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MEAT DEHYDRATION

NEW ASPECTS OF AN OLD INDUSTRY FOR DEVELOPING COUNTRIES 1/

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CONTENTS

Introduction

Of all the methods of food preservation, dehydration may be considered the oldest. It is, in a sense, a natural process since those foods which are capable of long storage are those which are harvested in a naturally dehydrated state. Thus, the seeds of plants come immediately to mind as examples of food which nature furnishes in a dry or dehydrated state and which man has always recognized as being capable of long storage. Before the dawn of history man probably knew that meat and some fruits could be preserved by drying in the sun or over fires. At least we know that primitive societies with which modern man has come in contact, such as the American Aboriginies after 1500 A.D., were in the habit of preserving meat and berries in this way.

More sophisticated societies utilized dehydration to a greater extent to preserve meat, and we are all familiar with such products as fermented sausages and country cured hams which owe their legendary keeping quality to their low moisture content. The Canadian voyageur and the South American gaucho dried their plentiful supplies of meat for subsequent use on their travels and explorations. (Sulzbacher, 1973b)

In this paper we will be concerned with meat which is dried in some technologically controlled manner rather than by utilizing the sun's energy or racks over open fires. Such a dried food is generally designated as "dehydrated" to distinguish it from the products of less sophisticated techniques. However, this use of the term "dehydrated" is purely conventional, and in referring to dehydrated meat we do not imply any scientifically more profound operation than we do bv the more proper English adjective, "dried." Indeed, it is my own opinion, which I hope to substantiate in this paper, that the commercial processes of dehydration as they apply to meat, require very little by way of special knowledge which the small independent processor in a developing country is unable to supply.

Although the history of dried, or dehydrated, meat is lost in antiquity, the first commercial production on a large scale probably occurred during the American Civil War when the Union Army contracted to buy dried meat for issuance to the troops in the field. Nothing is known today about the meat produced and there was no civilian production after the war. But, when the 1914-18 war placed severe demands on processors to provide meat for use at a distance from the supply, dehydration was extensively used and was again forgotten when peace arrived. Next, during World War II, the demands of war again forced food processors and technologists into the meat dehydration business. This time the demand was so great that, on the allied side at least, a major scientific and technological effort was put into operation, with cooperative activities organized in Great Britain, North and South America, Australia, and New Zealand. (Sharp, 1953)

This work was both so successful at the time, and so well conceived, that there was some small carryover into the peacetime economy and, we can safely say, that now dehydrated meat has finally become a standard item of commerce which promises to find expanding usefulness as time progresses.

For the purposes of this paper, I will divide the subject of meat dehydration along arbitrary product lines, considering in order dehydrated cooked meat, dehydrated raw meat, partially dehydrated shelf stable products, new types of products and processes, and quality control methods for processors. In each section we will consider the equipment needs and costs, the nature of processes involved, the packaging needs, and other pertinent details. There are first, however, some general considerations we should emphasize and keep in mind for all products.

Dehydration succeeds in preserving food because it reduces the amount of water in the food to a point below that required by microorganisms for their growth. (Scott, 1957) The ability of a food to support the growth of microorganisms, so far as water is concerned, is measured by the water activity (Aw) of the food. At a water activity below 0.70 practically no known food spoiling microorganisms can grow. This includes molds (able to grow at the lowest Aw values), yeasts, and bacteria. Also, at very low Aw values many chemical changes catalyzed by enzymes proceed at a slower rate. (Some, unfortunately, may proceed faster). Freezing is effective for much the same reasons, but in the case of freezing, energy is constantly required to maintain the low temperature of the food while in the case of dehydration, the energy is applied only at the time of processing. This is a very important economic consideration since it means that the cost of frozen food continues to increase up to the time of ultimate consumption, while the cost of dehydrated food is largely limited to the cost of production and initial distribution. Also, in contrast to both frozen and canned food, the cost of distributing dehydrated food is very favorably affected by its reduced weight.

The energy requirements of dehydration are fundamentally based on the heat of vaporization of water which is, in the temperature ranges we are concerned with, about 540 calories per gram or 1100 BTU per pound. These quantities will always have to be increased to allow for the inefficiencies and other energy requirements of each process. A very important factor in dehydration, and one often overlooked, is the influence of the water holding capacity of the muscle protein. This is not constant but varies with pH, salt concentration, and other compositional factors. The general shape of these relationships are shown in figure 1 where it can be seen that the smallest tendency to absorb water is found in the neighborhood of pH5, and above pH12. The way this affects various processes will be emphasized as we consider each one.

The ultimate value of any food product is, of course, determined by its quality. We make concessions for cost and convenience, but ultimately no food product can retain its acceptability unless it retains some minimum qualities which its eaters expect. Therefore, the success of any process for dehydrating meat will depend on the uses to which the dried product will be put and the tastes and prejudices of the consumers. No matter how a process may be viewed by the food technologist it is the opinion of the consumers which must be considered in any choices between alternative approaches.

Dehydrated Cooked Meat

Man's most extensive experience with dehydrated meat has certainly been with the large scale production of dehydrated cooked meat during World War II when millions of pounds were produced in North America, Australia and South America. The experimental work leading to this production has been summarized by Sharp (1953), for the British work, and in Circular 706 (USDA, 1944) for the American.

It is not generally feasible to dry large pieces of cooked meat and the usual commercial product is dehydrated granules or powder. Such materials enjoy a certain acceptability as soup ingredients, and have a continuing place in world markets. The essential stages of production require the preparation and boning of the carcass, grinding or mincing the boned meat, cooking, drying, and packaging. Compression prior to packaging may or may not be indicated. A wide variety of drying equipment may be used in producing cooked dehydrated meat and cooking may be carried on in a separate stage, in the drier but prior to the drying phase, and concurrently with the drying process. The choice among these alternatives is usually made on the basis of the sort of equipment and facilities on hand, but we will assume that we are contemplating setting up a new operation in a situation remote from existing meat packing facilities, and that our choices will be dictated by costs, manpower, and the ability to produce a highly acceptable product.

Although it is not our major concern, a word ought to be said about the livestock chosen for processing. Dehydration with heat is from a chemical standpoint, a rather violent process, and will not improve the tenderness and overall palatability of the meat. Therefore, while the livestock chosen need not be of the highest grade available, no one should assume that dehydration will turn a bunch of undesirable culls into a prime product.

Obviously, the first step in the industrial chain must be a sanitary, well run, slaughtering facility. If the slaughtering facility is intended solely as a source of supply for the dehydration plant, it is not absolutely necessary to provide refrigeration for chilling the meat to be dried, since hot boning immediately followed by cooking and dehydrating, will result in a significant saving of energy. Still, the greater flexibility afforded by being able to work with chilled carcasses, and the reduced water holding capacity of the chilled protein resulting from the drop in pH during chilling, (see figure 1) together with the better sanitary control afforded by chilling would make me opt strongly for a production schedule based on chilling all carcasses.

Subsequent to boning, the meat should be run through a coarse grinder. If the meat is to be cooked in separate equipment from the dehydrator, then it may be advantageous to grind after cooking (USDA).

During either the grinding or cooking phase an antioxidant should be added to the meat. This is because dehydrated meat is very subject to flavor deterioration resulting from lipid oxidation. Oxidation occurs both during the drying phase and during subsequent storage. A good antioxidant would be a mixture of ascorbic acid and either NDGA, BHA or similar compound. The regulatory authorities of the country where the work is contemplated should be consulted to determine what antioxidants are permitted for food use.

The choice of dehydration equipment depends heavily on economic factors. The availability and suitability of existing equipment, the size of the enterprise, the amount of money available, the talents of personnel, all play a significant part. Previous experience indicates that if ample funds are available, one of the best choices would be a vacuum rotary dryer. Such a drier should be large enough to handle the proposed throughput of the plant without mechanical strain. It should include a method of mechanical agitation, such as a revolving centre paddle, or a revolving shell which is polygonal in cross section. There should be a method of heating the meat in the drier (probably a steam jacket), both during a preliminary working stage and during drying. During preliminary cooking, the meat temperatures should be raised to about 74°C (165°F). During drying under vacuum the temperatures of the meat ought not to exceed 68°C (155°F). The whole process will be expedited if there is a means of carrying off excess moisture during the preliminary cooking stage. This may be done by passing hot air through the drier or by running the pump to provide a slight vacuum. During drying, the pump should be able to maintain pressures below 25 mm. of Hg. In the first stages of drying the pressure will, of course, have to be lowered with some caution since water at 25 mm. pressure has a boiling point of about 30°C. Such details of operation will have to be learned by the personnel on the spot since they are usually peculiar to each piece of equipment. Since the rapid evolution of water vapor will cool the meat, the greatest amount of heat will be needed at the beginning of the drying stage. Regulation of steam pressure in a heating jacket is probably the best means of controlling temperature in such a drier. (Noel, et. al., 1945)

A vacuum rotary drier such as the one described has the advantage of minimizing the exposure of the meat to air, thus minimizing the degree of oxidation occurring during drying, and retaining with the dried meat all the extractives including fat, which might otherwise be lost during cooking. Such a drier will yield a product of excellent organoleptic and nutritional value. One disadvantage of such a drier lies in the fact that it cannot be operated in a continuous fashion. However, very few slaughter facilities operate on a 24-hour day and, due to the time needed for cleaning and sanitizing, boning operations have to be shut down every few hours. Hence, a batch operated drier would only be a serious disadvantage in the very largest plant. Vacuum rotary driers of the general type described are available from several manufacturers in Europe and North America and their construction assumes rather sophisticated engineering and metal fabricating facilities. Such a drier, constructed of stainless steel, with a capacity of 1,000 lbs. (500 kilo) of raw meat and including vacuum pump and necessary driving mechanism for the agitator, but exclusive of instrumentation, would cost somewhere in the neighborhood of $95,000 in the United States. It should not be assumed that this figure would apply to any specific piece of equipment. It is given only to indicate the scale of such an undertaking and to establish an upper figure for capital cost of a dehydrator.

By far the major portion of the cooked dehydrated meat prepared during World War II was dried in modified equipment which was already on hand in most large packing plants. The usual piece of equipment employed was a rotary, through draft drier, which is a rotating heated cylinder, usually placed at a slight angle to the horizontal, and with internal fins or spirals, so that cooked wet meat can be fed in at one end and dry product expelled at the other. Such a drier is somewhat simpler to operate and is cheaper to construct than a vacuum rotary drier, and lends itself well to continuous operation. In use, the meat should again be precooked, perhaps in steam jacketed kettles or in a continuous cooker with a moving belt, to a temperature of 74°C (165°F). The use of an antioxidant is even more important here than in the vacuum dryer. In such a drier it is difficult to determine the temperature of the drying meat and the usual control is to adjust the temperature of the air so that there is a minimum amount of browning but still enough heat so that the exhaust air is about 68°C or higher.

Tunnel driers, where heated air moves through a tunnel in the opposite direction to the food are much used for drying vegetables, but are not, on the whole, well adapted to drying meat. However, they have been used and some may perform quite adequately, particularly where the meat is carried on a perforated belt. (Greensmith, 1971).

Drum driers are not well suited to producing dried meat. (USDA, 1944)

Cabinet driers are suitable for drying meat and are both simpler to construct and cheaper than the driers described above. In fact, there is no reason why one could not be built with simple materials almost any place in the world. All that is required is a relatively airtight cabinet arranged so that a stream of heated air will pass through the cabinet in which the meat to be dried is suspended on perforated trays or shelves. The air is driven by a suitable fan so that it passes over or through a heater (such as finned steam coils) as it enters the cabinet. A duct is provided to recirculate the air which leaves the cabinet back to the heater and fan. In such a drier the heat necessary is calculated by adding the heat required to evaporate water (1100 BTU/lb) to the heat needed to raise the air temperature the required amount. The usual figure used is that 1 cu. ft. of air requires 0.018 BTU to increase its temperature 1°F, or 1 gram of air requires 0.24 cal for a 1°C rise. The quantity of air required can be figured from the formula:

$$\frac{\text{Vol. of air required}}{\text{minute}} = \frac{\text{Heat required}}{(T_1 - T_x)\ (0.24)\ (D_A) + D_{wv}\ (0.47)}$$

Where T_1 = initial air temperature and T_x = final air temperature; 0.24 is the specific heat of air; 0.47 is the specific heat of water vapor; and D_A and D_{wv} are the specific gravities of air and water vapor respectively. The specific gravities and heat units must be expressed in the same type of units: that is, calories and grams/cu cm, or BTU and lbs/cu.ft.

In using a cabinet drier the meat is ground through a grinder with a coarse plate (about 1 inch holes) and precooked to at least 78°C (165°F). The cooked meat is transferred to the drier shelves and the fan started. Initial air temperature can be as high as 95°C, but as the meat begins to dry it should be reduced so that the temperature of the meat does not exceed about 68°C. Cooked meat dries more rapidly than raw meat, and, for this type of product, better results are generally obtained by precooking.

An interesting variation of such an air drier is an air flotation drier in which the particles of meat are floated on a rising verticle column of hot air and, as they become light enough through loss of water, are carried over from the top of the vertical drier into a collector. The air, of course, is recirculated through the fan and heater. Such a drier was built at Beltsville in 1943 entirely of plywood and sheet metal, except for the fan and heater. It could be operated continuously by feeding in cooked meat near the bottom of the vertical section. Both the cabinet drier and air flotation drier result in more fat being lost from the meat during dehydration than would be the case in a rotary drier, either vacuum or hot air. Aside from the economic loss, this can be a problem in cleaning the drier and could be a fire hazard during operation. For both nutritional and quality maintenance, it is desirable to retain all of the fat originally present in the meat in the dehydrated product. (Noel, et. al., 1945)

Many other types of driers can be used to produce dehydrated cooked meat, but those described above should serve to illustrate the principles involved and to emphasize the basic simplicity of the process. The capital equipment may be either expensive or cheap. Obviously, there will be some advantages to be had from the more expensive equipment, but they should not be great enough to prevent an enterprising and ingenious person from competing successfully with cheaper, and even with home made, qeuipment.

The important product characteristics to be achieved are (1) a moisture content of 10% or lower, (2) ease of rehydration, (3) good flavor and color, (4) absence of oxidation and rancidity, and (5) maintenance of nutritive value.

Packaging

If we may assume that our hypothetical ingenious person has learned to operate his equipment so that all the above characteristics are adequately achieved, the meat must then be properly packaged in order to preserve these characteristics. As we pointed out above, dehydrated meat is subject to rapid oxidation. This results in loss of color, loss of flavor followed by rapid development of off flavors, and loss of nutritive value. Thus, we can see that adequate packaging is an indispensable part of good production. Also, since the dehydrated product is quite light and of low density, it is desirable to compress it in order to reduce the package to a reasonable size.

The compressibility of dehydrated cooked meat was studied extensively during the war time investigation in England and the United States. The compressability was found to be influenced by water content, fat content, and particle size. Without reporting on these studies in detail, we can by summarizing the results, suggest the direction in which the modern operator ought to aim. Dried cooked meat samples will have, depending on fat content and method of dehydration, an initial density of between approximately 0.3 and 0.7, with around 0.4-0.5 typical for good quality samples. By compression at around 450 lbs/sq.in. this density could be increased to 1.0 within a rather wide range of particle sizes and fat content, provided the moisture content was greater than 5%. Since a moisture content below 5% is not desirable in any event this should present no problem. In order to prevent fat losses, compression should be carried out at temperatures of around 3° - 4°C. Although higher densities than 1.0 could be produced experimentally, this would not be practical, and a density of 1.0 was specified for packaged, cooked, dehydrated meat. (Hetzer and Hawkins, 1946)

The essential feature of the package for dehydrated meat is that it must be impermeable to both air and water vapor, and that no air be enclosed in the package beyond that amount which it is technically impossible to exclude. Beyond these restrictions, the shape, size, and material of the package will depend on the market for which it is intended. An evacuated or nitrogen flushed, hermetically sealed, tin can is obviously ideal for many purposes. For others, laminates of aluminum foil and plastic will be highly acceptable. If the dehydrated meat were being sold exclusively to reprocessors, for immediate use in soups or convenience foods, packaging in friction top cans might be possible and compression may not be needed. It is assumed that purchasers will set up their own specifications where their needs are sufficiently precise.

Control of Microorganisms

Since the process of dehydration does not destroy microorganisms, dehydrated meat must be produced under rigid microbiological control. This control can only be accomplished if strict sanitary precautions are taken in all phases of the operation, both before and during processing, and especially in all post processing handling. If the undried meat is heated to about 75°C, as we have recommended above, we should be assured of a low microbial load in the product as it begins to dry, and we ought to come out of the drier with a total count of less than 10^4 organisms/gram. It is important to remember that moist heat is much more effective in killing microorganisms than is dry heat, and effective pasteurization will only be achieved if the meat temperature is raised to the 75°C range before it loses any significant amount of its moisture. If the moisture content of the dried meat is below 10%, we will be assured of an A_w value for the dried meat of about .50 which is well below the limit for growth. A remaining problem, is then to be sure that no dangerous quantity of pathogens, or their toxins, have been preserved by the dehydration process, or gain entry after dehydration. This can be assured by maintaining strict sanitary controls through a quality assurance program. (Segalove and Dack, 1951)

Nutritive Value

In as much as dehydrated cooked meat does not seem to be as attractive a product to the general public as some new types, like freeze-dried meat, it is useful to remind ourselves of its excellent nutritional value. When compared in feeding trials to undried cooked meat, dehydrated meat was found to have growth promoting values that were equal to the undried meat. Comparisons with dried skim milk showed dehydrated cooked meat to be slightly superior in terms of the growth promoting value of its protein. (Hoagland and Snider, 1946) These findings were obtained in investigations carried out both in England and the United States with meat which had been dehydrated under carefully controlled conditions so that temperatures during its preparation did not exceed 80°C (in most cases 75°C was not exceeded). Thus severe protein denaturation was avoided. Growth promoting studies were carried out on dehydrated cooked beef, pork, and mutton with similar results for all three species. Even after 100 days of storage at 44°C the protein of dried pork retained its high biological value.

In addition to protein of high biological value meat, especially pork, is a superior source of B vitamins and their retention during dehydration is a matter of interest. When dried under good commercial conditions, dehydrated meat should be expected to retain from 60 to 90 percent of its original B vitamins (Orent-Keiles, et al., 1946). The addition of antioxidant improved vitamin B retention and drying from the frozen state did not seem to result in any significant improvement in retention. Even where the vitamin B losses were highest, dehydrated cooked meat, particularly pork, remains a good source of these nutrients.

Dehydrated Raw Meat

Because the dehydration of cooked meat implies, by its nature, a certain degree of protein denaturation and also imposes limits on the size of the pieces which might be dehydrated, there has been considerable interest in the drying of raw meat. Hypothetically, it is reasoned that if uncooked meat can be dehydrated, the nonheat denatured protein will be capable of more natural dehydration because the water holding capacity of the protein will be unimpaired. This would occur, not only because heating the protein decreases its solubility and water holding capacity, but also because heating shifts the isoelectric point toward the alkaline side, producing the lowest water holding capacity at a pH of about 6.1 (Lawrie, 1966). Because of these considerations, freeze drying seems particularly attractive. Then too, we know that freeze drying is used successfully for drying such delicate systems as living microorganisms and viruses, blood, tissues, and highly labile chemicals such as enzymes. Unfortunately, as we shall see, this hope has not materialized in the case of raw meat.

Freeze drying is based on the fact that water at temperatures below 0°C and pressures below 4.5 mm of Hg will pass directly from a solid to a gas when it is heated without going through the liquid phase. In a closed system, so long as the pressure is low enough, the temperature will not rise above 0° because heat will be absorbed to drive off the gaseous water vapor. (Desrosier, 1970). Biologists will recognize this as the familiar process of lyophilization.

The usual freeze drier, and the type generally used for meat, consists of a chamber like an autoclave, which can be closed against an airtight seal capable of maintaining an internal vacuum of 0.5 mm of Hg or lower. The chamber is fitted with hollow trays or plates through which refrigerant may be circulated. Provision is usually made to heat the plates, either by circulating hot water or steam through them or by electrical resistance heaters. The chamber is connected to a suitable trap (or condenser) and vacuum pump. The trap, which must be capable of rapidly capturing the moisture as it is released from the food, may be a cold trap or a dessicant, although mechanically refrigerated cold traps are most common. In use, the trays are loaded with prefrozen meat, such as frozen chops or thin steaks, and while refrigerant is circulating through the trays, the chamber is sealed and the vacuum pump started. When the pressure is lowered to about 1 mm or below, the refrigerant is turned off and the trays are heated. The system must be operated so that the capacity of the trap is not exceeded and the vacuum is constantly maintained. Toward the end of the drying cycle the temperature of the plates may be elevated to as much as, in some processes, 65°C, because by this time the moisture content is so low that no visible "wetness" of the tissue can be detected. Freeze dried meat is reduced to quite low moisture levels, under 1%. Tn order to determine the progress of dehydration, strain gauges are sometimes provided to monitor the weight loss of the product. There are many modifications of the type of freeze dried described, principally in the methods used to heat the plates and their shape and location. (Tuomy, 1971) At this writing a stainless steel freeze drier of the rather conventional type described, would cost, in the United States, something in the neighborhood of $75,000 for 100 square feet of shelf or tray capacity. This would represent a capacity of between 400 and 500 lbs. of meat. The figure given, $75,000, is only an approximate figure for capital cost of a hypothetical drier and does not include instruments or installation. It should be compared to the cost cited above for a vacuum rotary drier. It can be seen that capital costs for freeze driers are considerably higher than for thermal driers. Also, freeze driers such as the type described which depend on high vacuum operation, have no simple alternatives and are also rather expensive to operate, costing as much as 5 or more times as much as a thermal drier per pound of water removed.

Characteristics of Freeze Dried Meat

The supposed superior rehydration characteristics of freeze dried meat have not materialized and, although relatively large pieces can be successfully dried, their texture when eaten is tough and woody. This woodiness is very marked in the case of both raw and cooked meat which has been freeze dried. Dr. R. A. Lawrie, when he was at the Low Temperature Research Station, investigated this phenomenon and found that it was due to the precipitation of sarcoplasmic proteins around the muscle fibrils. He suggested that it might be avoided, or at least minimized, by using high pH meat as a raw material. This can be done by preslaughter treatments which inhibit glycolysis, but such treatments are not practical possibilities.

Another problem with freeze dried meat is its tendency to oxidize very readily. This is controllable to a considerable degree by good packaging and, to a lesser degree of antioxidants, but it is, nevertheless, a serious drawback to commercialization. Freeze dried poultry, especially chicken, is not seriously affected by woodiness as are pork, beef, and mutton--perhaps because chicken is inherently more tender, and some freeze dried chicken is now being used in dehydrated soups.

Freeze dried meat does have good flavor and its color is not unnatural. So far, all efforts to produce it have resulted in a very expensive product which has only a limited civilian market. It appeals mainly to the camper and outdoorsman, a limited but expanding market in Europe and North America. It does not seem to be a promising field for exploitation by new processors in developing countries. On the other side of the coin, however, I can relate that I was told by an official of a large American firm which was making freeze dried meat and discontinued their operations, that he thought a smaller firm might be able to succeed where they had failed because the scale of their operation could more nearly match the potential size of such a business.

Possibilities Other than Freeze Drying

Although freeze drying has not been successfully applied to raw meat preservation, there are some other likely possibilities which ought to be investigated. I will mention one or two briefly in case they may appear attractive to food scientists in developing countries who may be willing to investigate some "long shots."

Toward the end of the wartime studies, some attention was given to drying raw meat which had previously been frozen by hot air. In the experiments I refer to, the meat was ground, frozen by holding overnight in a refrigerator at -18°C, spread on the trays of a cabinet drier, and dried by circulating air at 50°C for four hours and 15 minutes. The resulting dehydrated meat had a moisture content of 3.8% and had the best flavor score of any of the samples tested (the other samples were all cooked, dehydrated meat), showed the longest stability on exposure to oxygen, and the best vitamin retention. This would appear to be an excellent product for further processing by soup makers or other users of dehydrated meat and one would think that, with some limited further experimentation, a successful and profitable process might be developed. It should lend itself very well to drying on a continuous belt, perhaps with a dry gas other than air.

Along the same lines, dehydration may be accomplished by circulating cold dry gas through a cabinet drier and, so long as the water vapor is continuously removed so that the partial pressure of water vapor is kept very low, the meat can be dried by sublimation from the frozen state without the need for expensive vacuum equipment. I have always wondered why such a system has not been more thoroughly investigated. Although it might not work for steaks and chops, it should be quite applicable to coarsely ground meat. Instead of a drying cabinet, such a system could employ a sort of fluidized bed where the gas was pumped through a bed of frozen ground meat. (Noyes, 1968).

Solvent drying of meat is another possibility and has already been the subject of at least one patent. The water of meat can readily be extracted by solvents, such as ethanol, and the solvents can easily be distilled and reused. In collaboration with a fermentation industry, or a petrochemical plant, such an approach might have definite economic possibilities in a developing country. (Thompson, 1965)

Since we have seen (fig. 1) that meat loses its moisture more readily at low pH, someone interested in an entirely new product might experiment with drying meat which had been prefermented at low temperatures (2° - 4°C) as is done for some sausages. Such a product would yield dried meat of unusual characteristics which could be used in novel products or for mixing with trimmings in the production of conventional dried sausage.

Problems and Limitations

The main difficulty faced by anyone interested in dehydrated raw meat and it applies in part to dehydrated meat in general, is the need to develop a market at the same time he develops a process. This is not an insurmountable problem, but it must be frankly recognized. Meat is a commodity which is commonly handled by purveyors in very large quantities, and businessmen, used to dealing in hundred thousands and even millions of pounds, are not easily disposed toward promoting a product with a smaller market potential. The present growth in North America and Europe of sales of convenience and frozen foods seem to offer an opportunity for dehydrated meats because of their uniformity and the ease with which they can be metered and distributed by automatic filling and packaging machines. However, if dehydrated cooked meat will satisfy this need well, and it does, there is little chance for dehydrated raw meat so long as it is made by an expensive process like freeze drying.

The possibility that large sales of dehydrated chops or steaks might develop, is quite remote, at least in the United States where the fresh chilled product is readily available and where domestic refrigeration is plentifully available for its preservation. It is conceivable that if dehydrated cuts were available at a low enough cost some market could still be developed for them in Western Europe, but it seems unlikely at this writing.

Partially Dehydrated Shelf-stable Products

Reference was made in the foregoing material to the importance of the concept of water availability to an understanding of food preservation. The microorganisms which are responsible, in large measure for food spoilage, are critically dependent on water for their ability to grow. Unless they can grow and reproduce they cannot spoil our food. It is well known that there are very definite minimum requirements for water which are specific for specific kinds of microorganisms. These requirements are expressed in terms of water availability, which is usually denoted by the symbol A_w and is derived from Raoult's law of vapor pressures (Scott, 1957). It is expressed as a decimal fraction which is also equal to the relative humidity of an atmosphere at equilibrium with the food in question. As was stated above, an A_w of .70 is the lower limit of growth for any microorganism known to be capable of growth on dried meat. However, nearly all dehydrated meat has an A_w value of below .50. Thus, there is a gap between the value of .50 and .70, or slightly higher, where spoilage organism could not grow, but which is not utilized by dehydrated meat as we generally think of it. This gap is filled by some traditional, partially dried products and by some new products of intermediate moisture content which are just now beginning to become available. It is very likely that among some of these products, either the new or the traditional, the meat processor of the developing countries may find his greatest opportunity.

Traditional Products

The traditional products of intermediate moisture content are many and varied and to outline the methods for their preparation would take a great deal of space and would hardly be necessary since they are already well known. They comprise such things as country cured hams and shoulders like the Norfolk ham of England, the Prosciutto of Italy, the Smithfield ham of America, or the Westphalian hams of Germany. The fermented dried sausages, which are produced in most European countries and in North America, and command there the highest prices of all meat products, are intermediate moisture foods which owe their keeping quality to their low A_w values and their acid content.

These products are all characterized by being cured with sodium chloride and nitrate and by subsequent drying, either in a smoke house or a special sausage dry room. As presently produced, such products try to maintain the original appearance and flavor for which they became famous, but a modern plant does not necessarily produce Norfolk hams exactly like a Norfolk farmer did 200 years ago. A producer in a developing country ought, in turn, to try to produce a product which would either be typical of some native cured meat product of his country, or else some entirely new product to which he could give his own stamp of individuality. An example might be found in the product known as "Lebanon Bologna" in the United States. This product was developed by German immigrants living near the town of Lebanon, Pennsylvania, and has little in common with either the famous City of Bologna or their own Deutsche Küche. It is now a famous sausage in its own right.

Anyone contemplating the marketing of such products on a world-wide scale from a base in a developing country would have a great many problems to overcome. These would include formulation and packaging problems as well as coping with many regulations imposed by importing countries. However, there is now a great demand for tasty meat products in many parts of the world and this would seem to be an ideal time for an ingenious food technologist to bring out a brand new line of African, or South American, or Polynesian meats. What is needed is to start with a basic curing process, adapt it to an industrial schedule, design a package which will insure the integrity of the product, and develop quality control methods that will maintain product uniformity. Marketing such products would be economically more desirable than shipping chilled carcasses. In the references at the end of this paper, I am including some general references which can help as a guide in some of the technical problems to be overcome. (Lawrie, 1966; Price and Schweigert, 1971)

New Products

Unlike the traditional cured products or the frankly dehydrated meat products, all of which are the result of modern industrial adaptations of ancient techniques, foods of intermediate moisture content are an entirely new attempt to create shelf stable products by consciously aiming at an A_w of between 0.70 and 0.75. This is the region where only a few molds can grow and these can be controlled by using mycostatic substances. It is also a region where meat would be edible without the need to dehydrate it. Such a product, while it would lack the favorable weight characteristics of freeze dried or dried cooked meat, might actually be even more convenient for use by the outdoorsman or the military consumer. The trick is to reduce the A_w to the required level without losing the natural moistures of the meat. Since Raoult's law indicates that increasing the number of molecules of a solute in a solution will reduce the vapor pressure of the solvent, the natural approach has been to add solutes. Salt is, of course, an obvious choice, but is self limiting at around 3%. Sugar has been used successfully in producing moist, shelf stable non-canned, dog food; but too much sugar is both nutritionally and organoleptically undesirable. Some of the glycols have been used to produce beef stew with good keeping quality in flexible plastic packages. This work has been done in answer to the needs of military procurement, but it points the way to a promising new market. The success of moist, intermediate moisture, pet food has demonstrated that such foods have a degree of eye appeal and ought to succeed as snacks and new types of handy foods.

Magnus Pike (1970) and N. W. Pirie (1967), among others, have commented on the possibilities of using for human food animals other than those with which we are generally familiar. If this is to be successful, it seems to me the first attempts will probably be made in some of the developing countries where such animal resources may now be found. In order to overcome a psychological bias among Europeans against their use, they might well be introduced in a novel form. An intermediate moisture product with a mildly acid pH (perhaps produced by adding KH_2PO_4, which would both reduce A_w and synergize added antioxidant) might make an excellent vehicle for a meat new to our experience.

Quality Control Methods

The large meat packer who may produce dehydrated meat will have no problem in setting up a quality control program. For the small operator, or the new producer in a developing country, however, this may present more than a few difficulties and some guidance may prove helpful. Uniformity of product and strict adherence to specifications are absolutely essential to a successful operation. The potential customer for the producer in a developing country will probably be a food processor in a developed country who uses dried meat in his products. He must be able to count on the expectancy that each order he receives will have the same chemical composition and the same organoleptic qualities. Since the producer will usually have to buy the livestock or raw meat which is offered him, the only way he can sell a uniform product is by blending batches, and he can only do this by having a reliable chemical analysis for each batch. He can obtain this either by sending samples to a consulting laboratory or by conducting the analyses in his own plant with his own staff. The latter alternative is usually the best and is worth some degree of additional expense. However, this decision will depend on how great the expense is, and on other factors which can not be prejudged but must be left to the decision of the operator. If he decides to have his analytical work done by an outside laboratory, he should at least be familiar with what the laboratory does and have an idea of how they go about it. What follows is intended for the guidance of the small operator interested in a minimum laboratory capability. It is assumed that others will already know how to proceed or will already have facilities.

Bacteriological Procedures

The bacteriological procedures present a somewhat more difficult problem for the small processor than do the chemical, largely because the average high school (or its equivalent) gives a kind of training which enables the student to perform simple chemical tasks but seldom provides comparable training in microbiology. It may therefore be necessary to enlist the aid of a local hospital technician or a consulting laboratory. However, the techniques needed are relatively simple and anyone who has completed a beginning laboratory course in microbiology should have no difficulty with them. Some facilities will be needed. These will include two small incubators or water-baths, one for 37°C counts and one for 20°C counts. The 20° incubator can be a waterbath housed in a refrigerator, if a refrigerated incubator is not feasible. Sterile media can be purchased ready to use or media can be prepared. In the latter case a small autoclave or large pressure cooker is needed. A domestic baking oven can be made to do service as a dry sterilizer for pipettes and glassware.

For monitoring plant clean up and for checking raw materials and finished product, total counts will sometimes have to be run. Counts at 20°C can tell us a good deal about the condition of the meat entering the dehydration process. No specific figures can be suggested, but each plant can learn from experience what is normal for its environment. Counts on the finished dehydrated product will often be required by purchasers' specifications and, in any event, the reduction in numbers can tell us a good deal about how well the whole process is working. Too great a reduction could indicate that we have allowed our temperatures to get too high, while too small a reduction might mean too low a temperature, indicating too rapid a dehydration rate.

Tests for specific groups of microorganisms such as Salmonellae, staphylococci or putrifactive anaerobes may be required to meet specifications. In such instances the specifications will usually indicate the sampling procedures and the method of identification to be used. If not one of the standard methods from any of the many texts can be chosen, the chapter on Quality Control Methods for Meat and Meat Products in the second volume of Kramer and Twigg's Fundamentals of Quality Control (Sulzbacher, 1973a) will furnish a good guide. Also the meat inspection services of many countries publish laboratory manuals of the methods they use and these are good methods for those dealing with the respective services to use. In any event the purpose of the plant laboratory is not to make the final critical analysis. This should always be made by some neutral referee who can adjudicate between buyer and seller. The plant laboratory is a monitoring device to make sure that all is going well and that the product remains within the tolerances set.

Chemical Procedures

The important chemical facts which will need to be known about each batch of dehydrated meat will be the water and the fat content. If the percentages of water and fat are determined, and three percent allowed for ash, then the sum of these subtracted from 100 will give a very good estimate of the protein. If salt has been added to the product, then the allowance for ash must be increased by a comparable amount.

Water can best be determined by drying to constant weight in an oven at 102°C or by a distillation method, if results are needed in a short time. Sulzbacher (1973a) and Tate and Warren (1936) described distillation methods for moisture. They are easy and quick, but oven drying is just as good and may be simpler in situations where immediate results are not imperative.

Fat can be determined by any of the several solvent extraction methods such as the Soxhlet or Goldfisch or by a modified Babcock procedure. The continuous solvent extraction procedures require somewhat more expensive apparatus and are more time consuming. Where a large number of samples are handled on a continuing basis, however, they are cheaper in the long run. Any text on food analysis will describe them adequately.

Of the many modified Babcock methods which have been used for meat, the one of Whalen (1966) appears to be one of the best. It is also described by Sulzbacher (1973a). Modified Babcock procedures seem attractive for the developing countries since the basic Babcock Test for milk is so widely known and equipment for it is often found in locations where other laboratory materials are unknown.

It is generally agreed that the capacity of dehydrated meat to reabsorb water when it is rehydrated is an important indicator of its quality. In order to determine rehydration capacity so that it can be used as a quality measurement, some reproduceable technique for its measurement is needed. The method of Hankins and Hetzer (1947) is a good one and is easy to carry out. Ten gram samples of dehydrated meat are soaked in distilled water for one hour at 28° to 30°C (room temperature). The samples are then drained of water and transferred to tared centrifuge boxes with bottoms made of an open wire mesh covered with coarse filter paper. The boxes are centrifuged at 1500 RPM for 40 minutes and weighed. The amount of water retained by 100 grams of dehydrated meat is calculated and is termed the rehydration value.

This method of determining rehydration value is not a widely recognized standard and can therefore be varied to suit the needs of the individual plant or operator. It is very important, however, that once a modification of the basic method is decided on, it be strictly followed in all instances. If one wishes, the result could be calculated on a basis of grams of water retained per 100 grams of protein. This refinement would add slightly to the precision of the method, but was not considered a significant improvement by the original authors. This measurement of rehydration capacity is perhaps the best tool the operator has for selecting between variables in raw materials, equipment, processing schedules, or other factors.

More involved chemical analyses are the province of the professional chemist who will know how to go about them without this elementary description. They would include protein analysis, both total protein and some tests of protein quality. Also tests like peroxide numbers or TBA numbers to determine fat quality.

Sampling Procedures

In any quality control program sampling is of basic importance. A representative sample is difficult to obtain in any situation, but in the case of dehydrated cooked meat, one can at least get good mixing because of the physical state and size of the particles. This goes a long way toward giving meaningful laboratory results. For bacteriological and chemical analysis one should start with a sample of about 1 kilo which has been drawn at random from the well mixed batch of product. In the laboratory this sample should again be mixed by tumbling in a large jar or special mixer, and subsequent samples taken from it. Bacteriological tests should start with 50 gram portions which can be mixed with sterile diluent in a blender, and diluted further to give the needed aliquots for plating or inoculating tubes. Chemical samples for moisture, if one is using a distillation method, should employ portions of the well mixed original. The chemical samples should be taken from a 200 gram portion which has been ground through a mill to reduce the particle size and remixed. The larger original particle size is helpful in reducing bumping when determining moisture by distillation. A portion of the original kilo should be reserved in an airtight jar, stored in a refrigerator for reference in case of doubt or dispute.

In a small plant, let us say for the sake of hypothesis, one dehydrating one to three thousand pounds of raw meat per week, one technically inclined employee and one or two willing assistants should be able to oversee all the technical phases of operating the driers and conducting a simple quality control program. Larger plants are assumed to already have a quality control staff and will know how to add the dehydration samples to their other work.

If determination of nutritive values are required, samples had better be sent to a specialized laboratory, other than for total calories, which can be calculated from the proximate analysis.

Summary and Conclusions

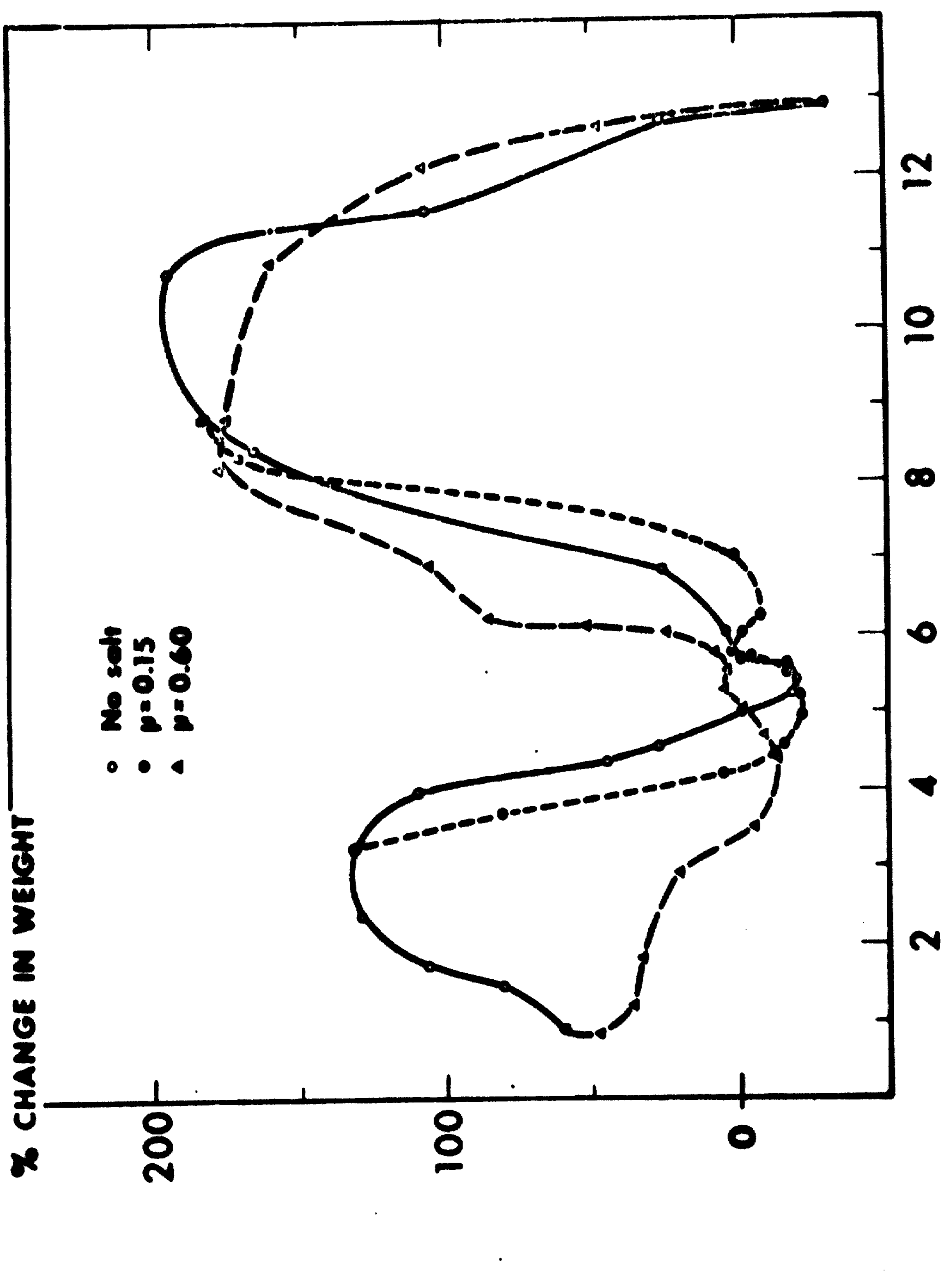
Dehydrated meat can be produced by many processors at rather widely varying capital costs. Very adequate equipment can be simply constructed and still yield good results. Dehydrated cooked meat is easier and cheaper to produce than dehydrated raw meat and is, all in all, a more satisfactory product. The case with which dehydrated meat can be produced makes it seem a natural choice for the meat processor in a developing country with a plentiful supply of livestock. One is usually prone to think of dehydrated meat, or any processed food produced in a developing country, as an item of world commerce. The good nutritive qualities of dehydrated meat, however, should not be overlooked as a means of improving domestic diets. Considerable attention has already been given to the possibility of mixing dehydrated meat with cereal products in parts of Africa where the protein quality of the dietary is low. A good deal could be done by extending this thinking to the food of many other parts of the world.

Meat dehydration is a process which should fit very well into an integrated livestock growing and processing facility. A selection of carcasses could be made so that those not ideal for block cuts could be reserved, together with other suitable trimmings for dehydration. Since most dehydrators operate as batch processing devices, it is not particularly disadvantageous to operate them intermittently, and dehydration could be one of several means by which the plant's product was marketed.

As a further extension of this idea, dehydrated meat from an integrated processing facility could form part of the raw materials of an associated food processing facility where convenience type dehydrated meals were processed.

In the foregoing material I have tried to give an overview of meat dehydration, touching on specific ideas for food scientists and also on general concepts for planners. To save space and to spare the patience of the reader, very few ideas have been developed to any great degree. Those who would like to explore this area in greater depth are referred to the references which follow.

Fig. 1. Relationships between salt, pH, and moisture holding capacity (from Sulzbacher, et. al., 1960).



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