STERILIZATION OF MEAL FROM MEAT WORKS WASTE IN A CASCADING ROTARY DRYER

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SUMMARY: For a cascading rotary dryer processing meat meal particles, dryer gas temperature and humidity, and meal temperature and moisture content were simulated using numerical integration of differential equations for the drying and heat transfer rates and algebraic equations for the mass and heat balances. The model is specific to single-pass dryers with co-current particle and gas streams. Provided meal particles are smaller than 15 x 8 x 10 mm (raw material ground through a 12.5-mm holeplate), and dryer burner temperature is above 640°C, the time/temperature processing conditions are predicted to be more than adequate to achieve meal sterilization. Trials using a Flo-Dry 7.5 dryer and commercial sterilization indicators confirmed predictions from the simulation. In these trials the best heat treatment was obtained at a dryer rotation of 5.5 rev/min, a burner temperature of 750°C and an outlet gas temperature of 125°C.

INTRODUCTION: Various rendering processes are used to convert waste tissues from animal slaughter into tallow, and meat meal for animal feed. For recovery of tallow, fat cells in the tissue must be ruptured. This is commonly done by applying heat, although enzymic and solvent-extraction rendering processes are also used. Rendering processes, which can operate in a batch, semi-continuous or continuous mode, are generally classified as wet or dry, depending on whether the fat is removed from the raw material before or after the drying operation. Traditional rendering systems remove water from the raw material using a severe heat treatment. Newer systems use a milder heat treatment, and are termed low temperature rendering (LTR) systems. In these systems, most of the water in the raw material is removed mechanically rather than thermally, before the defatted, wet solids are dried. An example of these newer systems is the MIRINZ Low Temperature Rendering (MLTR) process (Fig. 1), which uses a heat treatment of 80°C to 95°C for 6 to 8 min (Fernando, 1982). There is no one 'best' rendering process: the most appropriate system will depend upon the application.

Waste material from meat processing may be highly contaminated with pathogenic organisms. It is therefore important that the heat treatment during processing kills all such organisms, and certification of an adequate sterilization treatment is required for international trading of meat meals. The accepted heat treatment for inactivation of microorganisms in meals is raising the temperature of the material to 115°C for 60 min, or to higher temperatures for shorter times to obtain equivalent lethal effect, when there is free moisture in the environment. When there is no free moisture, the accepted treatment for sterilization is 140°C for 3 hours, or higher temperatures for shorter times (Hersom and Hulland, 1980).

In traditional dry rendering systems the material is held at 100°C at atmospheric pressure for 1 to 2 hours while most of the water is being evaporated. The temperature may then rise to 120°C to 140°C, especially in continuous dry rendering systems. Although meeting the requirements for moist sterilization, such treatment does not ensure sterility. At low moisture contents phase inversion occurs; the major phase changing from water to fat. Bacterial spores entrained in the fat are protected against thermal destruction by the low-moisture environment (Lowry *et al.*, 1979). Therefore, more severe heat treatments, which are detrimental to the nutritional quality of meals, are required to achieve sterility. However, the spores of potent pathogenic organisms, such as *Bacillus anthracis*, the aetiological agent of anthrax, are destroyed and the total number of spores is greatly reduced (Lowry *et al.*, 1979; Hansen and Ølgaard, 1984). The few surviving spores may include those of organisms that cause food poisoning, but at numbers too low to be of concern in a dry, microbiologically stable feed. Such 'commercial sterility' is considered acceptable. The heat treatments in low temperature rendering systems treatments are sufficient to achieve the destruction of all vegetative cells, but are inadequate for the destruction of spores (Lowry, 1983). Sterilization can be achieved, however, in the final drying phase of meal preparation.

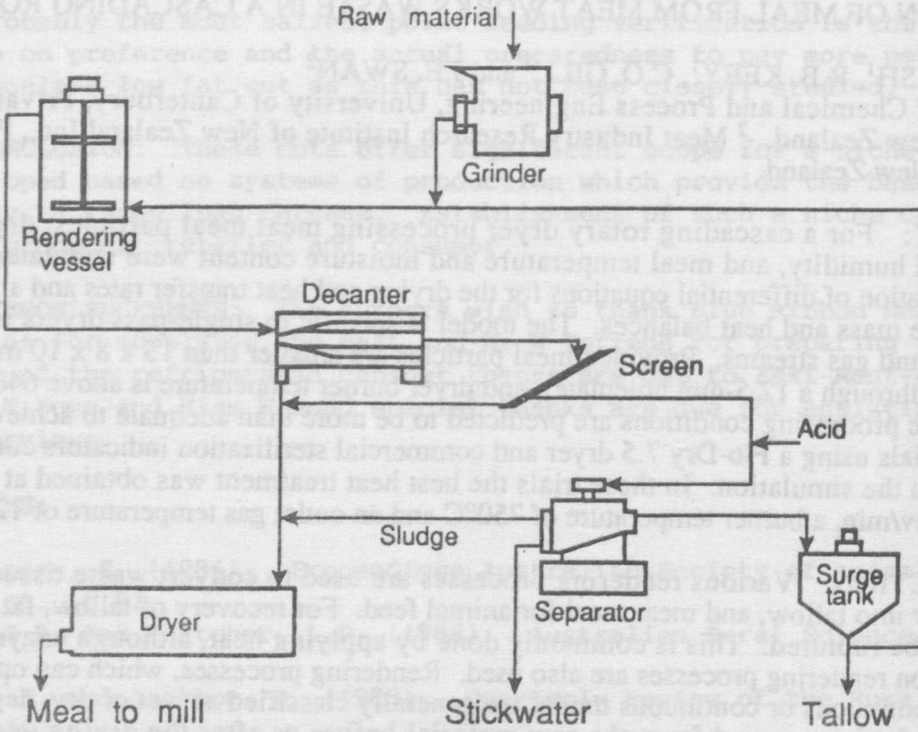

Figure 1. Schematic diagram of the MIRINZ low temperature rendering (MLTR) system.

In recent years, gas-fired cascading rotary dryers have been used to dry defatted solids from MLTR systems. Rotary dryers are versatile continuous systems, widely used for drying large quantities of granular material, particularly when the material is sticky or there are other solids-handling problems. These dryers are made from a cylindrical shell inclined at a small angle to the horizontal, and they can be single, double or triple pass. Wet feed is introduced at the upper end and dried product withdrawn at the lower end. A co-current or counter-current hot gas stream (>600°C) passes through the dryer shell (Fig. 2). The lifting flights in the dryer pick up the meal as the shell rotates and shower the particles through the gas stream. Most of the drying action occurs when the solids are in close contact with the gas. Because the period the particles are at rest within the lifting flights is relatively longer than the flight times, particles reach a fairly uniform temperature at the end of each rest period. Removing moisture from within a solid is a different process from that of evaporating liquid water, and the temperature of high-moisture particles in a rotary dryer can be above 100°C at atmospheric pressure.

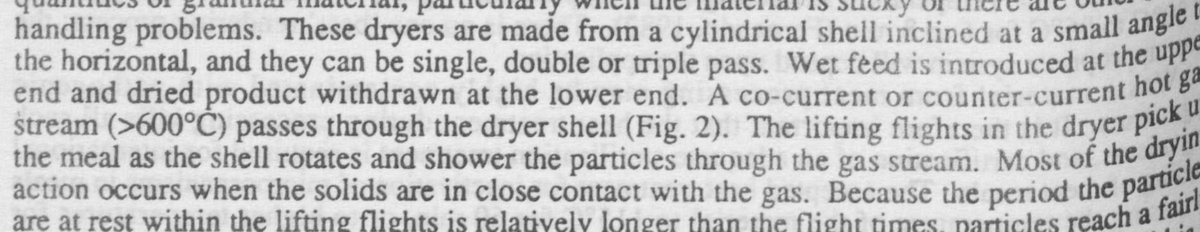

Figure 2. Arrangement of a Flo-Dry cascading rotary dryer.

Unfortunately, it is difficult to monitor the time/temperature conditions in rotary dryers. Moreover, the temperature of particles being bulk dried at atmospheric pressure will remain at or near the wet-bulb temperature as moisture evaporates and will rise above that only when the moisture content of the particles falls below a critical level. Those unfamiliar with the behaviour of material in rotary dryers are inclined to consider that conditions will be the same as for bulk drying. Consequently, doubts are often raised with regard to the sterilizing adequacy of the heat treatment afforded to low temperature rendered product. Therefore, a model was developed for predicting the temperature and moisture content of meal passing through a rotary dryer, and the operating conditions predicted to give sterilization were tested for a commercial dryer.

SIMULATION MODEL: The drying rate at any point along the dryer can be written in terms of the following variables: temperature and moisture content of particles, drying time, volume and surface area of particles, gas temperature and humidity, film heat transfer coefficient, and mass transfer coefficient. The most appropriate model for the drying kinetics of wet meal particles is not known. Simple drying models incorporate the concept of unhindered drying above the particle's critical moisture content; drying rate is constant and depends solely on the rate of heat transfer to the material. Below the critical moisture content, drying rate decreases. However, many materials, particularly foodstuffs, agricultural products and material in particulate form, do not show critical points, and hindered drying occurs from the start of drying.

A system of equations was developed to estimate the drying rate, particle temperature, axial advance, gas humidity and gas temperature in the cascading rotary dryer. The two differential equations for the drying and heat transfer rates, and the two algebraic equations for the mass and heat balance (which incorporate the effects of evaporative cooling), were solved by numerical integration to give profiles for the gas temperature, humidity, and particle temperature and moisture content along the dryer. The numerical integration procedure involved choosing a time increment and integrating along the length of the drum until the specified outlet moisture content was achieved. This time interval was progressively reduced until the predicted drying time changed from trial to trial by less than 0.5%.

The contribution of radiation to the total amount of heat transfer was ignored because Platin *et al.* (1982) showed in a similar simulation study that the radiant heat transferred from the solids to the gas is less than 10% of the total heat transfer, even at gas inlet temperatures of 800°C. Heat transfer between the particles and the dryer wall was also ignored. The amount of heat transfer from the gas to the dryer wall is typically two orders of magnitude less than that from the dryer wall to the particles (Langrish *et al.*, 1988). Hence the dryer wall and the particles are at similar temperatures at each cross-section of the dryer and the heat transfer from the gas to the dryer wall is the rate-limiting step. Both assumptions resulted in underestimating the amount of heat transfer from the gas to the particles, thus giving a conservative estimate of the equivalent sterilization times because the predicted particle temperature would be lower than the actual temperature.

The gas and solids conditions were simulated for three particle shapes and sizes (15 x 8 x 5 mm, 10 x 10 x 8 mm and 30 x 16 x 10 mm), two initial particle temperatures (15 and 30°C), an initial particle moisture content of 1.5 kg/kg dry matter, three inlet gas temperatures (600, 700 and 800 °C), an initial gas humidity of 0.112 kg/kg. The dryer was operated with co-current flow of gas and solids and the outlet solids moisture content was specified as 0.08 kg/kg. Drying was assumed to be adiabatic, as the dryer was covered by ceramic fibre insulation and measured heat losses were less than 5% of the burner's heat output. The drying kinetics of the meal particles were assumed to be represented by a linear falling rate curve. The particles were assumed to have a critical moisture content equal to the initial moisture content and an equilibrium moisture content of zero, and exhibit non-hygroscopic behaviour. The assumption of non-hygroscopic behaviour (with equilibrium moisture contents greater than zero) results in lower drying rates, higher particle temperatures and longer equivalent sterilization times, and therefore gives a conservative estimate of the degree of sterilization.

The model does not incorporate the biological factors involved in sterilization. The heat treatment to achieve meal sterilization is given by the Arrhenius-type equation $\tau = e^{(93.43 - 0.23T)}$, where τ is the holding time (min) at an absolute temperature, T. The particle temperature profiles obtained from the simulation were used, together with kinetic data for sterilization, to predict equivalent sterilization times at 115°C. To ensure the Arrhenius equation was not extrapolated beyond the limits of the data, the equivalent sterilization time below 110°C was assumed to be infinite and that above 131°C was taken as 1.5 min. Thus, a conservative estimate for the equivalent sterilization times was obtained.

EXPERIMENTATION: Trials were carried out in a new 15 tonne/h LTR plant consisting of one 5 tonne/h module with direct steam injection producing margarine grade tallow and two 5 tonne/h MLTR modules producing inedible tallow. The raw material in all modules was ground through a 12.5-mm hole plate of a Weiler grinder, then subjected to an average 6 min at 80 to 93°C in the rendering vessels. Cooked material was separated in Alfa-Laval CFNX 418 decanters, and the decanter solids (at around 70°C) dropped into a common screw conveyer feeding the rotary dryers. Two direct-fired Flo-Dry 7.5 dryers (Flo-Dry Technology Ltd, Auckland, New Zealand), of the same dimensions and design used in the simulation model, dried the decanter solids from an initial moisture content of 1.22 - 1.63 kg/kg to 0.06 - 0.11 kg/kg. The burner and dryer outlet temperatures were recorded every minute. The speed of each dryer, and the time for commercial sterilization indicators (see below) to pass through the dryer were noted.

It is difficult to measure particle temperatures along the length of the dryer to check the model's accuracy. Therefore, commercial sterilization indicators, which change colour when a given temperature and holding time in steam heating have occurred, were used. The ideal for a simple indicator is that it remains unchanged though most of the sterilization holding phase; undergoes a rapid and easily identifiable change after an acceptable period of heating; only changes if sufficient moisture is present to provide 'wet heat'; and is stable during storage. Commercial indicators do not undergo a gradual colour change through the heating period. By remaining apparently unchanged until the last minute or so, and then undergoing a rapid colour change, the indicator is able to give a more meaningful indication of sterilization conditions. Because indicators operate over a limited temperature range, a single type of indicator cannot be used for all sterilization procedures, and a suitable indicator must be selected for the processing conditions envisaged.

The following sterilization indicators were used: 121°C and 134°C ATI Steam-Clox indicators (Deseret Medical Inc., Becton Dickinson & Co., North Hollywood, CA 91605); 125°C (black spot) tubes and 135°C (yellow spot) tubes (Albert Browne Ltd, Leicester, England). Their operating characteristics are given in Table 1. Five of each type of indicator were simultaneously dropped into the dryer's feed screw with the decanter solids and retrieved from the meal surge bin at the dryer outlet. To help detect the glass tubes in the meal, these tubes were taped to a Steam-Clox indicator of the same temperature range, using Ceelon tape.

Table 1. Temperature-time conditions indicated by colour changes in indicators and the times for sterilization of meal at each individual temperature.

Indicator	Steam-Clox		Browne Tubes	
colour change	121°C	134°C	125°C	135°C
Up to one-third	unsterilized	unsterilized	≤ 5 min	≤2 min
Up to two-thirds	unsterilized	unsterilized	≤10 min	≤3 min
Full	sterilized	sterilized	≥11 min	≥3 min
Time for sterilization	15 min	0.7 min	6 min	0.6 min

RESULTS AND DISCUSSION: Simulations predicted that the temperature of the particles being dried would reach a maximum near the dryer inlet (Fig. 3). Calculations also suggested that the time for a significant thermal response in the particles is less than one minute. That time is of similar order to the dwell time of the particles in the lifting flights over each revolution of the drum, so the particle temperature should be nearly uniform during drying.

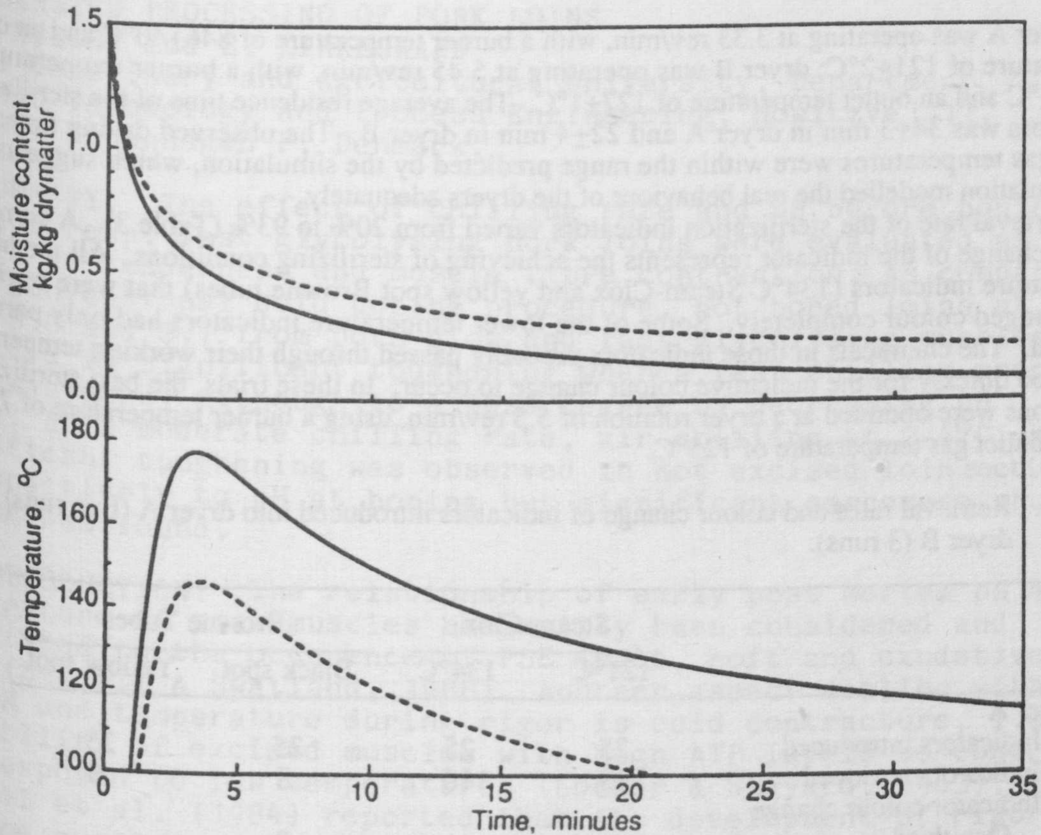

Figure 3. Simulated temperature and moisture profiles of 15 x 8 x 5 mm meal particles in a cascading rotary dryer. Particle inlet temperature 30°C; gas inlet temperature 700°C (--) and 800°C (—).

Changing the inlet particle temperature affected the conditions slightly (Table 2), but the equivalent times of heat treatment for the reference temperature of 115°C are well above the 60 min deemed necessary for sterilization. Changing the inlet gas temperature had a significant effect on the heat treatment predicted by the model. Inlet gas temperatures below 640°C gave insufficient treatment. Particle size influenced the time to dry the material to a moisture content of 0.08 kg/kg. Larger particles needed about 2 hours to be dried. However, although these large particles would have an excessive moisture content (0.18 kg/kg) if they were in the dryer for the maximum time of 50 min envisaged in practice, they still would have been adequately sterilized.

Table 2. Predicted drying times, outlet gas temperatures and equivalent heat treatment times at 115°C for different particle sizes and gas and solids inlet temperatures.

Particle size, mm	Inlet temperature, °C		Drying time, min	Gas outlet temperature, °C	Equivalent time at 115°C, min
	Gas	Solids			
15x8x5					
	600	30	∞	74.0	7
	700	30	∞	76.1	264
	800	30	36.9	115.8	830
	800	15	45.6	104.2	633
10x10x8	800	30	49.4	115.8	1112
30x16x10	800	30	108.2	115.8	2439

Dryer A was operating at 3.33 rev/min, with a burner temperature of 846±40°C and an outlet temperature of 121±2°C; dryer B was operating at 5.45 rev/min, with a burner temperature of 743±11°C and an outlet temperature of 127±1°C. The average residence time of the sterilization indicators was 34±3 min in dryer A and 22±4 min in dryer B. The observed drying times and outlet gas temperatures were within the range predicted by the simulation, which suggests that the simulation modelled the real behaviour of the dryers adequately.

Retrieval rate of the sterilization indicators varied from 20% to 93% (Table 3). A complete colour change of the indicator represents the achieving of sterilizing conditions. All the higher temperature indicators (134°C Steam-Clox and yellow spot Browne tubes) that were retrieved had changed colour completely. Some of the lower temperature indicators had only partially changed. The chemicals in those indicators probably passed through their working temperature range too quickly for the indicative colour change to occur. In these trials, the best sterilization conditions were obtained at a dryer rotation of 5.5 rev/min, using a burner temperature of 750°C and an outlet gas temperature of 125°C.

Table 3. Retrieval rates and colour change of indicators introduced into dryer A (five runs) and dryer B (3 runs).

	Steam-Clox		Browne Tubes	
	121°C	134°C	Black spot	Yellow spot
Dryer A				
Indicators introduced	25	25	25	25
Indicators retrieved	18	16	8	6
Indicator colour change				
One-third	-	-	8	-
One-third to two-thirds	5	-	-	4
Full	13	16	-	2
Dryer B				
Indicators introduced	15	15	15	15
Indicators retrieved	14	14	3	8
Indicator colour change				
One-third	-	-	-	-
One-third to two-thirds	9	-	3	-
Full	5	14	-	8

CONCLUSIONS: The simulation of meat meal drying in a Flo-Dry cascading rotary dryer predicted the real behaviour of the dryer adequately. Provided meal particle size is equal to or less than 15 x 8 x 10 mm (raw material ground through a 12.5-mm holeplate), and the dryer burner temperature is above 640°C, the particles will be subjected to a heat treatment greater than that required to achieve commercial sterilization.

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