Meat Processing by High-Frequency Methods Shows Promise

HIGH-FREQUENCY COOKING

High-Frequency Heating as a Unit Operation In Meat Processing

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The theory, design, and construction of equipment used in processing meat by high-frequency methods have been investigated. The increase in thermal energy of the material in the high potential field is explained as due to the particle motion increase of the material itself. The motion is internally vibrational or oscillatory, rotational, and translational. Most of the energy is probably due to an increased translational motion, because it is a continuous increase rather than stepwise as would be indicated by the other two forms. In the treatment of the results, a great deal of emphasis has been placed on the rates of energy increase and conversion efficiencies. Data on a typical run show that a 15-kw. high-frequency generator operating with a 56.6% conversion efficiency could possibly process more than 3500 pounds of meat in an 8-hour day. The dielectric process has been compared with conventional steam cooking. Disregarding initial investment, in processing large volumes of meat, the analysis suggests that the electrical process might compare favorably with steam. However, a new plant, which would have to consider cost of steam generation, would require an individual economic balance for the specific design.

HIGH-FREQUENCY HEATING, which depends upon energy conversion rather than heat transfer, has been widely used for increasing the thermal energy of plastics and wood bonding cements (*1*, *5*, *8*, *14*) but has not been commercially applied for processing food products. The method has been used experimentally for blanching vegetables (*6*, *9*, *12*), and basic patents covering its application to processing canned meat products were obtained by Bowman (*2*) and Bowman and Beadle (*3*).

The research reported here covers the basic investigations made to apply high-frequency heating as a unit operation in processing ground meat—more specifically, ground pork luncheon meat containing the usual curing ingredients (sodium chloride, nitrates, and/or nitrites and sometimes sugar).

When such a material is placed between two parallel plate electrodes and a high potential is applied until equilibrium is attained, there is little free electron motion, the ions move in a restricted manner, and only a very slight oscillatory and transcillatory movement effect can be detected in the molecules. However, if the potential is reversed 9,000,000 times per second, not the particle path restriction but the momentum change of the particle itself will be the restricting factor. As this particle motion is measured as the electrical current and the resistance to motion, except for some molecular "rubbing," has been reduced to the momentum change of the particles themselves, the current has increased considerably. The product of the square of this measured current times the resistance to it is the measure of the increase of the kinetic particle energy, which in turn is immediately indicated by a temperature increase. Thus, electrical energy has been converted into particle kinetic energy without any heat (thermodynamically defined as energy in transition between the system and the surroundings under the influence of temperature) (*4*).

This leads to two conclusions. This is neither induction heating, which de-

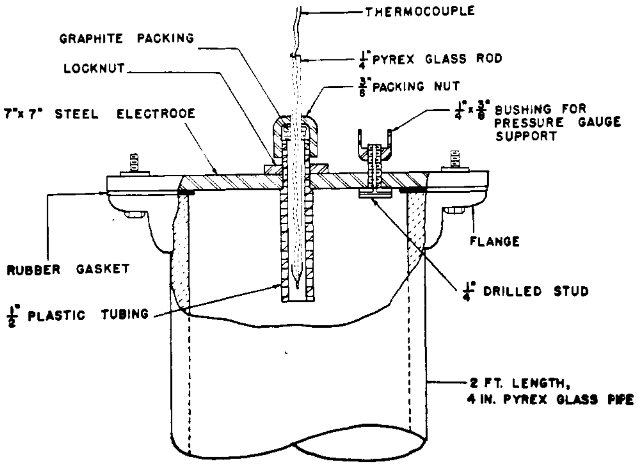


Figure 1. Processing cell with packing nut for thermocouple assembly

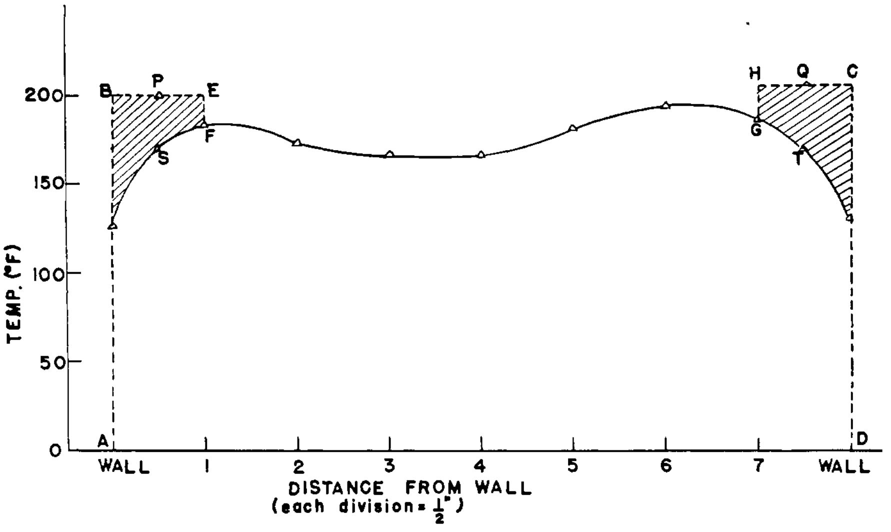


Figure 2. Typical temperature distribution along diameter of meat roll processed in cylindrical cell

pends solely upon electron motion, nor dielectric heating, which depends upon molecular motion. The second conclusion is that we have here a method of increasing thermal energy without need for a temperature differential. In other words, a product such as meat is capable of having its thermal energy increased homogeneously—that is, without a temperature difference between any two points in the meat.

Development of Equipment and Methods

Before this phenomenon could be used as the basis for a unit operation to increase meat temperature for commercial sterilization, more information was needed pertaining to the properties influencing it: the resistance, dielectric constant, and power factor of the meat.

Using a number of different measuring techniques (*7*) a value of approximately 145 was obtained for the dielectric constant, in rather close agreement with values obtained by von Hippel (*11*). Although von Hippel and Osswald (*10*) did not measure the same type of meat the authors' range of values indicated the validity of the figure given above. Resistance values at different frequencies at 70° F. were obtained; they ranged from 58.7 ohms/inch/square inch for a direct current circuit to 42.8 at a frequency of 29 mc. (*7*). The resistance of the meat was found to vary inversely with the temperature. The greatest change took place during the thaw from the frozen state. As the ground pork processed was not frozen, it presented no problems in keeping the circuit balanced during the processing.

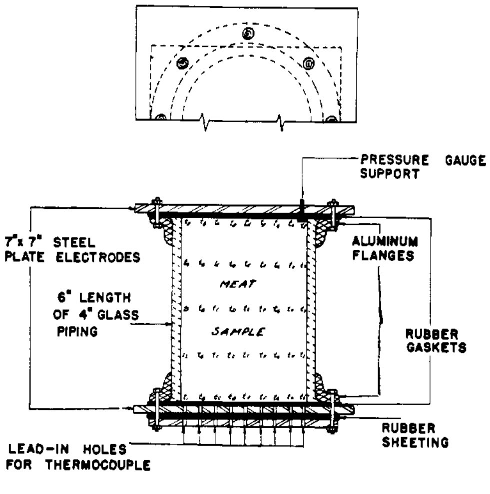
These fundamental measurements provided the necessary electrical data upon which the design of the processing cell (Figure 1) was based. Two 3/16-inch steel plates were bolted to the ends of a flanged borosilicate glass tube, 4 inches in diameter and 24 inches long. Rubber gaskets were used between the steel and glass, and a piece of 1/2-inch plastic tubing about 4 inches long, threaded at one end, was fitted through the center of one of the plates. The threaded end protruded about 1 inch above the steel plate; the remaining portion was embedded in the meat contained in the glass tube between the plates. The tube provided protective housing for a thermocouple probe, which was withdrawn into the plastic tube during the period of generation and pushed into the meat at 2-inch intervals immediately afterward to measure temperature along the axis of the tube of meat. A packing nut filled with graphite string packing acted as a pressure-tight seal along the sides of the thermocouple probe. At one side, close to the glass wall, was mounted a pressure gage. The support for the gage contained a "tap-off" just before the inlet to the pressure gage, which consisted of a gate valve which could be opened for reducing the internal pressure of the cell. An allowance was made for the expansion of the meat by cutting a 1-inch hole through the meat longitudinally from top to bottom.

The next step was to design a cell which made it possible to read temperatures throughout the whole body of the meat. It followed the same form as the cell just described. It was shorter, only 6 inches in length. The top end consisted of two aluminum plates with matching 1/8-inch holes drilled across the diameter of the plates. A piece of rubber sheeting was sandwiched in between, sealing the holes. The thermocouple probe design was modified for this cell. An asbestos-wrapped constantan wire was pushed through a section of 1/8-inch steel tubing used for making hypodermic needles. The end of the tubing and the wire were soldered and pointed, forming an iron-constantan junction. When temperature readings were desired, the rubber sheeting was pierced and the thermocouple probe injected into the meat. When it was withdrawn, the rubber sealed itself and prevented a leak. A temperature profile of the cross section taken at a perpendicular to the longitudinal axis of the meat was obtained in this manner (Figure 2). A temperature traverse of this nature was taken at intervals along the axis. This gave a temperature description of the cross section along the entire axis of the meat, as shown in Figure 3.

The rubber sheeting proved to be beneficial in another way. A hollow hypodermic needle connected to an aspirator was used to pierce the rubber sheeting and withdraw some of the air entrapped while the meat was packed initially. This made it possible to draw a vacuum of 25 to 30 inches of mercury in the container before processing was started. By diminishing the content of occluded air, the pressures generated at the higher temperatures during processing were reduced.

In conjunction with the development of the cell for the batch process, a continuous processor (Figure 4) was also designed. This consists of two sections of nylon tubing, 2.5 inches in diameter, connected by a solid copper coupling. A sheet of aluminum foil 9 inches wide is wrapped around the connection between the two tubes and coupling, and the current passes from the foil to the boundary copper tube. In order to increase resistance to the current, the path is increased in the following manner: Two copper rings, 4 inches in diameter and 1 inch wide, are placed concentric with the nylon shaft, one near each end of the aluminum foil. These copper rings act as the electrodes and are separated from each other by 6-inch sections of 4-inch borosilicate glass pipe. The path provided for the current leads from the generator to the first ring, through the meat to the aluminum foil, along the aluminum foil, through the meat to the

Figure 3. Processing cell with lead-in holes and points of temperature measurement on cross section of diameter along axis indicated



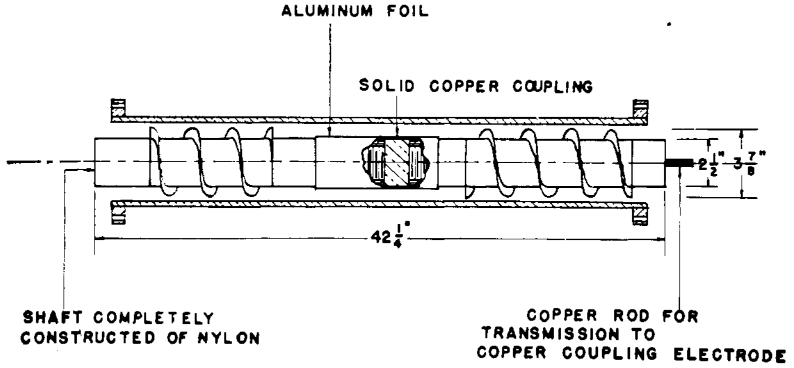


Figure 4. Direct pass continuous processor

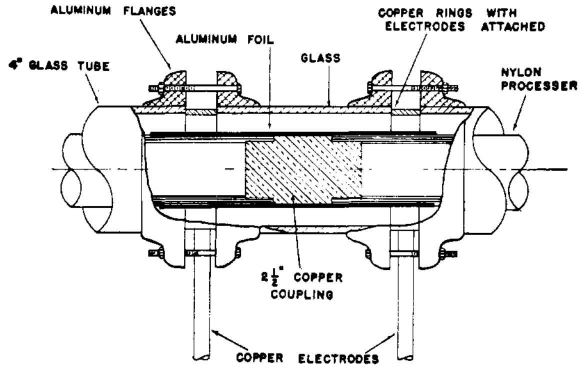


Figure 5. Multipass continuous processor

second ring, and finally to ground. The continuity of the meat flow is maintained by the screws, which were milled into the thick-walled nylon tubing connected to the nylon shafts supporting the aluminum foil. The assembly is illustrated by Figure 5.

For all processing studies an industrial model 15-kw. oscillator, 9-kv. plate voltage, operated at a frequency of 9 mc., was used as the energy source.

Experimental Results and Discussion

Table I records the data obtained from the runs made with the first cell described. A fair degree of uniformity of temperatures taken along the axis of each sample of meat is indicated. Figure 6, which presents only the data of runs 5 and 6, further substantiates this observation. However, a comparison of the averages of the temperatures for the six runs listed in Table I shows a variation in the ability of the meat to convert the electrical energy to thermal energy, if one assumes the heat capacity for the different samples to be identical.

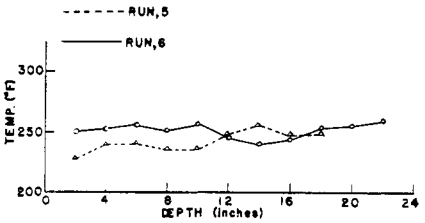


Figure 6. Temperatures taken along axis of meat roll for runs 5 and 6 processed in cylindrical cell

Figure 2 indicates the temperature distribution along the diameter, from wall to wall throughout the body of the meat processed in the 6-inch cell (Figure 3). It shows that a marked change of temperature occurs within an inch of the glass wall. This is due to the fact that the meat must heat the glass at the expense of its own thermal energy content. The shaded areas under *BPE* and *HQC* (Figure 2) represent the thermal energy taken by the glass. A continuation of the curve through the new points, *P* and *Q*, would be closer to the actual description of the thermal behavior of the meat without environmental interference. The dip in the center of the curve could be due to the distribution of the electrical current in this partial conductor. This is much less pronounced at higher temperatures of the meat.

With the data accumulated it was possible to calculate the efficiency of the process, defined as a ratio of the thermal energy output to the electrical energy input multiplied by 100. The electrical energy input was the input into the primary tank circuit and not that into the meat cell directly. The output included thermal energy loss to environment.

Data of Typical Run.

Total time of run, minutes	2.9
Starting temperature of meat, ° F.	51
Temp. of meat at end of run, ° F.	199
Weight of sample, pounds	10.3

CALCULATIONS. Energy Output

$$Q = WCp\Delta T$$

where Q = energy output, B.t.u.
W = weight of sample, pounds
Cp = heat capacity of meat (*13*)
= 0.74 B.t.u./lb./° F.
ΔT = temperature change of meat

$$Q = (10.3 \text{ pounds})(0.74 \text{ B.t.u./lb. } ^\circ\text{F.}) \times (148^\circ \text{ F.}) = 1130 \text{ B.t.u.}$$

Energy Input

Generator setting, 9 kv. and 1.5 amperes
(9 kv.)(1.5 amperes) = 12 kw.
(12 kw.)(2.9 minutes) × (56.92 B.t.u./kw./min.) = 2020 B.t.u.

$$\text{Efficiency} = e = \frac{1130 \text{ B.t.u.}}{2020 \text{ B.t.u.}} = 55.5\%$$

Data from 11 similar runs were treated in the same manner, and the efficiencies were averaged; the average conversion efficiency amounted to 56.6%. On this basis it was computed that a 15-kw. generator might process 3527 pounds of meat in an 8-hour day. The following calculations show the derivation of this figure:

% efficiency = 56.6% (assuming negligible losses based on insulation)
Power input, 27 kw.
B.t.u. provided to meat per minute = (0.566)(27 kw.)(56.9 B.t.u./kw./min.) = 870 B.t.u. per minute

Basis. One 15-kw. generator on 8-hour day shift (continuous operation) (870 B.t.u./minute)(60 minutes/hour) × (8 hours/day) = 417,600 B.t.u. per day

Assuming the necessary temperature increase to be 160° F. the daily meat rate is:

$$Q = WCp\Delta T$$

where Q = total thermal energy to meat
W = weight of meat
Cp = heat capacity of meat (*13*)
ΔT = temperature increase of meat

$$W = \frac{Q}{(Cp)(\Delta T)} = \frac{417{,}600}{(0.74)(160)} =$$

3527 pounds of meat per day-unit

Table I. Temperature Distribution Along Axis of Tube of Meat

(9 kv., 1.5 amperes)

Run No.	Temperature, ° F. 2 inches	4 inches	6 inches	8 inches	10 inches	12 inches	14 inches	16 inches	18 inches	20 inches	22 inches	Av. Temp., ° F.	Time for Run, Min.	Wt. of Meat Sample, Lb.
1	180	195	233	222	212	215	210	208	230	...	...	212	3.56	10.25
2	178	203	212	216	195	178	197	211	211	191	...	199	2.96	10.31
3	170	185	195	197	193	200	208	205	187	...	...	193	3.03	10.25
4	172	195	196	180	175	186	185	182	206	192	196	188	3.20	10.25
5	226	240	241	236	235	248	255	247	249	...	...	242	5.33	13.00
6	250	252	255	252	256	245	241	244	254	255	260	251	4.83	13.00

Table II. Results of Static Runs on Continuous Processor

Type of Circuit	*Time, Sec.*	*Temp., ° F.*
Low resistance	. . .	No cooking noticed
Direct pass matched	. . .	Warm, but did not cook
Multipass matched (wt. of meat approx. 3 lb.)		
A	[a]	
B[b]	10.4	Av. 120

[a] Meat cooked so rapidly that time was not recorded. Burning also occurred.
[b] Power input, 1.5 amperes, 9 kv.

A static run on the continuous processor was also conducted, and it was calculated that the apparatus (13.5-kw. input) would cook approximately 3 pounds of ground pork per minute (Table II).

Calculations. Weight of meat under copper rings (density = 0.034 pound per cubic inch), 0.52 pound.

Time of run = 10 minutes

$$\left(\frac{0.52\text{ pound}}{10\text{ seconds}}\right)(60\text{ seconds/minute}) = 3.12\text{ pounds per minute}$$

Practical Evaluation of Results

Thus, the rate and uniformity of thermal energy increase that this unit can effect are its outstanding features. This allows a sample of meat to be sterilized without overcooking any portion of it. This could be applied to any situation where close temperature control without a gradient was necessary.

An approximate cost analysis indicated an electricity cost of $0.00328 per pound of meat against a steam cost of $0.00118 per pound of meat based on a 2000-pound batch. Because of the sliding scale for electricity, a large volume of meat would bring the costs closer together. In addition, the dielectric continuous process would not involve any losses between batches as would the steam. The processing cost using steam and the amount of water, electricity, air, and cleanup associated with this process might bring the cost of processing by steam closer to that of the dielectric process, because the dielectric process should use less cleanup, water, and air.

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Absorption Qualities of Feeds Estimated as Basis for Molasses Use

FEED EVALUATION

Determination of Absorption Capacity and Fibrous Material of Pith and Certain Feed Constituents

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THE USEFULNESS OF AGRICULTURAL RESIDUE MATERIALS employed as ingredients in commercial livestock feeds depends not only on their nutrient value but also on their relative absorption capacity and particle-size distribution. Their absorption capacity is affected adversely by fiber characteristics, small particles, and dirt contamination. The absorption value is of great importance today, when feed manufacturers are being urged to increase the molasses content of all ruminant feeds.

The Northern Regional Research Laboratory has developed procedures for evaluating both absorption capacity and particle-size distribution. Pith separated from sugar cane bagasse was used in the development of these methods. Most of the equipment and apparatus needed may be purchased directly or fabricated from supplies sold by laboratory supply companies.

Other possible tests of quality, such as molasses absorption, bulk density, and drying rate, were investigated but were rejected as unreliable.

Absorption Capacity

The test of absorption capacity utilizes the principle of capillary action to determine the relative amounts of water that air-dry cellulosic materials can absorb. The material is deaerated by compression