uwe T., Rachel T., Jos V., Keith W., and Richard Z. I would also like to thank my family for their love and support during the entire process.

About the Author

Shai Barbut is a professor in the Department of Food Science at the University of Guelph in Ontario, Canada. He received his MSc and PhD at the University of Wisconsin in meat science and food science. He specializes in primary and further processing of poultry and red meat. His research focuses on factors affecting the quality of meat, as well as protein gelation with an emphasis on structure / function relationships, rheological properties and food safety aspects. He has published over two hundred peer reviewed research papers and is the author of the Poultry Products Processing – An Industry Guide textbook. He is a fellow of the Institute of Food Technologists and has received awards from the Meat Science Association, Poultry Science Association, and the Canadian Institute of Food Science and Technology. He is involved in a number of government committees as well as academic and industrial research projects.
© 2015 Shai Barbut

This work is licensed under the Creative Commons licenses noted below. To view a copy of these detailed licenses, visit creativecommons.org. Briefly, this license allows you to download the work and share with others as long as you credit the copyright owner.

You can’t change the content in any way or use it commercially. Other than as provided by these licenses, no part of this book may be reproduced, transmitted, or displayed by any electronic or mechanical means without the prior written permission of the copyright owner, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law.

Effective July 1, 2015, this book will be subject to a CC-BY-NC-ND license. This book contains information from authentic and highly regarded sources and a wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author cannot assume responsibility for the validity of all materials or for the consequences of their use.

Library and Archives Canada Cataloguing in Publication

Barbut, Shai, author

The science of poultry and meat processing / Shai Barbut, PhD.

Includes bibliographical references and index.

Issued in print and electronic formats.


TS1968.B37 2016  664'.93

C2015-903906-1  C2015-903907-X
18.1 Introduction

The food industry is facing increased pressure to reduce waste and become more efficient at recovering by-products. The term “agricultural waste” is used to describe residues that result from diverse agricultural activities such as the planting and harvesting of field crops, the production of milk and animals for slaughter, and the operation of feedlots. With regards to the meat industry, animal waste may be defined as carcasses or animal parts that are not intended for direct human consumption (Commission of the European Communities, 1990). Examples of poultry industry by-products include offal, bone, blood, viscera, feet and feathers but in certain regions these may be considered mainstream products (e.g., chicken feet/paws). Twenty to thirty years ago, meat that remained after automated or manual deboning was not harvested. Today, this is accomplished by mechanical deboners (as described in previous chapters) and the resulting meat is used as a major ingredient in emulsion-type meat products (e.g., bologna, frankfurters) and as a minor ingredient in ground meat products (e.g., sausages). The main by-products and wastes generated during the primary processing of poultry are shown in Figure 18.1.1.

An important driver behind finding better waste management solutions is the current global discussion regarding environmental preservation. Other major drivers include high land field fees in crowded urban areas and surcharges on waste water with high organic matter content. The meat industry generates a lot of waste water. Measuring its organic matter content is the first step in determining treatment(s) and estimating costs. There are several ways to measure and express the organic matter load: BOD$_5$ (biological oxygen demand); COD (chemical oxygen demand); total dissolved solids; suspended solids (SS); fats, oils and greases (FOG; these terms will be further explained below). Overall, meat processing effluents are high in nitrogen, phosphorus, solids, and BOD$_5$ levels (Table 18.1.1) and can potentially lead to eutrophication (Benka-Coker and Ojior,
1995; Arvanitoyannis and Ladas, 2008). It is often challenging to characterize the waste products of a typical plant because the load discharged varies seasonally, daily, or even hourly. Thus, a precise waste analysis is not simple.

Figure 18.1.1 Overview of poultry meat processing operation and generation of by products and waste. Adapted from http://www.gpa.uq.edu.au/cleanprod/res/facts/fact7.htm.
Table 18.1.1 shows COD, BOD₅, TSS, VSS, and Total P values from four studies of abattoirs, all of which are at least several times higher than those of average domestic sewage. Such effluents cannot be directly discharged into the watershed (e.g., rivers, lakes) or even to a regular municipal sewage system. In order to reduce waste water surcharges, most medium and large meat processing plants have their own waste water treatment operation. Smaller plants, at the very least, have a primary means of filtering out some of the large materials (feathers, offal) and small meat pieces that contribute to high BOD values. Where there is an opportunity to recover and sell valuable commodities (e.g., feathers for feather meal, bedding, or ornamental fancy feathers), the industry will invest money in recovering and collecting the by-products in a more profitable way; see discussion below. Also note that meat/poultry by-products and wastes may contain up to 100 different species of microorganisms that are introduced when the feathers, feet, and intestinal contents are removed. These microorganisms include potential pathogens such as *Salmonella* sp., *Staphylococcus* sp., and *Clostridium* sp. (Salminen and Rintala, 2002).

<table>
<thead>
<tr>
<th>Source</th>
<th>COD (mg L⁻¹)</th>
<th>BOD₅ (mg L⁻¹)</th>
<th>TSS (mg L⁻¹)</th>
<th>VSS (mg L⁻¹)</th>
<th>Total P (mg L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Study 2003</td>
<td>5800</td>
<td>2200-9800</td>
<td>2400-9400</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3. Study 2003</td>
<td>4000</td>
<td>1730</td>
<td>2580</td>
<td>1960</td>
<td>171</td>
</tr>
</tbody>
</table>

Overall, by-product disposal is both a challenge and an opportunity for the meat industry. The goal is to sell the by-products (residual meat, bone residues, feathers) to outlets such as animal feed and pet food processors. It is expected that this trend will continue as the industry searches for more ways to increase the added value of by-products. To give the reader an idea of the size of the industry, the results of a 2010 North American survey are presented in Table 18.1.2. These quantities were derived from the annual processing of more than 55 billion pounds of poultry and 150 million head of cattle, hog and sheep (Jekanowski, 2011).

Water discharge from meat plants is a major issue because relatively high volumes are required to process each animal. The total potable water required to process a
single bird in the Netherlands varies between 5 and 20 liters (Veerkamp, 1999). In the USA, the amount required is higher, 22.7 liters (6 gallons; see Chapter 2 for trends over the past 20 years), due to the prevalence of water chilling. Avula et al. (2009) reported 26.5 liters/bird during primary and secondary processing and suggested ultrafiltration as a means of recycling water. This latter value is representative of several European operations. Overall, cleaning accounts for 30-50% of the total daily water consumption. Veerkamp (1999) discussed ways/processes to improve water use efficiency such as recycling the so called “red-water”, using flat spray nozzles instead of showers, and using air rather than water chilling. More recently, innovations such as the Aero-scalder (which uses steam instead of water; see Chapter 5) have helped reduce water consumption in this operation by about 70%. However, the introduction of stricter microbiological standards has resulted in increased water requirements for the industry. Today, further reductions and increased recycling of water are becoming even more important as the cost of both fresh water (coming into the plant) and waste water disposal are steadily increasing all over the world. Water quality in terms of organic matter load, colour, and microbial count (including pathogens) is becoming an important issue. In several places the industry is already implementing new methods to recycle water (e.g., after a UV light treatment) in order to improve efficiency and reduce cost.

**Table 18.1.2** Volume production of rendered proteins in Canada and USA in 2010. From Jekanowski (2011).

<table>
<thead>
<tr>
<th>Type of Rendered Protein Product</th>
<th>Pounds</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruminant meat and bone meal</td>
<td>2,853,257</td>
<td>30.9</td>
</tr>
<tr>
<td>Poultry by-product meal</td>
<td>1,744,176</td>
<td>18.9</td>
</tr>
<tr>
<td>Non-ruminant mammalian meat and bone meal</td>
<td>1,580,518</td>
<td>17.3</td>
</tr>
<tr>
<td>Mixed ruminant/non-ruminant meat and bone meal</td>
<td>1,403,261</td>
<td>15.2</td>
</tr>
<tr>
<td>Feather meal</td>
<td>673,147</td>
<td>7.3</td>
</tr>
<tr>
<td>Other proteins</td>
<td>491,209</td>
<td>5.3</td>
</tr>
<tr>
<td>Ruminant blood meal</td>
<td>240,150</td>
<td>2.6</td>
</tr>
<tr>
<td>Non-ruminant mammalian blood meal</td>
<td>234,162</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>9,219,879</td>
<td>100%</td>
</tr>
</tbody>
</table>

The amount of animal by-product after selling the dressed bird or cut up portions is calculated as: carcass weight ÷ live weight x 100. Mountney (1989) reported expected yields of 77% for turkey broilers, 70% for chicken broilers, 58% for
Peking duck, and 78% for pheasant. Additional values are presented in Chapter 2. The leftover material (23 – 42%) is the amount of by-products and waste. Lortscher et al. (1957) reported that this portion can be divided into 17.5% offal, 7% feathers and 3.5% blood in the case of broilers, 12.5, 7 and 3.5% in turkeys and 17, 7 and 3% in fowl.

18.2 Waste Water Treatment

Meat processing plants generate a significant amount of waste water with a relatively high content of organic matter from protein, fat, and microorganisms. The processor must decide to treat the waste water or send it to a municipal sewage system (note: in recent years, many municipalities have refused to treat water with organic matter levels that are higher than the domestic sewage level). Therefore, it is in the best interest of the meat processor to treat the water, as much as possible, prior to sending the water to a municipal sewage system. The treatment can range from a simple filtration system to sophisticated aerobic lagoons. Overall, volume, capital, and operating costs determine the level to which a plant treats its waste.

The main steps of waste water treatment can be divided into:

a. Preliminary (e.g., screening of meat pieces, feathers)
b. Primary sedimentation
c. Secondary treatment (e.g., biological oxidation)
d. Secondary sedimentation
e. Tertiary treatment (e.g., filtration)
f. Disinfection (e.g., chlorination)
g. Sludge dewatering (receiving material from the secondary and tertiary treatments)

All of these steps will be described in more detail later in the chapter.

The processor may choose to install one or all of the components as shown in Figures 18.2.1 and 18.2.2. Cost analysis is the first step in determining the appropriate treatment. The numbers are based on capital expenditure, expected operational cost, volume of waste water, local and federal regulations, expected charges for waste water treatment by the municipality, and expected production figures for the plant. This is usually done by a qualified local consultant who can determine the scope of the operation required and provide accurate capital and operational costs.
Figure 18.2.1 Illustration of steps involved in waste water treatment. A meat processor may choose to install all/several steps. From Wikipedia.

Figure 18.2.2 Aerial picture of a waste water treatment plant. From [http://www.mewr.alexu.edu.eg/](http://www.mewr.alexu.edu.eg/).

The main terms and criteria used to calculate surcharges for waste water treatment are listed below.
a. Biological oxygen demand (BOD) is a semi-quantitative measure of organic content in waste water. It is used to estimate the amount of oxygen required for microbial degradation of the affluent. BOD$_5$ refers to the amount of oxygen (in ppm) required to decompose the organic matter by aerobic microorganisms in a waste water sample over a five day period. Note that the decomposition can take more than five days, but this is a common index (Carawan et al., 1979). Table 18.1.1 shows abattoir waste water values ranging from 1,300 to 9,800 ppm with a more common value around 2,000 ppm. Earlier, Parker and Litchfield (1962) estimated that waste water from meat processing plants have a BOD$_5$ of 1,100 ppm. Packing house and stockyard waste water usually have a BOD$_5$ value of 600 and domestic sewage that contains no industrial waste has a value of approximately 200 ppm.

b. Chemical oxygen demand (COD) measures pollution by using a strong oxidizing compound, orange dichromate, while maintaining the reaction at a high temperature. In acidic conditions orange dichromate, K$_2$Cr$_2$O$_7$, oxidizes organic matter and turns into a green chromium ion via acid reflux. This is a faster method than BOD (about 2 hrs) and also measures non-degradable organic compounds such as cleaning solvents. Although there is some overlap with the BOD$_5$, regulatory agencies will not usually accept COD data unless it is reported as a COD/BOD ratio (note: values can also vary from site to site due to changes in waste water characteristics).

c. Total solids (TS) is a measure of the combined organic and inorganic matter in waste water. It is measured by gentle drying of a known volume of waste water in a predetermined volume of a crucible.

d. Total suspended solids (TSS) measures the total non-filterable residue that is retained by a membrane filter (glass or fiber) when filtering a predetermined volume of waste water. The solids are then dried for an hour at a temperature of about 103°C. Parker and Litchfield (1962) reported values of about 820 mg/L for waste water from meat plants and about 600 mg/L for waste water from packing houses and stockyards.

e. Total organic carbon (TOC) determines the amount of CO$_2$ released from a catalytic oxidation at 900°C. This is a very fast method that correlates fairly well with the standard BOD$_5$, but it requires a sophisticated laboratory set up.

f. Total oxygen demand (TOD) measures the amount of oxygen required for combustion of all the material in a water sample at 900°C.

g. Dissolved oxygen (DO) determines the amount of oxygen in the waste water by an electrode or by an iodometric titration. This is important during secondary treatment (usually done in an aerated lagoon during the biological oxidation step; see below).
h. Fat, oil and grease (FOG) are extracted with an organic solvent, separated, and then heated to evaporate the solvent. Values are reported as mg/L.

Overall, waste water treatment follows a logical sequence that starts with crude screening to remove large particulates (e.g., feathers, meat particles) and ends with breaking down dissolved organic matter (nanometer size) by microorganisms (Figure 18.2.3). Below is an explanation of the required steps.

---

**Figure 18.2.3** Diagram showing the relative effectiveness of reducing total solids and BOD by the different treatments. Redrawn from Hill (1976).
Preliminary treatment – first, screening is an efficient and inexpensive step designed to remove large particles by using a coarse screen that detains large particles such as meat pieces and feathers. This step also protects downstream machinery. Figure 18.2.4 shows a simple device used for screening. As simple as it looks, such a system is extremely useful in substantially reducing the BOD₅ value because it removes large pieces of organic matter. A second, smaller screen can follow the first. The collected solids are usually dewatered by compression and then sent to a rendering plant or landfill for solid waste disposal. It is in the best interest of the processor to remove organic matter as quickly as possible; i.e., before microbial degradation/fermentation and odour production takes place (Green and Kramer, 1979). If composting is to be used, it is important that the right group(s) of microorganisms are used for fast and efficient degradation.

Screening is also used at the plant for items such as feathers, which are removed during the picking operation with the help of a water wash. Feathers can pick up 10-15% water during the scalding and de-feathering processes. Dewatering them by compression/centrifugation is also an easy and economical way to reduce handling and transportation costs.

Primary treatment – is used to remove small particles from the water. Relatively inexpensive equipment can be used to effectively separate the particles by weight through the sedimentation of heavy particles and flotation of light particles such as...
oil and grease. An example of a procedure where a combination of sedimentation and flotation are used is shown in Figure 18.2.5. It takes longer for particles to settle as compared to mechanical screening. The particles that sink to the bottom are scraped away by a moving belt equipped with paddles and are collected in a lower pit that can be cleared by a pump. Compounds such as lime, alum, ferric sulphite, and synthetic polymers can be used to speed up solid separation. As shown in Figure 18.2.3, sedimentation can remove a substantial amount of particulate matter and reduce the BOD by about one third. Flotation to separate out fat and liquid oil is fairly simple. Also, there are chemicals and physical means (e.g., air bubbles coming from the bottom) that promote flocculation and can speed up the process. Floating particles are skimmed off the top. Over the past 20 years the agro-food industry has attempted to improve organic matter separation through new inorganic and organic coagulants (Aguilar et al., 2005). Effectiveness also depends on the composition of the waste water, temperature, the rate of mixing, and the order in which coagulants/flocculants are introduced. When dissolved in waste water flocculants may be either ionized (called soluble polyelectrolytes) or non-ionized (Arvanitoyannis and Ladas, 2008; Henze et al., 2008). The main advantage of using flocculants is that energy cost is fairly low since gravity and flotation are used.

![Figure 18.2.5](image)

Figure 18.2.5 Primary waste water treatment showing sedimented sludge scraped to a pit at the bottom, while floating material (e.g., fat, feathers) is skimmed off at the top. Courtesy of Envirex Inc.

Overall, coagulation and flocculation are used to remove colloidal material. The major goal of these treatments is to capture small organic particles. The process can result in a 75–80% BOD$_5$ reduction and has the additional advantage of removing large quantities of nitrogen and phosphorus from the waste water. The efficiency of the process can be studied by comparing the particle size distribution before
and after the addition of a coagulant (Aguilar et al., 2005). Examples of specific coagulants include Fe\(_2\)(SO\(_4\))\(_3\), Al\(_2\)(SO\(_4\))\(_3\), and anionic polyacrylamides (AP) such as Fe\(_2\)(SO\(_4\))\(_3\) + AP, and Al\(_2\)(SO\(_4\))\(_3\) + AP polyelectrolyte.

**Secondary treatment** – is achieved through biological means and relies on the breakdown of dissolved organic matter by microorganisms. Such a treatment can range from aerobic or anaerobic lagoons to advanced activated sludge processes. The suspended organic matter is digested by microorganisms that metabolize it as an energy source. During the process, organic matter is captured by bacteria, metabolized, and some is released as gas (e.g., CO\(_2\)) and water. The microorganism biomass is later filtered out of the water in a much more cost-effective way than it would have been to filter out the dissolved organic matter (e.g., via ultra-filtration or reverse osmosis). In a typical aerobic activated sludge system (Fig. 18.2.6), a floating mechanical aerator is used to introduce oxygen into the water. Aerobic lagoons can be up to 3 m deep. The introduction of oxygen enhances biological oxidation and maintains an environment of dissolved oxygen in the range of 1-3 mg/L. The aerator also helps to keep the solids suspended (Marriott, 1999). As shown in Figure 18.2.3, the reduction in BOD after this point can be around 70% of the incoming waste water. The solid sludge can be transported to a landfill or used as a fertilizer while the remaining water is processed in a so-called polishing pond or sand filter.

![Figure 18.2.6](image.png)

Another option is to use anaerobic microorganisms where no oxygen is introduced. In a similar process to the aerobic lagoons, the organic matter in the water is utilized while biomass, gases (e.g., CO\(_2\), CH\(_4\)), and water are produced. Construction of an anaerobic lagoon requires relatively low capital investment for the typical 1 to 3 m deep lagoons and operating costs are minimal since no agitation devices or air...
bubbling equipment is required. Loading rates are usually in the range of 250-
1,100 kg/hectare/day, where temperature is an important factor in determining the rate of organic matter loading capacity. When the temperature is ≥ 22°C, a BOD$_5$ reduction efficiency of 60-80% can be expected within 0.5-3 weeks (Marriott, 1999). Significant attention has recently been given to biogas production (e.g., methane) and its recovery as a renewable energy source. Anaerobic treatment is one of the major biological waste treatment processes used for the production of these gases. Salminen and Rintala (2002) studied the effect of hydrolic retention time (HRT) and loading on anaerobic digestion of poultry slaughterhouse wastes using a semi-continuously fed laboratory-scale digester at 31°C. Anaerobic digestion appeared feasible with loading up to 0.8 kg volatile solids (VS) m$^{-3}$ day$^{-1}$ and an HRT of 50–100 days. The specific methane yield was high, ranging from 0.52 to 0.55 m$^3$ kg$^{-1}$. On the contrary, at a higher loading (1.0 to 2.1 kg VS m$^{-3}$day$^{-1}$), the process was inhibited or overloaded. Arvanitoyannis and Ladas (2008) compared results from 12 studies dealing with anaerobic treatment of slaughterhouse waste water and also showed that the percentage of organic matter removal varies depending on the loading rate and reactor type. Overall, they reported 30-95% removal of organic matter with an average of 75%. They concluded that anaerobic digestion is an effective process for the treatment of slaughterhouse waste water but that one should be careful in selecting conditions.

Aerobic digestion in ponds remains the main form of biological treatment for removing soluble organic matter. Overall, a number of secondary biological systems are currently used (e.g., trickling filters, activated sludge systems). Trickling filter treatment is a relatively simple configuration where water flows over a stationary media, such as recycled tires and rocks, that is arranged in such a way that aeration is achieved by exposure to a large air surface. The microorganisms are attached to the rough surface of the media (e.g., plastic media, rocks) while the recirculating water trickles from above. After a certain number of cycles, the water passes through a clarifier to help collect the biomass.

Biological degradation is the main technology that makes use of microbes to oxidize and decompose the solute or suspended protein, fat, and carbohydrates. Furthermore, aerobic treatments are very effective at reducing odours and pathogens. As indicated above, aerobic treatments include aerobic lagoons, activated sludge processes, oxidation ditches, sequencing batch reactors (SBRs), trickling filters and rotating biological contactors are used for this purpose (Mittal, 2006).

**Tertiary treatment** – is one of the last phases and is applied to remove odours, flavouring compounds, and colour. A series of filtrations through coarse, then
medium, then fine gravel/sand (Fig. 18.2.7) is common for the separation and removal of small colour and odour compounds. Activated charcoal or carbon can also be used to remove these compounds since they have a high affinity for organic matter. The activated carbon should be replaced on a regular basis because it becomes ineffective after reaching a maximum load capacity. Sand filters are cleaned on a regular basis by back flushing. It is common to have a series of filters so that some stay in operation while others are being cleaned. A tertiary waste water treatment can also include an ion exchange unit (similar to a residential water softener) or an electro-dialysis unit where minerals (e.g., salt from a meat plant brine) are removed/exchanged.

![Figure 18.2.6 Secondary treatment - a re-circulating surface aerator feeding into an activated sludge system which contains aerobic microorganisms digesting dissolved organic matter. From Hill (1976).](image)

![Figure 18.2.7 Tertiary treatment - using gravel/sand/polymers to filter small compounds such as odour, flavour, colour molecules.](image)

**Disinfection** – is the last stage prior to discharge into rivers and lakes. Chemical agents such as chlorine and hydrogen peroxide are used to inactivate bacteria, viruses, etc. that were not filtered out during tertiary treatment. This is important as high microbial loads can pose a risk to humans and the environment. It is recommended that water be disinfected when both organic and microbial loads are lowest (i.e., the phenomenon that disinfecting agents, such as chlorine, react with organic material is similar to the situation described in a poultry water chiller; see Chapter 5). Disinfection can also be accomplished by gases such as chlorine oxide or ozone ($O_3$) and by physical means such as ultraviolet light and, to a lesser extent, microwave and gamma radiation.

**Comments on water recycling** – Due to environmental and budget constraints, technologies that recycle and treat waste water are increasing. Avula et al. (2009)
indicated that ultrafiltration of poultry waste water improves the quality of the recycled water and provides solutions to water resource limitations. Ultrafiltration is a pressure-driven process that separates materials based on molecular diameter. New membrane bioreactors that integrate biological degradation of waste products with membrane filtration are also quite effective at removing organic and inorganic contaminants from waste water. During the process, value added products such as crude proteins could be separated from poultry waste water, which could subsequently reduce the chemical oxygen demand. Ongoing research in membrane separation techniques involves exploration of new membrane materials and of new module configurations to address issues of membrane fouling and treatment of waste streams containing high suspended solids or viscous wastes. Overall, poultry processing plants use large volumes of water at several stages in the process due to set policies regarding pathogen reduction (see Chapter 2). Recovery of waste water can benefit the plant by reducing fresh water demand, waste water volume, and energy. For example, dissolved proteins that come from carcass debris/blood are major pollutants in the scalding and chilling operations. Ultrafiltration is one method that efficiently reconditions waste water and recovers protein and fat. Although the capital costs of ultrafiltration are high, the life cycle costs are comparable to other conventional treatments. Furthermore, the footprint of an ultrafiltration system could be 30–50% of that of conventional filters and may consume fewer chemicals.

18.3 Disposal of Solid Waste and Composting

Solids wastes are usually shipped by truck to a composting plant or a dump where they are properly buried (i.e., most countries have very strict regulations regarding waste disposal). Retaining solid waste near the processing plant can cause serious odour problems, spread disease (e.g., through wildlife), result in insect manifestation, and potentially pollute ground water. Composting is becoming a popular alternative for organic waste disposal since environmental issues are gaining attention and landfills are filling up quickly. Stabilizing organic matter through microbial activity provides humus that can be used as a farm fertilizer and/or to improve soil texture (Arvanitoyannis and Ladas, 2008; Jayathilakan et al., 2012). An inoculum of specially selected aerobic bacteria is recommended in order to speed the process and improve humus quality. Mesophilic and thermophilic microorganisms are involved and their growth succession is important in managing the composting process. In general terms, composting kills pathogens, converts nitrogen from unstable ammonia to stable organic forms, reduces waste volume, and improves the nature of the waste. During composting, solid waste should be aerated regularly by inverting or mixing the material. If
the waste material is too large or dense it should be ground first to increase the surface area exposed to microorganisms and air. The process can be completed within 1-4 weeks depending on factors such as waste type, temperature, aeration, and inoculation level. It is usually recommended that solid waste from different operations (e.g., meat, dairy and vegetable) be mixed together to get a better and faster fermentation. The composting area should be well managed and fenced to prevent wildlife (birds, mammals) from entering. In this way, composting provides an inexpensive alternative for the disposal of butcher wastes and meat scraps that cannot otherwise be sold (Mittal, 2006).

18.4 By-products: Edible and Inedible

The definition of edible and inedible can vary by country (e.g., chicken feet are categorized as edible in some areas and not in others). In North America, the meat industry considers everything produced by or from an animal, except dressed meat, a by-product or offal (Ockerman and Hansen, 2000). This includes both “edible” and “inedible” parts. The former consists of a variety of meats such as liver, hearts, and gizzards, which are referred to as the giblets in the poultry industry (see Chapter 5). Blood, which is sometimes used as an edible item, is also included in this category. The inedible portion includes parts such as the viscera (gut), head, and bones, which are commonly used in pet food, in growing fur-bearing animals (e.g., mink), and in feeding fish and hogs. Because of the danger of transmitting pathogenic organisms to other animals, the offal is usually heated to a high temperature (> 100°C, under pressure) to ensure microbial destruction. When the by-product will be used as feed, decontamination is mandatory in order to stop the spread of human pathogenic zoonoses (e.g., Campylobacter, Salmonella and Yersinia) and to minimize the microbial break down of amino acids that can result in the formation of toxic metabolites during storage.

The actual heating and rendering processes are described in more detail below. Treated offal is usually high in protein and can be mixed with other ingredients (e.g., cereal, vitamins) to produce a balanced animal feed and pet food. One of the main products, meat and bone meal (MBM), has been widely recommended and used in animal nutrition as a protein source in place of other more costly vegetable proteins (e.g., soy beans). The MBM has most of the essential amino acids, minerals, and vitamin B₁₂ needed in monogastric and ruminant nutrition (Deydier et al., 2005).

As a result of the recent bovine spongiform encephalopathy (BSE) crisis in the beef industry, the use of animal by-products is now tightly controlled. As of November
2000, MBM can no longer be used to feed cattle, but can be incorporated in feed for pigs, poultry, fish or domestic animals (Deydier et al., 2003). In the European Union, there are currently two regulations (Regulation EC No. 1774/2002 and its amendment No. 808/2003) that legislate animal by-products not intended for human consumption. These regulations explain the disinfection and control conditions necessary to ensure pathogen removal in meat wastes.

The following sections describe the rendering industry and its production of animal feed and oils, the pet food industry, and the unique process of producing feather meal. The latter two have substantial economic potential for the meat and poultry industries.

18.5 The Rendering Industry

Rendering is a process that converts animal waste into stable, value-added materials. It refers to the processing of any animal products into more useful materials (e.g., animal feed) and/or specifically rendering animal fat into purified fats like lard or tallow. Animal fats have been used for decades to waterproof clothing and to make soap and candles. Some of the earliest documented evidence for using soap goes back to the Babylonians in 2800 BC. The Phoenicians and Romans were also knowledgeable in the art of soap making, which was performed by experienced individuals who operated small shops. Today, the rendering industry operates and recovers raw materials on a much larger scale (Table 18.1.2).

There was a major development in industrial-scale rendering in the early 19th century (Dainty, 1981) when animal by-products were first used in large scale fertilizer production. Prior to that, animal by-products were buried and basically had no economic importance. Furthermore, burying the material added costs to the meat processor who needed to pay for transportation, labour, and landfill space. In the 19th century, it was realized that the growing meat industry could recover money by transforming waste material into farm fertilizers. Today, the rendering industry produces hundreds of useful products that are divided into edible, inedible, oils, chemicals, meat meals, and bone meals (Okerman and Hanson, 2000). Some of the larger meat processing plants have their own rendering facilities/spin-off companies whereas smaller plants use the services of an independent rendering contractor who collects and processes the material. The available rendering systems can be generally divided into: a) dry batch, b) autoclave or wet rendering, c) dry continuous processing, and d) continuous low temperature system (Ockerman and Hansen, 2000).
a. The dry batch system includes a cooker with steam-jacketed walls that prevent the steam from coming into direct contact with the material inside. Sometimes a hollow steam-filled agitator is employed. Ground by-product material, usually bigger than 2.5 cm, is batch fed into the system. During the process, water and fat are released. There is no contact with direct live steam and the fat is not severely degraded (i.e., as in the autoclave system discussed below). The cooled material is then removed and the free-flowing fat is drained off. The remaining moist material is then pressed by a hydraulic press (i.e., batch type), a continuous screw press, or a decanter centrifuge to remove the water.

b. The autoclave system consists of a cooker filled with pre-ground raw materials that is hermetically sealed prior to a steam injection (≈ 140°C). The process usually takes 3-4 h and involves high pressures (e.g., 360 kPa) that are reduced to the regular atmospheric pressure of about 100 kPa toward the end. The slow pressure reduction is important to avoid emulsification of the aqueous and fat phases. Figure 18.5.1 shows a wet rendering process where the liquid is separated via centrifuge after the heating phase. Afterwards, a high-speed three-phase separator separates the fat and water.
c. A continuous dry system is fairly similar to the dry batch rendering system. However, the material is continuously fed into the system and treated under atmospheric pressure. The cooker is usually horizontal, has a steam jacket, and sometimes has a hollowed, steam-heated agitator. The material enters at one end and exits at the other in a continuous manner. The time the material is exposed to heat depends on the size and retention volume of the cooker. The discharged material is dumped into a percolator that consists of a tank with a strainer at the bottom. The free fat is drained and the remaining material is pressed to remove the trapped fat. The remaining solids are then pressed and ground into a meat meal product.

d. A continuous, low temperature rendering system, sometimes called a mechanical dewatering system, employs a mechanical means to remove the water and fat. Overall, the raw by-products are ground up and then passed to a low temperature, dry or wet cooker (also called pre-heater or coagulator) where the material is kept at 60-90°C for 10-30 min. This causes some of the fat cells to break and release their contents. The material is then pressed using a continuous screw-type press and the fat and water are extracted. The remaining solids are then centrifuged for additional water and fat removal. This process results in a lower heat treatment and reduced energy costs compared to the other processes.

18.6 Pet Food

The pet food industry has been steadily growing around the world. In the USA it was estimated that people spent $55.3 billion on their pets in 2013 (APPA, 2013). Broken down, the expenditures were $22.2 billion on food, $13.2 billion on supplies and medicine, $14.2 billion on veterinary care, $2.3 billion on purchases of live animals, and $4.5 billion on grooming and boarding. Overall, this is a tremendous increase from 1993 ($16 billion) and 2003 ($32 billion). Ockerman and Hansen (2000) noted that the first commercially prepared dog biscuit was introduced in England in 1860. Canned cat food and dry meat dog food were introduced in the USA by 1930. New expanded pet food products were introduced in the 1950s and semi-moist pet food in the 1960s. The demand for pet food (estimated to be over 1 million tons/year of poultry, meat and seafood by-products) has provided the meat industry with a good and stable source of income and pet owners with high quality and nutritious pet food.

The USA pet population increased steadily by 1.3% annually between 1990 and 1997 (Hoepker, 1999) and in 1997 it was estimated that homeowners in the USA kept 56 million dogs and 68 million cats. This partially explains why the pet food
industry has grown so quickly. It should also be mentioned that today people are willing to spend more on their pets and that there are well over a thousand different pet food items estimated to be available in the US market. An annual growth of 4% in pet food retail sales in Japan is also expected due to changing social trends rather than an increase in the number of total pets. Some of the increases are the result of new pet superstores, premium pet foods, and increased awareness/knowledge of feeding pets a nutritionally balanced diet.

The meat industry ships fresh and/or frozen materials to the pet food industry (i.e., freezing is used when delays between shipping and processing are expected). The pet food industry cooks the meat at high temperature and mixes it with other ingredients to produce a balanced diet for different pet food categories. Common ingredients include corn meal, soybean meal, and vitamins. Examples of labels appearing on three types of pet foods are provided below.

### Dry dog food

Ingredients: ground corn, wheat shorts, poultry by-product meal, corn gluten, soybean meal, poultry fat preserved with mixed tocopherols (to preserve flavour), rice, molasses, tripolyphosphate, dry whey, calcium carbonate, salt and vitamins.

- Protein (min) 21.4%
- Fat (min) 10.6%
- Crude fiber (max) 4.3%
- Moisture 10.0%

### Canned dog food

Ingredients: poultry by-products, meat by-products, chicken, ground wheat gluten, minerals and vitamins (calcium, potassium, zinc, iron, iodine, vitamins A, B1, D3 and E), bone meal, citrus pectin, guar gum, sunflower oil, tri polyphosphate, natural flavours.

- Protein (min) 8.7%
- Fat (min) 6.6%
- Crude fiber (max) 1.4%
- Moisture (max) 77.0%
Canned cat food

Ingredients: chicken and chicken by-products, meat by-products, vitamins and minerals, vegetable gums, natural flavours, natural colours, caramel and water added for processing.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (min)</td>
<td>8.4%</td>
</tr>
<tr>
<td>Fat (min)</td>
<td>4.3%</td>
</tr>
<tr>
<td>Moisture (max)</td>
<td>81.0%</td>
</tr>
<tr>
<td>Ash (max)</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

The first formula, dry dog food, is mainly based on cereal products that provide a high percentage of protein and some carbohydrate. Poultry by-product meal is included as a main protein and mineral source. The poultry fat is supplemented with tocopherol (an antioxidant) to protect it from oxidation during heating and storage.

The second formula, canned dog food, adds a cereal component to improve the texture, add bulk, and add crude fiber (plant material) to the formula. The formulation also contains different gums (pectin, guar) to assist in texturizing the product. Natural flavour ingredients, usually poultry or beef extracts, are also included.

The third formula, canned cat food, illustrates a formula based on meat (listed as chicken) and meat by-products that has been fortified with vitamins and minerals. As with other foods, ingredients are listed in descending order by weight but the nutritional labeling requirements for pet food are not as stringent as they are for human food. For example, the pet food manufacturer can declare a minimum protein content and does not have to provide a list indicating the amount of vitamins and minerals whereas fortified human food must have a precise declaration of all ingredients).

Pet food is sold in different ways (wet, semi dry, dry) and protein content can range from 10 to 50%. “Wet” canned food usually has about 12-14% protein, semi dry food has 21-25%, and dry food has 20-50%. Recently, there has been substantial product development activity in the high end pet food industry as margins in that sector are high. Pet food companies have also invested in products that adjust for the nutritional needs and flavour and texture preferences of different pets. Advanced processing equipment (e.g., extruders) is becoming more popular as the need to texturize and shape the food is important in this highly competitive market segment.
18.7 Utilization of Feathers

Feathers are unique to the avian species. They represent about 7% of the live body weight of a broiler (Lortscher et al., 1957) and are also considered to be of major economic importance (as stated in Chapter 2, over 50 billion pounds of poultry was produced in the US in 2013). The feathers are made of a complex keratin protein matrix. The amino acid sequence of a broiler’s feather is very similar to that of other poultry/bird feathers and the keratin found in reptilian claws. Feathers are a rich source of protein with approximately 90% protein, 8% water, and 1% fat. Once processed into a regular feather meal, it contains about 70-80% crude protein. However, before using feathers as an animal feed, the protein complex has to be broken down as explained below. Feathers are also used for bedding, ornaments, sporting equipment, and as filler in chemical fertilizer (Ockerman and Hansen, 2000).

According to Hardy and Hardy (1949) and Pacific Coast (1997), feathers can be classified as:

a. Saddle feathers – long, narrow, vaned feathers from the saddle and back of a rooster
b. Hard feathers – stiff quills, heavy vanes and a very small amount of fluff

c. Half fluff – vaned feathers with fluff along the lower half of the quill
d. Three-quarters – vaned feathers with fluff along the lower three-quarters of the quill
e. Fluff – body feathers with firm shafts bearing only fluff, or the soft part of a feather
f. Plumules – small down feathers with soft shafts, bearing only fluff
g. Down – feathers without a shaft, composed of only a tuft of fluff

When feathers are used for animal feed they need to be hydrolyzed to break down the complex protein (keratin) structure; otherwise they would be indigestible. The feathers are first washed to remove dirt and then they are dewatered by compression or centrifugation because they do absorb some moisture during processing and washing (e.g., at the meat processing plant they usually pick up between 7 to 15% moisture during the scalding and picking operations; Lortscher et al., 1957). After some of the water has been removed the feathers are cooked for 1-2 h to hydrolyze the complex protein structure. Heating is commonly done in a pressure cooker (under 2-3 atm of pressure), which increases the rate of hydrolysis. The feather’s digestibility is proportional to cooking time and temperature where higher temperature and longer cook times result in higher amino acid availability. The cooked feathers are then dried (e.g., air) and ground, resulting in a product
known as feather meal. The grind size should be such that all particles pass through a US No. 7 screen and 95% pass through a US No. 10 screen. The common composition of a feather meal is: 75% crude protein (some contain up to 90%), 10% moisture (maximum), < 6% fat (maximum or minimum as specified), and 3-4% fiber (maximum).

Feather meal is rich in sulfur containing amino acids such as cysteine, arginine, and threonine, but is deficient in lysine, histidine, methionine, and tryptophan. When the meal is fed to poultry or swine (monogastric animals), these limiting amino acids should be added. The common feeding level is 0.5 to 1.5% of the diet (Ockerman and Hansen, 2000). When fed to beef cattle (ruminant animals), feather meal efficiency can be improved by adding urea.

**Bedding** – this industry commonly uses small, fine feathers. Down is the most preferred material because it possesses a unique structure that allows it to hold large volumes of air (Fig. 18.7.1) and down is an excellent insulator. Down usually represents 12-15% of the total feather weight in ducks and geese. The remaining feathers on the bird are designed for water and air flow so the bird can swim/fly.

![Branched downy barb](image)

*Figure 18.7.1 Structure of a down feather from lateral body apterium taken from a Single Comb White Leghorn. From Lucas and Stettenheim (1972).*
In the bedding industry feathers are thoroughly washed and rinsed and then blow-dried or steam-dried. This process promotes opening the structure of the down feathers (fluffing), which enhances the feather characteristics as a bedding material. Breathability, compressibility, and the ability to return to its original shape and volume are also important characteristics in selecting feathers for bedding (Mountney, 1989). The fill-power or “loft” is a measurement used for feather quality, which provides a numeric value to describe the amount of space the down will fill under a standard pressure. It is desirable for feathers (used for bedding) to have maximum volume when in use and minimum volume during storage (e.g., goose down usually has a higher fill-power compared to duck down when obtained from birds of similar age). A high fill-power of 750 in³/oz is given to feathers that are strong, soft, have high insulating efficiency and durability, and have little loss of resiliency over time. A fill-power of 300 in³/oz is given to smaller clusters of down with lower resilience and therefore faster wear is expected.

Feathers are sorted into different size groups after cleaning and drying. Sorting is done by air currents which blow the down and feathers through a series of vertical baffles, suspended from both the top and bottom of the separator. Lighter down feathers are blown further away than the heavier feathers (Pacific Coast, 1997). According to US regulations, a product identified as down must contain 80% down and no more than 20% other feathers. This distinction was made because it is almost impossible to get a complete down separation i.e., some light feathers, usually no longer than 6 cm, will also be blown into the down compartment.

After the introduction of synthetic fibers there was a reduction in the use of down for bedding. However, high quality down is 4 x more thermally efficient and 10 x more durable than synthetic fibers and a surge of high end down filled bedding/coats has been seen in recent years (Ockerman and Hansen, 2000). Also, feathers are classified as a natural product and contain no toxins, require no toxins to produce, do not pollute, and are biodegradable.

**Ornamental feathers** – tail and wing feathers from pheasant, rooster neck hackles, ostrich, etc. need to be removed before exposure to hot scalding water. This is done by hand and is obviously time consuming and more expensive than mechanical defeathering (i.e., a picker uses fast moving rotary rubber fingers in a fairly aggressive way that damages the shape and structure of the feathers). Feathers used for sporting equipment, such as for fetching arrows, are carefully hand selected to assure quality (note feathers for an individual arrow must all come from either the right or left wing to provide a proper rotation of the arrow; Mountney, 1989). Feathers can also be used for manufacturing artificial fishing lures and for shuttlecocks used in badminton. Coloured feathers are used for decorative purposes and are sometimes dyed and trimmed to a desired shape and pattern.
Careful cleaning of feathers is required when feathers are used for bedding, clothing, or sporting equipment. If the feathers are going to be saved for more than a day prior to processing, they can be soaked in a 5% salt, 0.3% hydrochloric acid solution. The feathers are washed about half a dozen times with a soap solution and cleaning detergents to remove all dirt. A mild soap should be used to protect the essential oils in the feathers and a neutral pH should be maintained to protect the feathers (Mountney, 1989). Sometimes a special high flash point gasoline is used to remove foul odours. In such a case, the processor can later lightly spray the feathers with mineral oil to replace some of the original oil. In some processes, where decolourization is required, blanching agents such as hydrogen peroxide, chlorine, or potassium permanganate are also used. Inappropriate cleaning will cause problems with mildew, degradation due to microbial activity, and reduce the insulating properties.

With the increased demand for natural products in the marketplace, feathers are gaining popularity and that is good news for the poultry industry. Attention toward recovering by-products from meat and other ingredients is also expected to rise as the price of material disposal is continually increasing.
References


Green, J.H. and A. Kramer. 1979. Food Processing Waste Management. AVI Publ., Westpoint, CT.

Hardy, J.J. and T.M.P. Hardy. 1949. Feathers from domestic and wildfowl. US Department of Agriculture Circular 803, Washington, DC.


