# Carcass rendering systems for farm mortalities: A review

**A. Kalbasi-Ashtari, M.M. Schutz, and B.W. Auvermann**

**Abstract:** Improper animal-mortality disposal may allow pathogenic microorganisms to spread diseases in soil, plants, animals, and to humans; and resulting odor reduces the quality of life for neighbors. Health hazards posed by neglect in carcass disposal would be pronounced in the event of a natural catastrophe, disease outbreak or intentional depopulation of herds or flocks. Conventional rendering systems have been utilized for the last two decades to convert various animal carcasses to different products. However, considerations regarding prion diseases will further shape the rendering industry. New rendering technologies that convert suspected prion-infected animal tissues into tallow and protein for use as a biofuel and fertilizer, respectively, are beginning to emerge. This paper reviews the rendering industry and new methods for carcass rendering to produce safe and economically valuable products while minimizing impacts on public safety and environmental quality.

*Key words:* rendering, carcass disposal, meat and bone meal, animal mortality, prion disease, livestock.

**Résumé :** La disposition inadéquate d'animaux morts peut permettre à des microorganismes pathogènes de propager des maladies dans le sol, aux plantes, aux animaux et aux humains; de plus, les odeurs qui en résultent réduisent la qualité de vie des voisins. Les dangers pour la santé posés par l'élimination négligente de carcasses pourraient être accentués en cas de catastrophe naturelle, d'épidémie ou de réduction intentionnelle des cheptels de bétail ou des bandes de volailles. Les systèmes d'équarrissage conventionnels ont été utilisés au cours des deux dernières décennies pour convertir les carcasses de divers animaux en différents produits. Toutefois, les dangers concernant les maladies à prions affecteront encore plus l'industrie de l'équarrissage. De nouvelles techniques d'équarrissage qui convertissent les tissus d'animaux suspectés d'être infectés aux prions en suif et en protéines pour utilisation respective dans les biocarburants et les fertilizants commencent à émerger. Cet article analyse l'industrie de l'équarrissage ainsi que les nouvelles méthodes d'équarrissage des carcasses dans le but de générer des produits de manière sécuritaire et économique tout en minimizant les impacts sur la sécurité du public et la qualité de l'environnement.

*Mots-clés :* équarrissage, élimination des carcasses, farine d'animaux d'équarrissage, mortalité animale, maladie à prions, bétail.

[Traduit par la Rédaction]

## Introduction

One of the largest agricultural businesses in the United States is the combined livestock and poultry industry. More than 54 billion lb (~24 billion kg) of poultry meat (46 broilers + 1 chicken + 7 turkey) and 45 billion lb (~20 billion kg) of red meat (cattle, calves, sheep, hogs, and goats) were produced during 2004 (US Department of Agriculture, Economics and Statistics Systems 2005). Yet every year, despite the best attempts of farm managers, veterinarians, and pharmaceutical companies, millions of livestock and poultry perish because of diseases or accidents preventing human consumption. While more than 439 million chickens (excluding commercial broilers) and 264 million turkeys were raised for commercial sale in the United States in 2004, more than 34% (about 101 million) of chickens and more than 10% (about 26 million) of turkeys died from diseases, natural causes, or from other reasons such as natural disasters before they were marketable (US Department of Agriculture, Economics and Statistics Systems 2005).

Ruminant mortalities (cattle, sheep, lamb, and goats) in the US have a similar situation and out of 95 billion head of all cattle and calves raised in the US, more than 20% were lost prior to slaughter during 2004 (US Department of Agriculture, Economics and Statistics Systems 2005). In 2004, Hurricane Ivan caused considerable damage in the northern counties of Georgia and a single farm in Gilmer County lost 96 000 chickens and 19 dairy cows (Georgia Department of Agriculture 2005).

Infectious and non-infectious diseases cause heavy losses of animal populations worldwide every year (Texas Department of Agriculture 2002). In addition to economic consequences, catastrophic mortality losses may threaten the

Received 16 November 2006. Revision accepted 3 December 2007. Published on the NRC Research Press Web site at jees.nrc.ca on 27 March 2008.

**A. Kalbasi-Ashtari.** Food Technology Engineering Department at Tehran University, Karaj, Iran.
**M. Schutz.**[1] Department of Animal Sciences, Purdue University, 125 South Russell, #105, West Lafayette, IN 47907, USA.
**B. Auvermann.** Biological and Agricultural Engineering Department at Texas AM University, Amarillo, Texas, USA.

Written discussion of this article is welcomed and will be received by the Editor until 30 September 2008.

[1]Corresponding author (e-mail: mschutz@purdue.edu).

 doi:10.1139/S07-051 

public health and environment in the wake of natural disasters.

To prevent these undesirable impacts, government agencies around the world have established strict rules and standards for dead animal disposal. For example, in Ontario, Canada, livestock producers must dispose of dead animals within 48 h of death (Ontario Ministry of Food and Agriculture 2001). In Minnesota, Texas, and Indiana, dead animal carcasses must be properly disposed of within 24 h of death (Morse 2001; Texas Natural Resources Conservation Service and Texas State Soil and Water Conservation Board 2002; Indiana State Board of Animal Health 2002).

At the beginning of the 20th century, the rendering system emerged initially for animal byproduct feed sources and secondly for carcass conversion. Besides animal protein and tallow production, the North American rendering industry has played a major role in conversion of perishable livestock materials of different species into valuable ingredients for manufacturing soaps, paints and varnishes, cosmetics, explosives, toothpaste, pharmaceuticals, leather, textiles, and lubricants and, more importantly, maintaining a clean environment. In 2005, the US rendering industry produced about 1.65 million tons of inedible tallow, usually produced from farm animal mortalities (National Renderers Association, Inc. 2006). A vast number of nutrient-rich and flavorful ingredients that result from the rendering process serve not only livestock and poultry production, but also the pet food industry for rations that maintain healthy companion animals.

The number of US rendering plants declined from 990 in 1978 to approximately 331 in 1992 (Singeltary 2000). The decline of roughly 50 operations per year was attributed to several factors, including changes in technology, greater use of less expensive plant proteins to replace animal proteins in animal rations, emergence of knowledge about resistant proteins (prions) in rendering products, and changes in slaughter industry practices. On the other hand, the older and more resource intensive batch-rendering processes were quickly being replaced by more efficient continuous-processing technologies. The new, more efficient, larger continuous rendering plants replaced local suppliers of rendered materials. They began to out-compete other less-efficient renderers, not only for customers, but also for the raw material.

Though the recovered protein meal and fats can be used in animal and other industries, there are significant risks associated with these products. Most importantly, the prions responsible for bovine spongiform encephalopathy (BSE, commonly known as "mad cow disease") are highly resistant to rendering conditions. Prion diseases are usually lethal diseases affecting the nervous system of cattle and other ruminants, characterized by twitching, intense itching, excessive thirst, emaciation, weakness, and finally paralysis. Scrapie in sheep and chronic wasting disease in cervids are other examples of prion diseases. To prevent any risk associated with animal feed, the US Food and Drug Administration (FDA) set up strict rules for using dead animals as raw materials for production of animal feed, which will be discussed later.

## Principles of carcass rendering

The concept of rendering is the heating or cooking of carcass materials (with complex or simple mixtures of proteins, minerals, and fatty substances) to liquefy the fat and break down membranes or other structures that may hold the fat (Romans et al. 2001). Modern carcass rendering is a process of using high temperature and pressure to convert a variety of highly perishable protein and fat materials including condemned, fallen, culled, and experimental animals with little or no value into safe, nutritional, and economically valuable products (Prokop 1996; Romans et al. 2001).

Generally, the rendering process is accomplished by receiving raw materials followed by removing undesirable parts, cutting, mixing, sometimes preheating, cooking, and separating fat and protein materials. Then the concentrated protein is dried and ground. Further refining of gases, odors, and wastewater (generated by the cooking process) is also required in most cases.

Rendering plants that employ "inedible rendering" processes convert the fat, protein, and keratin (hoof and horn) materials found in dead carcasses into inedible tallow, carcass meal, and fertilizer, respectively. In these plants the rendering process is accomplished by receiving raw materials followed by removing undesirable materials (such as ferrous metals) by passing through metal detectors or carcass parts by cutting, mixing, sometimes preheating, cooking, and separating fat and protein materials. The hide is not usually removed from hogs and small animals, but the hair of such animals should have been removed before washing and cleaning. After preparation processes, the following processes will occur under a conventional rendering system:

- Under atmospheric pressure, ground carcass material entering the cookers with maximum particle size of 40 mm, is heated up to the maximum temperature range of 120–140 °C (248–284 °F) for the average cooking time of about 3.5 h (Expert Group on Animal Feeding Stuffs 1996).
- In some plants the load is discharged once the maximum temperature is reached; in others there may be a holding time of up to 20 min.
- On discharge, the "free-run" fat is drained off; and the residual impure "greaves" (a high-protein solid residue from the cooking process) are removed for pressing and (or) centrifugation to refine and remove the fat and protein materials (Auvermann et al. 2004).
- The remaining greaves (mainly protein material) are dried and subsequently ground to produce meat and bone meal (MBM) or sold as greaves to other renderers for further processing (Auvermann et al. 2004).
- High intensity odor emissions, which result from heated materials on the "percolating pan" and the screw presses, are condensed. This condensing is followed by chemical scrubbing or incineration (afterburners) and (or) a biofiltration for non-condensable odors.

Solvent extraction was a preferred method for extracting more tallow from greaves from about 1950 to 1970. Its extra cost was justified by the fact that the animal feed industry desired MBM with fat content of only 1 to 5%; and the price of tallow increased beyond that of MBM (United Kingdom Department of Environment, Food and Rural Affairs (UKDEFRA) 2000). However, after 1970 animal-feed manufacturers began to produce higher-fat feeds (about 10 to 12% fat). The solvent-extraction process eventually fell out of favor, mainly because of its cost and its risk of explosion (Arnold 2002).

## Factors affecting the carcass rendering processes

Factors such as time, temperature, pressure, particle sizes, liquid levels, and speed of the rotor in cylindrical tanks directly impact the quality and quantity of finished rendered products (Prokop 1996). Other factors such as electrical loads on certain equipment, control valve settings, and equipment on or off status are considered indirect parameters. In modern rendering operations, computerized systems monitor and provide instantaneous indications of all of the above. Key factors of time, temperature, pressure, and particle size will be discussed herein.

### (*A*) Time and temperature

As the pressure and temperature increase, the time to complete the rendering process decreases. For example, the same material that requires 3.5 h at a pressure of 1 bar and a temperature of 125 °C (257 °F) may only require 35 min at 2 bars and 141 °C (286 °F) (Expert Group on Animal Feeding Stuffs 1996). The cooking time depends on the temperature, air pressure, type of rendering system (wet or dry, batch or continuous) used, particle size and chemical composition of carcass materials. If a dead animal is high in fat and low in moisture, its tallow in the material will melt out of the solid at around 45–50 °C (113–122 °F). Once the material reaches 100 °C (212 °F), free moisture is driven off and the solid residue cooks very quickly, virtually frying in the hot tallow (UKDEFRA 2000). On the other hand, some carcass by-products such as offal, which are higher in moisture and lower in fat, will take longer to render at a higher temperature. As a practical matter, most renderers choose maximum temperatures below 140 °C (284 °F) and adjust processing times. At these temperatures vitamins and trace elements in the solids are not greatly affected, but solids are sufficiently crisped to facilitate grinding. Renderers of low-quality material can afford to use higher temperatures.

The conventional rendering process does not inactivate prion proteins; but it can reduce their infectivity. Prions are completely inactivated when the rendered materials are cooked at 132 °C (270 °F) around 3 bar (45 psi) for 4.5 h (Taylor 2000).

### (*B*) Air pressure

Air pressure inside the rendering system has an important impact on the cooking temperature and as a result on the quality of outgoing products.

While increasing pressure and temperature in the cooking process reduces the potential BSE infectivity of MBM, it likely also decreases the nutritional value of MBM. Shirley and Parsons (2000) studied the effects of different rendering pressures of 0, 2, and 4 bar (0, 30, and 60 psi) on amino acid digestibility in meat and bone meal, and on the deactivation of the BSE agent within MBM. They concluded that increasing pressure during the rendering process, even for short time periods (i.e., 20 min), reduced the content of cysteine and lysine in MBM, and the true digestibility of these two amino acids (AA) was also significantly decreased. The digestibility of cysteine was observed to be 65, 50, and 15% at 0, 2, and 4 bar, respectively; and the digestibility of lysine was observed to be 76, 68, and 41% at 0, 2, and 4 bar, respectively (Shirley and Parsons 2000). These results showed that applying high pressure without increasing temperature will break the prion molecules but reduces the content or digestibility of the amino acids in the meal.

Pressure also affects separation processes to some extent. Clottey (1985) indicated that lowering the pressure at the end of the heating time, and simultaneously allowing the tank to cool for 40 to 45 min, will help to gravitate the heavier material to the bottom. Water will be collected above this in a middle layer, and the fat rises to the top.

### (*C*) Particle size

The particle size of carcass material has a considerable effect on its core temperature during cooking, inactivation and material denaturizing processes. To inactivate the BSE-causing prions and the agents of scrapie in a continuous rendering system and reach temperatures above 133 °C in 20 min, all mammalian animal waste must have a maximum particle size of 50 mm (European Community 1999). These conditions are somewhat different in batch rendering. The particle size of raw materials (especially non-desiccated) entering batch systems should be a minimum of 30 mm and a maximum of 50 mm in 2 dimensions (European Community 1999). The rate of heat penetration is directly related to the particle size of rendering feedstocks.

## Logistical components in rendering plants

Raw materials, transportation and storage facility, energy, trained personnel and equipment are essential logistic components for producing safe and marketable rendering products in rendering plants (Meeker 2006).

### (*A*) Raw materials

Different carcasses that might be used by independent renderers include (*a*) cattle, pigs, goats, sheep, poultry and all other species kept for agricultural production that died on the farm (due to normal or disaster situation) but were not slaughtered for human consumption, as well as stillborns and fetuses; (*b*) dead animals not referred to above but that are killed in the context of disease-control measures; and (*c*) farm animals that have died in transportation. Some of the carcasses and their by-products are high-risk materials and must be either processed in an approved rendering plant under official veterinary surveillance to be incorporated into animal feed, or disposed of by burning or burial methods (European Community 1999).

Because of the consequent health implications of feeding meal protein to animals, the FDA has banned feeding of ruminants with meat meal proteins obtained from rendering certain species of animals (mainly cattle, goats, sheep, and farm raised deer or elk) to prevent transmission of transmissible spongiform encephalopathy (TSE) in ruminant animals (Bern 2002). However, according to the 1997 FDA “feed rule”, feeding porcine and equine protein meal to cattle is allowable (they are specifically exempt). Also, ruminant protein meal is allowed to be used for swine feeds, as is protein meal of any origin (FDA 2005). It should be pointed out that alkaline hydrolysis has been proposed as an alternative method to rendering that is known to destroy prions (Kaye 2003). This method has been used recently to dispose of a quarantined herd of BSE infected sheep by USDA's National Animal Disease Center.

No restriction has been made on feeding ruminant animals with meat and bone meal obtained from rendering non-ruminants such as poultry. The specific risk materials proposed to be banned included (1) the brain and spinal cord from cattle 30 months and older that are inspected and passed for human consumption, (2) the brain and spinal cord from cattle of any age not inspected and passed for human consumption, and (3) the entire carcass of cattle not inspected and passed for human consumption if the brains and spinal cords have not been removed. Based on the "proposed rule" of the FDA, on 6 October 2005, using tallow containing more than 0.15% insoluble impurities will be also banned from all animal feed if such tallow is derived from the proposed prohibited materials. The FDA is currently reviewing the comments submitted and has not taken any further action (Hamilton 2006).

The TSE prions are responsible for several neurodegenerative diseases in humans and animals. The current US ban on feeding of ruminant proteins to other ruminants includes (1) a ban on importation of ruminants and ruminant products from countries with BSE, (2) ruminant feeding restrictions to prevent the amplification and spread of the infective agent in the event BSE occurs in our domestic cattle, and (3) a ban on withholding the specified bovine offal (SBO) from human consumption and careful surveillance of BSE agents and their spread throughout the world.

The quality of the carcass influences the protein content and total bacteria counts in the final products (dry meal). Because of the rapid putrefaction of dead-animal bodies, Clottey (1985) emphasized that only recently deceased animals can be used for rendering; and use of fallen animals in late stages of decomposition should be avoided. Cleaning and hide removal of decomposed carcasses are very difficult, and the fat and protein resulting from such carcasses is generally of poor quality. In the case of a disaster, the decayed dead animals without entrails along with dumped paunches should be segregated and hashed, respectively, prior to washing. Hoofs are not routinely removed before rendering. They either are ground up and become a very small portion of non-digestible material, or screened off after cooking and re-cooked under pressure to make their protein digestible.

The term "meat and bone meal" (MBM) is defined as a meal produced from red meat animals and excludes meal produced from poultry (European Commission 2003). According to Animal By-Products Regulations Northern Ireland (2003), the "meat and bone meal" or "mammalian meat and bone meal" means mammalian protein derived from the whole or part of any dead mammal by rendering, with the heat treatment to at least 140 °C for 30 min at 3 bars pressure. In the same document, "protein" means any proteinaceous material that is derived from a carcass (but does not include milk or any milk product; dicalcium bone phosphate; dried plasma or any other blood product; gelatin; or amino acids produced from hides and skins). The MBM in the United States is defined as a multiple source of protein derived from the processing of animal carcasses (Zamzow 2003).

Livestock mortalities are a tremendous source of organic matter. A typical fresh carcass contains 32% dry matter. The protein, fat, and ash contents of the dry matter are 52%, 41%, and 6%, respectively. The protein and fat contents of different carcasses (dead stock, whole animal), respectively, range from 22% to 28% and 10% to 12%, and the fat contents of sheep and hog carcasses are about 22% and 30%, respectively (United States Environmental Protection Agency (2002). These proportions are approximate and vary slightly for each type of livestock. Water, a major component of the live weight of the animal, varies between 70% and 80%, and is about 65% for carcass byproducts (European Commission 2003).

In the presence of moisture and suitable temperatures, bacteria are primarily responsible for putrefaction of proteinaceous matter, thus making it unsafe and unpalatable for use in livestock feed. Fat, on the other hand, becomes rancid by chemical oxidation (Kumar 1989). The compositional differences between species result in different optimal processing conditions. For example, under comparable conditions, the wastewater generated by rendering hog carcasses may require more separation to remove all the fat as compared to wastewater generated by rendering cattle carcasses.

### (*B*) Transportation and storage of carcasses

Farm mortalities are usually transported either by farm trucks, in an effort to reduce expenses, or by the renderers' trucks. However, transporting mortalities in farm trucks is illegal in some states. As of late 2005, the customary charge for hauling carcasses in tractor-trailers ("semis") was US$2.00 per mile in Colorado (Colorado Governor's Office of Energy Management and Conservation (GOEMC) 2003), which would be a necessary expense in the event of a large number of mortalities. In any case, the trucks should be covered and sanitized before loading on the farm and after unloading in the rendering plants. Refrigerated, insulated trucks are preferred. Ideally, animal collection areas should be located near access roads so that rendering trucks may maintain a minimum setback from farm facilities and fixed traffic areas. Similarly, separate traffic lanes to collection areas for rendering trucks should be maintained if possible to prevent cross-contamination of other farm trucks or equipment.

When the quantity of carcasses received exceeds the processing capacity of a rendering plant, it is necessary to store the carcasses as a surplus of raw material. According to Alberta Agriculture and Rural Development (2002), carcasses requiring storage for more than 48 h after death may be stored (*a*) in an enclosed, refrigerated structure (0–5 °C, or 32–41 °F), (*b*) outside during winter months when the ambient temperatures is low enough to maintain the carcasses in a frozen state, and (*c*) in a freezer unit.

Some animal production operations use special, low-temperature storage bins, to refrigerate or freeze carcasses until they can be taken to a rendering facility. Using cold storage for carcasses not only reduces chemical and microbial activities and their associated odors, it also keeps them out of sight and prevents scavenging. Furthermore, carcass storage areas and the surrounding vicinity should be located in areas that will minimize the spread of disease and will be thoroughly cleaned before and after use. Wastewater and rainfall runoff should be prevented from entering streams or other surface waters.

To control the transmission of infectious diseases, with special emphasis on anthrax, some countries have defined legal requirements for collection, storage, and rendering process of fallen or "stamped out" animals and put the whole system under veterinary supervision (Scientific Steering Committee Working Group 1999).

**(*C*) Electrical and heat energy**

Simply put, tremendous quantities of energy are consumed by the rendering process to release fat, evaporate water, and sterilize the raw materials. Due to the mixture of fat and water in the rendering process, the heat transfer coefficient varies, and therefore the required heat energy varies as well. According to Herbert and Norgate (1971), the heat transfer coefficients of rendering systems decline rapidly from 170 to 70 BTU/(ft$^2$·h·°F). They explained that as water is evaporated during the rendering process, a phase inversion occurs from (*a*) tallow in water dispersion, initially present in the cooker, to (*b*) water in tallow dispersion. A minimum value of heat transfer coefficients is reached when all water droplets have disappeared and remaining water is present only as "bound water" in the protein particles. Maintaining some free water of mixed material during rendering to keep high heat transfer coefficients became the basis for changing from high temperature rendering (HTR) to the low temperature rendering (LTR) system.

Kodfodfabrikken Ostjyden or KOFO (1986) introduced a new concept of "wet pressing," which was developed and tested in a pilot experiment station of the Danish Meat Research Institute in Roskilde. This process was based on the discovery that it is possible to separate nearly all fat, and more than 60% of the water, from the solids of the raw materials by means of a pressing process at low temperature (50–60 °C or 122–140 °F, just above the melting point of the animal fat). Wet pressing reduces the energy consumption for water–oil separation by 53%, requiring only 35 kg oil per metric ton of raw materials as compared to 75 kg oil per metric ton of raw materials for the standard process. As a further advantage, no organic solvents are needed for wet pressing, which separates the materials into a solid phase with low fat content and a liquid phase containing more than 60% of the total water and nearly all of the fat. The solid phase is dried in an indirectly heated drier. The fat from the fluid phase is removed in a "tricanter," and 80%–90% of the water in the resulting liquid phase is removed in a three-stage vacuum evaporator using waste heat from the driers. Not only does this system produce protein meal and tallow with higher quality and quantity compared to the HTR system; but it considerably saves on the amount of energy used. Fernando (1984) compared HTR to LTR and concluded that LTR systems required around 0.45 kg (1 lb) of steam/1 kg (2.2 lb) of raw material, whereas HTR required around 1.0 kg (2.2 lb) of steam per kg (2.2 lb) of raw material. That is, under equal conditions the consumption of steam in HTR is twice that of LTR systems.

**(*D*) Processing equipment**

The machinery and equipment required for carcass rendering depend on the specific rendering option, the input weight capacity (whole carcass or carcass parts), the degree of automation, and the extent of end product refining and storage. In batch systems, only minimal equipment is required (sometimes only one vessel) and flow (addition and removal) of materials is static. In a continuous system, materials flow in a steady stream, therefore pre- and post-rendering equipment is needed in addition to the main rendering unit.

Although traditional, batch carcass-rendering systems include a vessel in which most of the rendering process occurs, dry and continuous carcass-rendering systems require auxiliary equipment, such as a pre-breaker, hasher and washer, metal detector, screw conveyor, fat refining system, and centrifugal extractor. Usually this equipment is installed along with the rendering cooker mainly for pre-rendering and post-rendering processes. Although optional for animal by-products (like offal), use of such pre-rendering equipment is necessary for rendering whole carcasses because of the size and nature of the materials.

To protect the original quality of raw materials by minimizing rendering time and using the lowest possible sterilization temperature, carcass materials are crushed and mixed before rendering using equipment such as crushers, mixers, mills, screeners, decanter centrifuges, driers, and millers.

Size reducers, cookers, presses, evaporators, and centrifuges are the equipment types most likely to be used on a continuous basis. Surge bins, along with variable-speed drives between different units of operation, provide a relatively even flow and control of material through the system. The most common pre-processing equipment types are as follows:

***Size reducers or crushers***

A "crusher" or pre-breaker is used to break carcasses prior to passing through size reduction equipment and subsequently entering a continuous pre-heater or cooker–drier. A pre-breaker contains "anvils" in place of knives that rotate between parallel bars at the bottom of the pre-breaker to break the large materials. The pre-breaker crushes carcasses (meat and bones) to bring the product to a uniform size. Because raw material is sent to the crushing machine and the output is removed in a constant stream, these types of equipment are inherently continuous. According to Ockerman and Hansen (2000) the cutting edges of rotating knives (parallel to the surface of the rotor) are 7–10 cm (2.7–3.9 in) wide and protrude only a few centimetres from the rotor they are mounted on. Also the rotor length on a large pre-breaker will be less than a metre, yet the rotor requires a 150 kW (200 hp) or larger motor to operate. Since the volume of bone pieces should be no more than 10 cm$^3$, at most, their width and thickness should be around 1–2 cm (0.4–0.8 in). The capacity of size reducing equipment must be adequate to maintain a steady throughput of pre-ground material through the rendering plant.

Further size reduction is accomplished with rotating hammer devices called "hammer mills," grinders with rotating knives that operate by impacting and pinching actions to force crushed materials through a retaining screen. As the rotor turns, hammer-heads swing and beat and drive the materials into a breaker plate and through a retention screen. Depending on the nature of the raw materials, cutters or bars may be used instead of hammers.

Other pieces of equipment that may be used for carcass pre-processing include hasher–washer units, metal detectors, and screw conveyors. The combined hasher and washer chops and washes carcass material, and, in some cases, soft tissue such as stomachs and intestines. A metal sorter detects and removes metal (commonly including ear tags, magnets, consumed metals, buckshot, and broken needles) from crushed raw materials. Finally, a screw conveyor transports crushed raw material to the pre-cooker or cooker.

### *Cooking system*

An integral part of any continuous rendering system (wet or dry) is the cooker, comprised of sections of pre-heater and heater. Cookers are constructed in a cylindrical form through which the ground carcass material is conveyed by means of a rotor or agitator in the form of a screw conveyer. For efficient heat energy use and transfer, most cylinders and agitators are steam heated. Various steam jacket designs have been used; if the cooking cylinder is too long, the steam jacket can be divided into sections. Each section is provided with devices for individual condensate discharge to regulate the steam supply and thus maintain the proper temperature for each section. Like some heating equipment used in food processing, the hollow agitator or rotor is part of the cooking system. According to Ockerman and Hansen (2000), the cooker has a shaft pipe to which hollow flights are welded.

A combination of pre-heater, twin screw press, and waste heat evaporator will have a considerable effect on energy savings. As Kaarstad (1995) reported, by introducing this equipment into an existing plant, rendering capacity can be increased by 60%–70% without changing the cooker or boiler. Several factors, such as loading rate, temperature, pressure, and quantity of steam used, control the average cooking temperature and retention time of the materials inside the rendering tank.

Various names such as "renderer," "rendering vessel," "rendering melter," or "rendering cooker" are given to the principal piece of equipment used in the rendering process. According to Kumar (1989), the conventional cooker is a horizontal, steam-jacketed vessel made up of two concentric cylindrical shells of milled steel (covered with end plates) and fitted with an agitator. The mixer is made of a shaft and attached solid or hollow blades. Along the horizontal central axis of the vessel, the shaft passes through the two end plates and is supported by heavy-duty bearings on either side. The blades are designed to continuously scrape the inner surface of the cooker, thus preventing scorching and overcooking. A manhole at the top of the cooker is used for maintenance and repairs. The vessel is equipped with an entrance gate for crushed raw material. Valve and discharge gates are fitted at one of the end plates. A suitable gear drive box and motor for the agitation are mounted on the other end plate of the vessel. Depending on the required rendering capacity, dry rendering cookers are manufactured in various sizes, but most are generally manufactured to withstand a working steam pressure of 7 bars or 100 psi (Kumar 1989). In dry rendering systems (batch or continuous), steam is the main heating source which is injected into the steam-jacket layers; in wet rendering, by contrast, steam is injected directly into the raw materials.

Electrical instruments such as starters and reversing switches, as well as fittings such as pressure gauges (for the steam jacket and internal shell), safety valves, vapor line valves, steam condensate discharge valves and water jet condensers are provided at a convenient place for operation and monitoring.

### *Pressing units*

Pressing units may be used to press (*a*) the input materials going to the cooker or (*b*) the output products from the cooking process. Typically, screw presses with one or two rotating elements operate in a continuous manner. Ockerman and Hansen (2000) reported that wet output material is fed into an inlet chute (a sloping channel) at the end of the press and fills the free space between the screw flights and the strainer plates. When the materials roll along with press screws, the empty gap cross section (between the screws) will decrease. The materials are subjected to steadily increasing pressure that causes an efficient squeezing of the wet material. The liquid materials (mainly water and fat) escape through the perforated strainer plates around the screws and are colleted in a tray equipped with a discharge pipe. The solid or pressed, dewatered, and defatted material is discharged axially at the end of the press and falls down onto a suitable conveying system.

The characteristics of the material to be pressed have significant effects on the throughput and volume ratio of screw presses. Ockerman and Hansen (2000) indicated that for moist and soft materials, there is generally a quick initial compression followed by a more gradual compression rate during the subsequent pressing.

The performance of single-screw presses is very similar to double-screw presses, with a reduction of volume as material moves down the screw (due to the change in pitch and diameter of flights). It squeezes the solids and thus results in dewatering along with defatting. Chokes may be positioned according to the main motor load (Ockerman and Hansen 2000).

### *Evaporators*

The liquid mixtures coming from the rendering process contain considerable water, which can be removed economically using efficient evaporators. Water evaporation is an energy-intensive process; low-pressure evaporators are more efficient than open kettles or other systems operating at atmospheric pressure. At a pressure of 0.5 bar (almost 0.5 atmosphere), water boils at 81.5 °C (179 °F), therefore the use of low pressure evaporators can produce "waste" vapors that can be used as a heat source for the evaporators.

Increasing the efficiency of evaporators has been accomplished in several ways. One is using the condensed live steam after leaving the jacket of cooker–drier as a heat source to drive the evaporator. Another technique is to use multiple-effect (stage) evaporators. Ockerman and Hansen (2000) reported that addition of every stage to the evaporator will nearly double the efficiency of evaporation, meaning twice as much liquid is evaporated per quantity of live steam or waste vapor consumed in the steam jacket. In a multiple-effect evaporator system, vapor from an effect is condensed in the steam jacket of a succeeding effect. Increasing the heat transfer surface has been successfully practiced in modern evaporators. Instead of simple jacketing of the boiling chamber, vertical tube bundles can be used with the heating medium on the outside of the tubes and the product boiling on the inside.

In the heat tubing evaporators, the product is either moved downward through the tubes (falling film), or upward through the tubes (rising film). The main purpose is to feed the evaporator and make a thin film of product and a proper flow rate, thus minimizing the overall heat resistance coefficient inside the tubes. This results in high heat transfer coefficients; and a significant amount of water can be boiled off within a relatively small area of equipment.

### *Solid–liquid separators*

Although tallow, water, and solid protein stay at three different levels in the rendering tank, each fraction has considerable impurities. Separation is achieved using both simple and sophisticated separation tools such as decanters, strainers and centrifuges. Ockerman and Hansen (2000) specified three purposes of decanters for clarification of rendered products, namely (1) primary clarification of tallow, (2) dewatering of coagulated blood solids, and (3) dewatering of solids from effluent. They recommended using decanters for removal of solids from slurry containing 30%–40% solids. A drum rotating at 3000–4000 rpm (revolutions per minute) separates the liquid phase, which remains close to the axis of rotation of the machine, from the solid content or heavier phase, which goes to the outside of the rotating drum. The solids are transported along the shell to the conical section with the aid of a screw and are discharged.

### *High speed separators*

Based on the application of centrifugal force, effective separation of tallow, water, and solid protein can be achieved. Various types of centrifugal separators, such as decanters and disc-type high-speed separators are used in the rendering industry. Cracklings from the percolator are loaded into a perforated basket covered with a filter cloth and fitted inside a centrifugal fat extractor. As Kumar (1989) indicated, centrifugal fat extractor (an ordinary centrifuge) runs at a high speed of 600 to 1000 rpm, and provides for passing steam through the loaded cracklings to keep the fat in a molten state. When the centrifuge is in operation, it separates fat and moisture from the cracklings by centrifugal force, and the fat is collected in a tallow sump.

In a relatively new type of decanting or desludging centrifuge, a solid bowl (drum) rotates horizontally up to 25 rpm faster than a screw conveyor that is inside and rotates in the same direction (Fellow 2000). This causes the solid protein to be conveyed to one end of the centrifuge that has smaller diameter and the mixture of water and liquid fat are discharged to the other end of the equipment.

Today, high-speed disc centrifuges are commonly used as they are well suited to separate and purify the tallow from water. Separation takes place in the disc stack of the centrifuge. While the lighter phase, or clarified and purified tallow, is discharged axially at the top of the centrifuge, the solids part accumulates in the widest part of the bowl and is discharged intermittently by opening a discharge slit (Fenton 1984; Fellow 2000).

### *Driers*

The solid protein materials leaving the rendering tank are the substances that contain the most moisture. That is, dry-rendering cookers are not capable of releasing the extra water of carcass meal, which requires subsequent driers. Different drying equipment has been used to dehydrate these wet materials. The Dupps Company (2003) built the Ring Drier, which was energy saving. In this system, the heat energy of exhausting air and dried product were recovered more efficiently than in conventional driers. According to Ockerman and Hansen (2000), a major advantage of the Ring Drier was recycling of 60% of the heated air back through the drier, which helped to make drying of a high-moisture substance, such as carcass protein or blood, economically feasible.

### *Odor control equipment*

Odor control equipment systems include condensers, scrubbers, afterburners (incinerator), and biofilters.

*Condensers* — Since carcass material boils off during cooking and to some extent during drying processes, these steps generate steam with the strongest odors. Condenser units wash the cooking steam with cold water and then liquefy all condensable materials (mainly steam and water-soluble odorous chemical compounds). According to Fernando (1995), this process reduces the temperature of the non-condensable substances to around 35–40 °C (95–104 °F) and transfers the heat. The cooling water removes up to 90% of odors and recovers heat energy from the cooking steam.

*Scrubbers* — Although the condensing unit absorbs water soluble odors, it is not capable of absorbing chemical compounds, which are released from the condenser. To address this problem, two chemical scrubbing systems have been used. The venturi type scrubber is used for facilities generating low-intensity odors, and the packed-bed scrubber with various chemicals is used for facilities generating high-intensity odors.

Depending on the chemical composition of odors produced, different chemical solutions can be utilized. To prevent the generation of odorous chlorinated compounds from ammonia and amine materials during the rendering process, an acid pre-wash (such as dilute sulfuric acid, pH 1.6) is used in the first-stage scrubber (Fernando 1995). Then, a second stage scrubbing is accomplished with strong alkaline (pH 12–13) sodium hypochlorite with considerable excess of available chlorine. Alternatively, acidic sodium hypochlorite with pH = 5.0 may be used in the first stage, and sodium hydrogen sulfite and sodium hydroxide in sequential order can be used in the second stage to remove aldehydes. A condenser followed by a two-stage scrubbing unit can provide up to 99% odor reduction.

*Afterburners* — An afterburner is used to burn the gases released from the exhaust side of a scrubber. Afterburning parameters include the residence time and minimum burning temperature. According to Fernando (1995), the minimum requirements for complete burning are a residence time of 0.5 s and a temperature of 750 °C. The test on the composition of the gases released from the exhaust of the afterburner showed that it was completely free of hydrogen sulphide, mercaptans, and amines. Since this equipment requires a high burning temperature, fuel costs would be high unless the air is preheated by the use of the final exhaust gases. Hot water may be used elsewhere to conserve energy.

*Biofilters* — Animal rendering gas emissions can have an odor concentration of up to one million odor units per cubic metre of gas volume ($OU/m^3$) that are objectionable and must therefore be controlled (Luo and van Oostrom 1997). A biofilter is a system that releases odorous gases (including air) underground and passes them through a damp bed of organic material such as woodchips, bark, peat moss, rice hulls, compost, or a combination of those materials. Gases are then digested to non-odorous compounds by aerobic microbial activity (USEPA 2002). The sub-grade plenum is filled with gravel to form a bed and the organic material is placed on the top of the gravel. Luo and Lindsey (2006) used biofilters at a rendering plant that contained different sizes of crushed pine bark or a mixture of zeolite and crushed bark to treat the exhaust gases from direct-fired meal dryers. While odor concentration of the exhausting air ranged between 50 000 and 307 200 OU $/m^3$, they could increase the biofilter odor-removal efficiency up to 99% at various influent odor concentrations and air loading rates and there was no obvious deterioration in performance of these biofilters.

Besides the nature of gas absorbents, the efficiency of a biofilter depends strongly on the air humidity, oxygen content, microbial load, uniform distribution of gases through the bed, bed permeability, effectiveness of the liquid drainage system under the bed, and gas temperature entering the bed. Fernando (1995) explained that the rate of gas passing through the biofilters depends on the strength of the odorants in the gas and varies between 10 and 120 $m^3/(h \cdot m^2)$ of the filter area, and it can be matched for different gases (mixtures of air and odors).

## Carcass rendering options

In spite of the variation in investment and energy costs, different rendering systems, including dry rendering, batch rendering, and continuous dry rendering work well for small (poultry), medium (swine, sheep, calves), and large sized (cattle and horse) mortalities. While wet rendering can produce good-quality tallow, it is no longer used because of its high energy consumption and loss of up to 25% of meal in wastewater (Ockerman and Hansen 2000). Most US plants use a continuous, dry rendering system. New techniques called press dewatering and wet pressing methods have shown potential for future carcass rendering.

### (*A*) Dry vs wet rendering

Dry rendering is a newer method than wet rendering. In this system, heat generated by steam condensation is applied to the jacket and agitator blades to ensure uniform heat distribution and shorten the time necessary for cooking the carcass materials. According to Kumar (1989), during the cooking time (which ranges from 45 min to 1.5 h), the jacket pressure is normally maintained around 4.2 bar (60 $lb/in^2$), and the internal shell pressure around 2.8 bar (40 $lb/in^2$).

Steam pressure and continuous agitation break down the fat cells, disintegrate the material, and convert the moisture in the carcasses to steam. The cooker is brought to a desirable steam pressure at which it is maintained for a period of time. Through a sampling valve, the cooked material is monitored periodically to determine when the cooking process is complete. The slight grittiness and fibrous nature of the cracklings provide indications of the progress of the cooking process. Slippery cracklings indicate under-cooking, while the disappearance of fiber indicates over-cooking (Kumar 1989).

After cooking the crushed carcasses, steam generated inside the cooker is removed through a steam release valve. Since the discharge of remaining sticky and viscous liquid in a dry rendering process is not easy, it is dried inside the vessel, contributing to the higher yield of meat meal observed for dry rendering as compared to a wet rendering process.

The wet rendering method uses direct pressurized steam to cook carcasses along with grinding in large closed tanks. Dry rendering cooks the ground carcasses indirectly in their own fat while contained in a horizontal, steam-jacketed cylindrical vessel equipped with an agitator. In each case, the final temperature of the cooker (120–135 °C [250–275 °F]) destroys harmful pathogens and produces usable end products such as meat, feather, bone, and blood meal that can be used in animal feeds (Franco and Swanson 1996; Environment Protection Authority of Australia or EPAA 2002). Dry rendering can be accomplished in batch, semi-continuous and continuous systems.

### (*B*) Batch rendering

Usually in batch rendering of inedible foodstuffs, multiple cookers are used and the final solids, called cracklings, are ground to produce protein meal. By opening the steam in the jacketed vessel, the fat and protein mixture is indirectly heated and boiled for about 15 min and then a pump transfers the mixture to another vessel. During the settling process, the heavy portion of the mixture (water and coagulated protein) decants to the bottom of the fat portion in the vessel. The proteinaceous matter and water are removed through a draw-off valve. However, fat collected in the tallow tank contains considerable suspended protein material and water and should be refined to remove these impurities. To separate suspended proteins from the fat material, Kumar (1989) recommended spraying saturated brine (around 20%–25% salt content at the rate of 10% *v*/*v* of fat) on the fat surface and boiling the fat solution for 10 min. The salt (brine) breaks the water–fat emulsion with a corresponding increase in the difference in specific gravity between the fat and suspended matter. In this process most of the coagulated protein, along with the brine, will settle to the bottom while clear fat floats to the top. The suspended matter is then easily removed through a draw-off valve. The remaining water and proteins can be separated from the fat solution by high speed centrifugation. The fat is centrifuged or filtered to remove any remaining protein solids and is then stored in a tank. Both dry and wet rendering systems may be used in a batch configuration.

**(*C*) Continuous dry rendering**

Although a variety of rendering options have been designed and operated since the early 1960s, most of them have a "continuous cooker" and use heating, separation, and cooling processes on a continuous-flow basis. The EPAA (2002) explained that in this system, all the rendering processes are done simultaneously and consecutively. It can be concluded that in most of the continuous rendering systems there is no need for manual operation and in case of constant supply of raw material, the finished product will be delivered in a steady state and constant rate. In this system more automatic control is exercised over the crushing of big particles, uniform mixing of raw material, and maintaining the required time and temperature of cooking process.

Continuous systems generally also offer greater flexibility, allowing a wider range of time and temperature combinations for cooking raw materials. Figure 1 shows that the flow diagram of a continuous dry rendering system is similar to batch rendering, but materials are added and product is removed in a continuous manner.

**(*D*) Press dewatering method**

Although under similar conditions dry rendering systems use less energy than wet rendering systems, an increased emphasis on energy conservation forced renderers to seek new rendering processes that use even less energy. A variety of methods have been suggested to use less heat and at the same time produce tallow and MBM with higher quality and quantity. In the press dewatering method suggested by Rendertech Limited (2002) the main processes are similar to continuous low temperature rendering (LTR) system, and raw materials are heated until all the carcass fat is melted. After pressurizing the mixture with a double screw press, the solid protein and liquid portions are separated. The fat layer is removed by disc centrifuge and the remaining liquid portion is evaporated. To produce the MBM, the thick liquid from the dehydrator is added to the solid protein left over on the press and the mixture is dried and sterilized.

**(*E*) Wet pressing method**

Another method of conserving heat energy is the wet pressing method. KOFO (1986) summarized the process, stating that offal and condemned animals are pre-broken (max. size 70 mm), transported to a weighing bin, and screened by metal and non-metal detectors, as well as a heavy duty electro magnet assembly specially designed and mounted on the entrance of the bin conveyor, to remove magnetic materials. The raw material, free of metal, is hashed or chopped to a size of less than 19 mm and indirectly preheated with hot water to 60 °C (140 °F) in a coagulator. After it passes a strainer screw with adjustable sized holes, it is condensed in a twin-screw press. This process divides the raw materials into two portions, a solid phase (press cake) containing 40%–50% water and 4%–7% crude fat on a dry matter basis, and a liquid phase containing fat, water, and some solids. The liquid phase is heated to 100 °C (212 °F) with live steam and passed through a 3-phase decanter (tricanter), which separates it into fat, stick water (the viscous liquid), and grax (suspended solid proteins).

The grax is returned to the coagulator, the fat is sent for refining and sterilization, and the stick water (containing 8% dry matter and 0.6% crude fat) is pumped into the 3-stage waste heat evaporator for concentration. This concentrate, containing 35% dry matter (with 8%–9% fat in dry matter), is mixed into the press cake, which is dried in a plate contact drier indirectly heated by live steam. The meal leaves the drier at no less than 110 °C (230 °F) at which temperature sterilization is accomplished. The meal has a moisture content of 5%–7% and a fat content of 7%–8%. It is transported to milling by means of a pneumatic transport system. The drier gasses pass a scrubber where the particulates are removed from the vapors and a small proportion of the vapor is condensed. The scrubber liquid heats water (90 °C or 194 °F) for the coagulator via a heat exchanger. Because lower temperatures are used in the dewatering and wet pressing, sometimes they are called LTR methods.

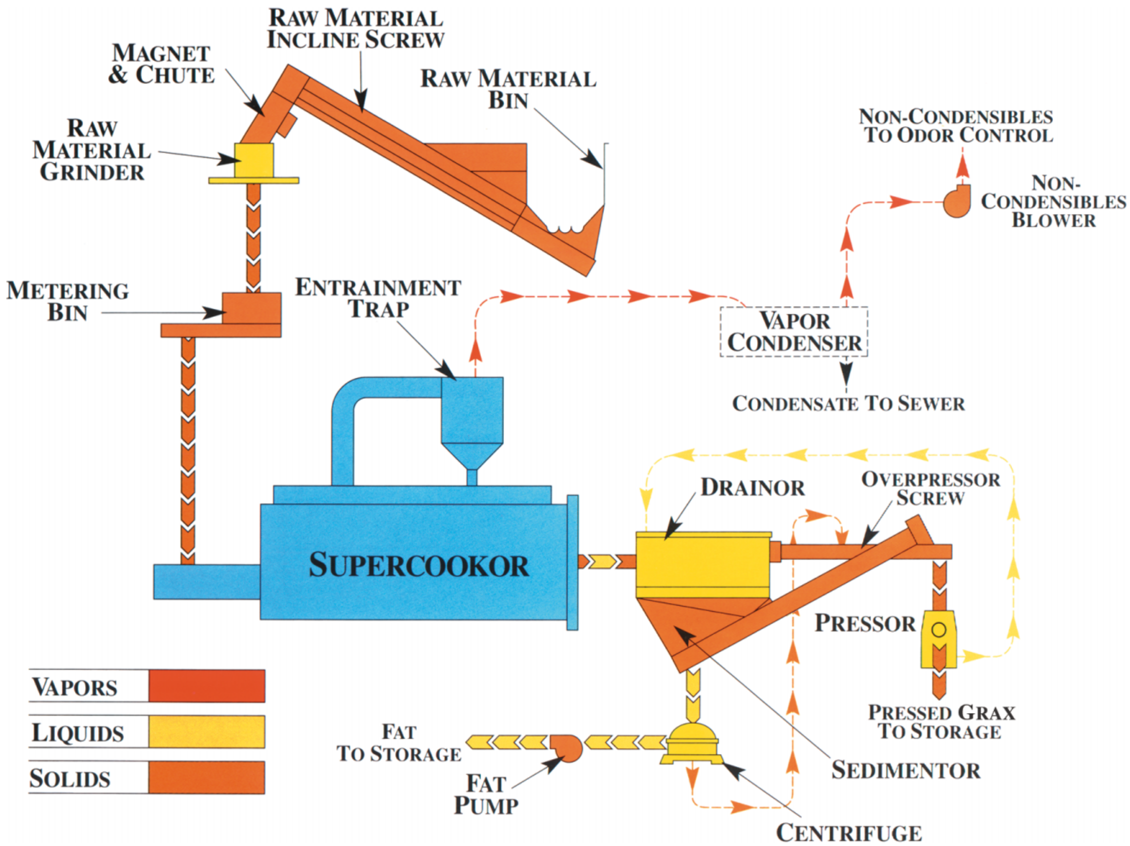
## Comparison of low versus high temperature rendering

Cooking temperature (in batch or continuous systems) makes detectable and noticeable changes in the final rendered products. Taylor (1995) indicated that low temperature rendering (LTR), especially with direct heating (wet rendering), resulted in higher chemical oxidation demand (COD) loadings in wastewater but lower odor production when compared to high temperature rendering (HTR). He mentioned that the reduction of organic materials in LTR wastewater can be achieved by adjustment of the polishing centrifuge. He also explained the concentrated wastewater of LTR, which is only 5%–10% of the total and has a large load of COD, can be treated by processes such as ammonia stripping. This option was previously regarded as too expensive for abattoir wastewater, but may be a sensible choice for the treatment of the rendering stream.

In traditional, high-temperature, dry rendering processes, water begins to boil rapidly and evaporate after the raw material temperature in the cooker reaches 100 °C (212 °F). When the temperature rises to 110–130 °C (230–266 °F), there is no free water and the meal is deep-fried in hot fat. Due to the fact that the cooker contents (batch or continuous) are subjected to temperatures above 100 °C for relatively long periods, Ockerman and Hansen (2000) emphasized using only washed raw material for rendering to remove paunch contents and other "dirt." Otherwise, the dirt color from the raw material becomes "fixed" in the tallow, and the tallow will be downgraded.

Since phase separation is carried out easily in LTR (70–100 °C [158–212 °F]), there is no need to wash the raw materials because the color of paunch contents and other dirt are not fixed in the tallow. As mentioned earlier, in the case of a good controllable LTR system and post rendering processes such as polishing the wastewater and removing the organic materials from the stick water, the final product meal will have low fat and moisture contents. Ockerman and

**Fig. 1.** Schematic diagram of machinery, equipment, and material flow in a continuous dry rendering process (Illustration courtesy of Dupps Co., Germantown, OH). Animal carcasses are received in temporary raw material bins (1) and conveyed by incline screw conveyor (2) and discharged across a magnet (3) to remove ferrous metal contaminations. A grinder (4) then reduces the raw material to a uniform particle size for better handling and improved heat transfer in the cooking step. The ground raw material is fed at a controlled rate from a metering bin (5) into a continuous cooker (6). The discharge is transported to a drainer conveyor (7) that separates liquid fat from solids, which are then conveyed by a discharge conveyor (8). In the discharge conveyor, solids from the drainer conveyor are combined with the solids discharged from the settling tank or sedimentor (10) and from the decanter-type centrifuge (11). The solids from the discharge conveyor go to the presser (9), which reduces the solids' fat content, to about 10 to 12%. Solids that bypass the screw presses go to the pressed cake conveyor for further processing into meal. The fat removed in the screw presses goes to the centrifuge (11), which separates large particles from the liquid fat and returns them to the discharge conveyor. The fat from the press fat conveyor is pumped to the fat storage (12). Water vapor exits the continuous cooker (6) through a vapor duct system that generally includes an entrainment trap to separate and return entrained particles to the continuous cooker. The vapor duct system transports the vapor stream to an air cooled condenser (13), which condenses the water vapor. Other forms of condensers, such as direct contact or indirect shell and tube units, may also be used.




Hansen (2000) also reported the fat contents of meals in HTR (usually batch dry-rendering) and LTR to be about 10%–16% and 3%–8%, respectively. Also the protein content of meal in rendering plants is affected by the heating temperature during pre-heating and main cooking processes. Fernando (1984) used raw materials composed of 60% water, 20% fat, and 20% fat-free solids (a composition typical to animal carcasses) in LTR and HTR and compared the quantity of their final products. The experiments employed a rendering capacity of approximately 10 t/h, 12 h/d, and 200 d/year. In HTR and dry rendering, the loss of protein materials was at least 2% higher than LTR. The high temperature processes produce fines that pass into tallow and are lost in the effluent from the tallow-polishing centrifuges.

## Conclusions

Carcass rendering, if done properly, results in an array of beneficial end products that can be used as animal feed, industrial chemicals, fertilizer, and biofuel. Every year millions of livestock and poultry perish due to diseases, natural causes, natural disasters or other causes before they are marketed. The following conclusions can be drawn from the information given on the principles and logistical challenges of carcass rendering:

- To minimize the environmental impacts, rendering of animal mortalities should begin within 24–48 h of death. The raw materials used by independent rendering plants include (*a*) bovine animals, pigs, goats, sheep, poultry, and all other that were kept for agricultural production and have died on the farm but were not slaughtered for human consumption, also stillborn and unborn animals; (*b*) dead animals not referred to above but those that are killed in the context of natural disasters and microbial and non-microbial diseases; and (*c*) farm animals that have died in transit without prejudice to instances of emergency slaughtering for reasons of welfare.

- To convert appropriate dead animals into animal feed, and control infectious diseases, especially anthrax and TSE, the collection, transportation, storage, and rendering process of fallen or euthanized animals (high risk materials) must be done in an approved rendering plant under official veterinary supervision and surveillance.
- Innovations in rendering processes (such as wet pressing, using multiple effect evaporators, etc) and equipment (such as using high-speed disc centrifuges, ring drier, etc) allow carcass meal and tallow to be obtained with much higher efficiency, better nutritional values, and considerably reduced energy costs.
- More than 90% of odors resulting from cooking and drying of carcass materials can be absorbed by cold water washing. Non-condensable gases or volatile organic compound (VOC) emissions emitted from the condenser may be eliminated by different scrubbers (venturi or packed bed type) with two sequential acid and alkaline wash processes. Afterburners with a residence time of 0.5 s and a temperature of 750 °C can be used to burn hydrogen sulphide, mercaptans, and amines released from the exhaust side of a scrubber. Finally, the biofilters break down the remaining gases to non-odorous compounds by aerobic microbial activity under damp conditions.
- In spite of the variation in investment and energy costs, different rendering systems (wet, dry, batch, and continuous) work well for small (poultry), medium (swine, sheep, calves), and large sized (cattle and horse) mortalities.
- Injection of live (pressurized) steam into the raw material increases the rate of temperature increase inside enclosed tanks and speeds up the process. However, it also causes overheating of nutrient materials. Wet rendering can produce good-quality tallow, but because of its high energy consumption, loss of meal (up to 25% in wastewater), increasing chemical oxygen demand (COD) in wastewater, and being a labor-intensive process, it is no longer in favor.
- Dry rendering cooks the ground carcasses indirectly in their own fat while contained in a horizontal, steam-jacketed cylindrical vessel equipped with an agitator. Dry rendering can be accomplished in batch, semi-continuous, and continuous systems.
- Continuous cookers use heating, separation, and cooling processes on a steady-state flow basis and all the rendering processes are done consecutively. More automatic control is exercised over the crushing of big particles, uniform mixing of raw material, and maintaining the required time and temperature of the cooking process. This process divides the raw materials into a solid phase (press cake) containing 40%–50% water and 4%–7% crude fat, and a liquid phase, which passes through a 3-phase decanter (tricanter) and separates it into fat, stick water (the viscous liquid), and grax (suspended solid proteins). Additionally, the continuous systems achieved a significant savings in fuel usage by the boilers and consumed less electric power for agitation as compared to equivalent batch systems. They are labor-efficient and more conducive to computerized control via centers located inside environmentally controlled rooms.
- Although capital investment for batch rendering systems is much less than continuous ones, they produce darker tallow compared to tallow from low-temperature rendering (LTR) methods (dewatering and wet pressing). In this system, the high cooking and pressing temperature produces fines that pass into the tallow and are lost in the effluent from the tallow-polishing centrifuges. Since batch rendering processes are not contained in enclosed vessels, cooked products may be re-contaminated and it is more difficult to control and keep the batch processing plants clean and tidy.
- LTR, especially with direct heating (wet rendering), resulted in higher COD loadings in wastewater but with lower odor production than high temperature rendering (HTR).
- The new process of “wet pressing” not only separated nearly all fat, and more than 60% of the water from the ground carcasses at low temperature (50–60 °C or 122–140 °F, just above the melting point of the animal fat), it optimized the energy necessary for sterilization and removal of water, thus reducing the energy consumption from 75 kg oil/metric ton raw materials in the traditional process, to approximately 35 kg oil/metric ton of raw material in the new process. This system also produces protein meal and tallow with higher quality and quantity, in comparison to the HTR.

## Acknowledgement

This material was made possible, in part, by a Cooperative Agreement from the United States Department of Agriculture’s Animal and Plant Health Inspection Service (APHIS). It may not necessarily express APHIS views.

## References

Alberta Agriculture and Rural Development. 2002. Livestock Mortality Management (Disposal). Available from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex6081 [cited 29 November 2007].

Animal By-Products Regulations of Northern Ireland. 2003. Fertilisers (Mammalian Meat and Bone Meal) (Amendment) Regulations (Northern Ireland) of 1996. Statutory Rule 1996 No. 458 Crown Copyright 1996. Available from http://www.hmso.gov.uk/sr/sr1996/Nisr_19960458_en_1.htm [cited 17 December 2003].

Arnold, T. 2002. Producing Salmonella-free. Render, The National Magazine of Rendering. 1 (Feb.), 10–12p. Available from http://www.rendermagazine.com/February2002/Salmonella-freePercent20Meal.pdf [cited 23 April 2003].

Auvermann, B., Kalbasi, A., and Ahmed, A. 2004. Rendering. Carcass Disposal: A Comprehensive Review. Carcass Disposal Working Group, USDA-APHIS Cooperative Agreement Project, National Agricultural Biosecurity Center Consortium. Kansas State University. Available from fss.k-state.edu/research/books/carcassdispfiles/PDF%20Files/CH%202%20-%20Incinertion.pdf [cited 1 November 2005]

Bern, L. 2002. FDA continues work to help prevent mad cow disease. FDA Consumer magazine. FDA/Office of Public Affairs. Available from http://www.fda.gov/fdac/features/2002/302_bse.html [cited 4 August 2004].

Clottey, J.A. 1985. Manual for the slaughter of small ruminants in developing countries. Food and Agriculture Organization of the United Nations, Rome, Italy. Available from http://www.fao.org/DOCREP/003/X6552E/X6552E00.htm [cited 14 October 2003].

Colorado Governor’s Office of Energy Management and Conservation (GOEMC). 2003. Hog mortality composting, final report.

225 E. 16th Ave., Suite 650, Denver, CO 80203. Available from http://www.state.co.us/oemc/pubs/hogs/hogmortality.pdf [cited 1 September 2003]. Also Presented and Distributed by Franklin Haywood at the Midwest Regional Carcass Disposal Conference, August 20–21, 2003. Kansas City, MO.

Environment Protection Authority of Australia (EPAA). 2002. Air emission control. Abattoirs, 59–61 Goulburn Street, Sydney, Australia. Available from http://www.epa.nsw.gov.au/mao/abattoirs.htm [cited 19 June 2003].

European Commission. 2003. Draft Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries. Integrated pollution prevention and control. Institute for prospective technological studies (Seville). Technologies for sustainable development, European IPPC Breau. Available from http://www.p2pays.org/search/pdfframe.asp?pdfurl=/ref/21/20574.pdf [cited 6 October 2003].

European Community. 1999. The risks of non conventional transmissible agents, conventional infectious agents or other hazards such as toxic substances entering the human food or animal feed chains via raw material from fallen stock and dead animals (including: ruminants, pigs, poultry, fish, wild/exotic/zoo animals, fur animals, cats, laboratory animals and fish) or via condemned materials. The Scientific Steering Committee of European Community at its meeting of 24–25 June 1999. Next2.doc. Available from http://europa.eu.int/comm/food/fs/sc/ssc/out54_en.pdf [cited 14 June 2004].

Expert Group on Animal Feeding Stuffs. 1996. Rendering in the United Kingdom. Annex 2.4. Available from http://www.mad-cow.org/~tom/render.html [cited 12 June 2003].

Fellow, P.J. 2000. Separation and concentration of food components. Food Processing Technology. Principle and Practice. Second Edition. Pages: 140–169. ISBN: 1 85573 533 4 Woodland Publishing Limited. CRC Press. Combridge, England.

Fenton, C.J. 1984. Edible rendering. Proceedings of Meat By-products Quality Control Workshop, Richmond, NSW, Australia 13–17 May, CSIRO Meat Research Laboratory, 57–71 p. Cannon Hill, Australia.

Fernando, T. 1984. Edible rendering. Proceedings of Meat By-products Quality Control Workshop, Richmond, NSW, Australia 13–17 May, CSIRO Meat Research Laboratory, Cannon Hill, Australia.

Fernando, T. 1995. Odor control technologies (first article) and Recovery of protein (second article). Flo-Dry Engineering Ltd, New Zealand. Third International Symposium Nutrition, Protein, Fats and the Environment, in 61–64p and 75–78p, respectively. Australian Renderers Association Inc. Sydney, Australia.

Food and Drug Administration (FDA). 2005. Bovine Spongiform Encephalopathy (BSE), 1997 Feed Rule. US Food and Drug Administration. December 2005. viewed on June 8, 2005 on http://www.fda.gov/cvm/bsetoc.html.

Franco, D.A., and Swanson, W. 1996. The original recyclers. Published Under the Supervision of the Animal Protein Producers Industry. The Fats Proteins Research Foundation and The National Renderers Association, 24–25 p.

Georgia Department of Agriculture. 2005. Management of Animal Mortality in Georgia. Management of Mortality. Agrosecurity. Pages 1–21 Annex06_Mortality.pdf 01-Mar-2005 20:47. Available from: http://www.agrosecurity.uga.edu/annexes/Annex06 Mortality.pdf [cited 27 October 2005].

Hamilton, R. 2006. Rendering Industry Changes and Implications. A presentation in Nebraska Beef Roundtable Series. Darling International Inc. 7–9 February 2006.

Herbert, L.S., and Norgate, T.E. 1971. Heat and mass transfer in a batch dry rendering cooker. J. Food Sci. **36**: 294–298. doi:10.1111/j.1365-2621.1971.tb04046.x.

Indiana State Board of Animal Health. 2002. Livestock Dealers, Marketing, Exhibitions, and Slaughter Livestock. Indiana Administrative Code, Title 345, Article 7. Available from http://www.in.gov/legistlative/iac/T03450/A00010.PDF [cited 15 March 2004].

Kaarstad, S. 1995. The twin screw press and the waste heat evaporator in the rendering industry, Stord international. Proceedings of the 3rd International Symposium Nutrition, Protein, Fats and the Environment, ISBN 0646161288, pp. 113–114. Australian Renderers Association Inc. Sydney, Australia.

Kaye, G. 2003. Disposal of animal mortalities. Midwest Regional Carcass Disposal Conference, 20–21 August 2003. Kansas City, MO.

Kodfodfabrikken Ostjyden (KOFO). 1986. Inedible rendering by means of the wet pressing process, energy analyzed. Commission of the European Communities. EUR 10652 EN, Luxemburg. Final report of Contract No EE/084/82.

Kumar, M. 1989. Handbook of rural technology for the processing of animal by-products. FAO Agricult ural Services Bulletin 79, FAO of the United Nations, Rome.

Luo, J., and Lindsey, S. 2006. The use of pine bark and natural zeolite as biofilter media to remove animal rendering process odors. Bioresour. Technol. **97**: 1461–1469.

Luo, J., and Van Oostrom, A.J. 1997. Biofilters for controlling animal rendering odor. Pure Appl. Chem. **69**: 2403–2410. doi:10.1351/pac199769112403.

Meeker, D. 2006. Essential Rendering. Published by National Renderers Association, Arlington, Virginia. ISBN: 0–9654660–3-5. Available online at *http://www.animalprotein.org*.

Morse, D.E. 2001. Composting animal mortalities. Agricultural Development Division, Minnesota Department of Agriculture, St. Paul, Mn 55107. Available from http://www.mda.state.mn.us [cited 2 January 2006].

National Renderers Association, Inc. 2006. US production, consumption and export of rendered products for 1998–2005. Statistics. National Renderers Association. Available from http://www.renderers.org/Statistics/index.htm [cited 5 August 2006].

Ockerman, H.W., and Hansen, C.L. 2000. Rendering: Animal by-product processing and utilization. CRC Press LLC, Washington, D.C.

Ontario Ministry of Food and Agriculture (OMFA). 2001. Managing on-farm mortalities. Division of Agriculture and Rural, Ministry of Agriculture and Food, Ontario. Order No. 01–025, Agdex No. 400. Available from http://www.gov.on.ca/OMAFRA/english/livestock/deadstock/facts/01-025.htm [cited 14 October 2003].

Prokop, W.H. 1996. The rendering industry- a commitment to public service. The original recyclers (the book written by Franco, D. A., and W. Swanson). The Animal Protein Producers Industry. The Fats Proteins Research Foundation. The National Renderers Association.

Rendertech Limited. 2002. Rendering processes.110 Mays Road, P O Box 12 629, Penrose, Auckland 1006, New Zealand, Phone +64 9 634 5375, Fax +64 9 634 5376. Available from http://www.rendertech.co.nz/rendering_processes.htm [cited 14 July 2003].

Romans, J.R., Costello, W.J., Wendell Carlson, C., Greaser, M.L., and Jones, K.W. 2001. Packing house by-products. The Meat We Eat. Interstate Publishers, Inc. Danville, Illinois, USA.

Scientific Steering Committee Working Group. 1999. Preliminary scientific report on the risks of non conventional transmissible agents, conventional infectious agents or other hazards such as toxic substances entering the human food or animal feed chains via raw material from fallen stock and dead animals (including also: ruminants, pigs, poultry, fish, wild/exotic/zoo animals, fur animals, cats, laboratory animals and fish) or via condemned materials. Food Safety from farm to the Fork, Food safety, European Commision. Minutes of the Scientific Steering Committee Meeting of 18–19 March 1999. Available from http://europa.eu.int/comm/food/fs/sc/ssc/out46_en.pdf [cited 5 August 2004]

Shirley, R.B., and Parsons, C.M. 2000. Effect of pressure processing on amino acid digestibility of meat and bone meal for poultry. Poultry Science, **79**: 1775–1781.

Singeltary, T.S., Sr. 2000. Qualitative Analysis of BSE Risk Factors in the United States (Part 2). VegSource #1 (Veg Site on the net!). February 13, 2000 at 3:41 pm PST. Available from http://www.vegsource.com/talk/madcow/messages/7246.html [cited 7 June 2004].

Taylor, J. 1995. Wastewater in the rendering industry. Third International Symposium Nutrition, Protein, Fats and the Environment, ISBN 0646161288. Australian Renderers Association Inc. Sydney, Australia. 61–64 p.

Taylor, D.M. 2000. Inactivation of transmissible degenerative encephalopathy agents: A review. Veterinary Journal, **159** (1): 10–17.

Texas Department of Agriculture. 2002. Catastrophic animal mortality management (burial method), technical guidance. Available from http://tammi.tamu.edu/burialguidance.pdf [cited 29 November 2007].

Texas Natural Resources Conservation Service (TNRCC) and Texas State Soil and Water Conservation Board (TSSWCB). 2002. Technical Guidance. Catastrophic Animal Mortality Management. Texas State Soil and Water Conservation Board, USDA/Natural Resources Conservation Service. Available from http://tammi.tamu.edu/burialguidance.pdf [cited 26 November 2005].

The Dupps Company. 2003. Introducing the new quadpass dual-zone, four-pass rotary drier. Render, The National Magazine of Rendering, June 3: 7 p.

United Kingdom Department of Environment. Food and Rural Affairs (UKDEFRA). 2002. Livestock Welfare (Disposal) Scheme, Animal Health  Welfare. FMD cases in 2001. Available from http://www.defra.gov.uk/footandmouth/cases/index.htm [cited 11 May 2003].

US Department of Agriculture. Economics and Statistics Systems. 2005. Poultry production and value-2005 summary. Economics and Statistics Systems, US Department of Agriculture. Available from http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1101 [cited 18 September 2006].

United States Environmental Protection Agency (USEPA). 2002. EPA development document for the proposed revisions to the national pollutant discharge elimination system regulations and the effluent guidelines for concentrated animal feeding operations, chapter 8. Available from http://www.epa.gov/unix0008/water/wastewater/cafohome/cafodownload/cafodocs/DDChapters8.pdf [cited 23 April 2003].

Zamzow, J. 2003. Recent alpaca tragedy. Dynamite Marketing, Inc., 310 E. Watertower Lane, Meridian, ID 83642–6283. Available from http://www.dynamitemarketing.com/alpaca1.PDF [cited 15 December 2003].