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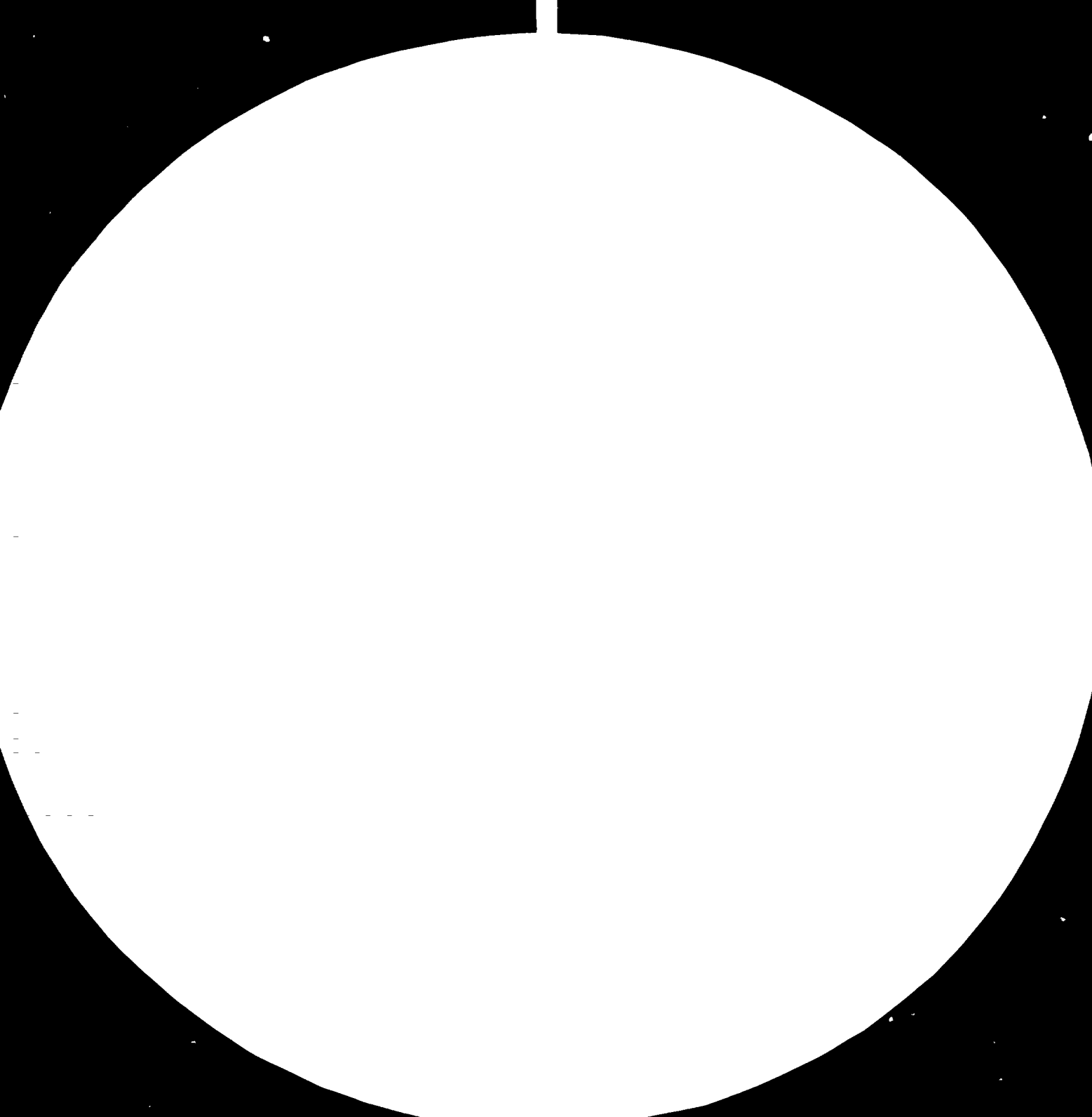

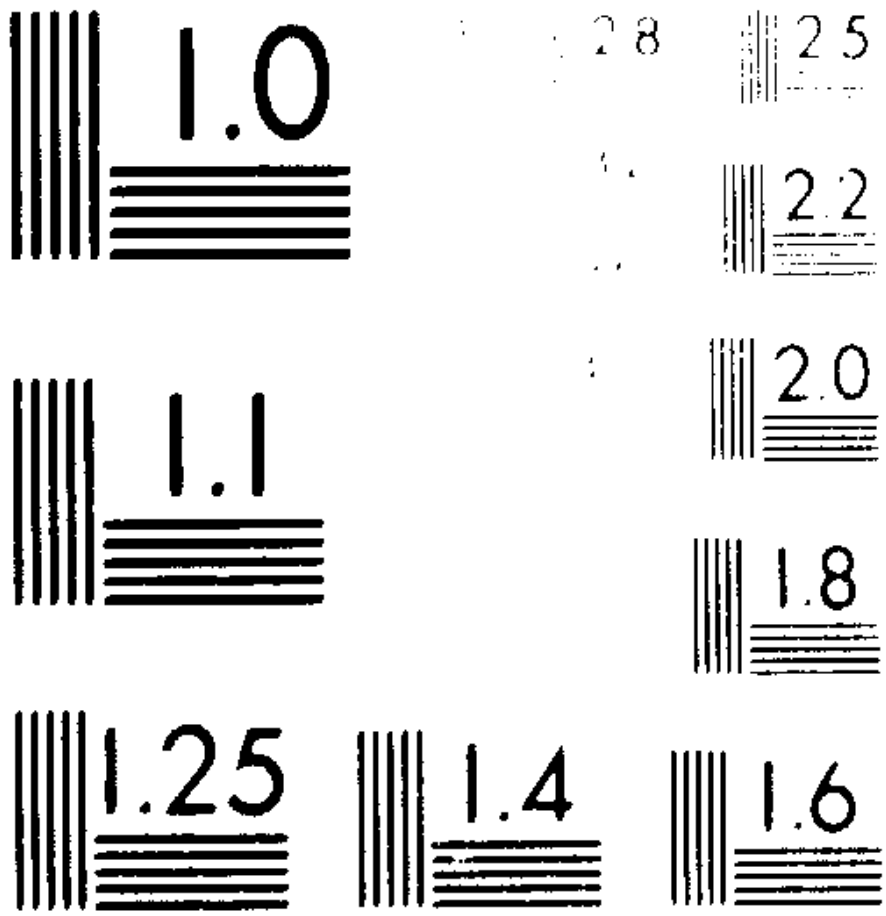
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CONSOLIDATION OF THE MEXICAN INSTITUTE FOR ASSISTANCE TO THE INDUSTRY

DP/MEX/78/011

MEXICO,

Technical report: Production of flexible packages *.

Prepared for the Government of Mexico
by the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of Seymour T. Gilbert, expert in the production of flexible packages

United Nations Industrial Development Organization
Vienna

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TABLE OF CONTENTS

	page
Objective of the project	2
Introduction	2
Accompishments for this mission	4
Findings and recommendations	8

ANNEXES

I.	List of recommended equipment	9
II.	The sterilizable flexible package	10
III.	Control de calidad en envases flexibles esterilizables	17
IV.	Food preservation by use of high temperatures ...	20

OBJECTIVE OF PROJECT

To advance the capabilities of the Mexican Institute for Assistance to Industry (I. M. A. I.) in the field of packaging with special attention to advanced training in flexible package technology and to aid in the planning of pertinent projects.

INTRODUCTION

The Institute is presently housed in temporary quarters in the grounds of the National Laboratories for Industrial Promotion (LANFI) which was created in 1948. The I. M. A. I. was constituted in 1977 under the present Director General, Dr. Juan Antonio Careaga V.

Major current research programs include the following:

(1) Substitution of tin plated cans by alternate packaging materials

(2) Flexible and retort packaging.

(3) Preservation of perishable agricultural products.

(4) Toxicological and microbial research on foostuffs.

(5) Food processing and packaging of basic products.

The equipement is being developed for these tasks. The personnel, while of excellent basic scientific training, have only limited experience in packaging science and tecnology. The food related sciences are represented by persons with good academic training in these areas.

The inadequacies of space, equipement and training are being provided at a well organized rate of development which includes a building under construction, the proposed purchase of $ 4000,000.00 U. S. of equipement and the extensive training program in which I participated.

Financial support is from both the United Nations Organization and the Mexican Government. The budget is being used mainly for expanding the tecnical capabilities of I. M. A. I., by purchase of equipement for conducting the more sophisticated modern packaging tests as a service to Mexican Industry. I. M. A. I., has already recruited persons capable of operating with such advanced technology as was shown by our work in laboratory projects at LANFI.

The prospects are excellent for early and effective use of their budgeted additional equipement. Such purchase will also enable further expansion of the training program in Mexico without requiring extensive travel abroad.

Accomplishements

The project was divided into the following parts:

(1) Lectures and demonstration of the principles of Storage Life of Food Products. A series of laboratory exercises were conducted on packaging of fresh product and on fatty low moisture foods to provide a wide coverage of food types.

(2) Lectures and demonstrations on Gas and Water Vapor Transmission (Permeability) of Flexible Films and Packages with particular reference to the prediction of storage stability of foods in various alternate packaging systems. The equipement used was the Gilbert-Pegaz cell with accessories which was brought to I. M. A. I., by Mr. Luis Madi, the previously assigned expert, after construction under my supervison in the United States of America.

A gas chromatograph was made available for this work at LANFI with IMAI, persons previously trained in G. C., assigned to conduct the test as arranged prior to my arrival.

(3) Lectures and laboratory project on Fresh Produce Packaging
Tomatoes of different degrees of ripeness were packaged in various films and the effect of CO_2 / O_2 gas permeability on quality change during storage evaluated. The objective was to establish methodology for improving the quality of various types of Mexican fresh produce under shipment to internal and external markets.

(4) Prediction of Shelf Life - a project intiated under Mr.Ma_ di's supervision on effect of water absorption of fatty food packaging was completed and a report prepared. This report presents a mathematical equation to enable calcula t.on for prediction and optimization of quality retention under different storage conditions. This project will pr_ vide a basis for extensive studies of alternate food packa ging systems.

While the present facilities are inadequate for precise work it was possible to establish the principles so that implementation of such projects can be made upon the projec ted availability of the necessary facilities for control of control of storage conditions.

(5) Lectures and laboratory demonstration:

Methodes for Identification of Composition of Various Packaging Films and Laminates.

A companion lecture on Mechanical Properties was supplemented by work with the Instron, shock and vibration equipement avaliable at I. M. A. I.

The chemical analysis laboratory of LANFI was made available for demonstration of methodology applicable to packaging studies.

I. M. A. I., has in the procurement budget corresponding special equipment which is essential for further progress.

(6) Lectures and laboratory demonstrations of Safety and Quality of Packaging Material for protection agains the presence of hazardous substances (indirect food additives) which may migrate from package to contained food.

These included plasticizers, residual solvents from printing and residues of potentially toxic monomeric substances (e. g. vinyl choride) in fabricated package of polymeric material. (Instruments were used as stated in 5).

(7) Development of alternate Packages to Tin Plate. This project was developed to an action plan and implementation was made during the latter period of the mission.

A Manual for Quality Control Flexible Retortable pouches was prepared and translated into Spanish Equipement for testing burst and temperature change during retorting was designed and plans for fabrication have been made.

The Stock Retort of LANFI was fitted with racks for pouches will be tested for use as a Pouch Retort.

Test for safety from health considerations were inagurated as per 6 above.

A development program initiated with CELLO PRINT, S. A., to fabricate pouches to be tested by I. M. A. I.

FINDINGS AND RECOMMENDATIONS

The present staff, equipment and physical facilities are undergoing a rapid development to enable a fully operational institute by the end of this year. The overall plans and projects are realistic in terms of the needs of Mexico and its packaging industry. The recruitment and training of operational personnel is well advanced so that additionally needed equipment will be properly used when available.

A major improvement is needed in developing strong relations to pertinent industrial organizations but this may await the full development of I. M. A. I., when its value to Mexican industry can become a major factor in such technological assistance.

ANNEX I

LIST OF RECOMMENDED EQUIPEMENT

1. VACUUM GAUGE
2. AUTOMATIC HEAT DISTORTION TESTER
3. PUNCTURE TESTER
4. FALLING DART IMPACT TESTER
5. IMPACT RESISTANCE TESTER.CHARPY/IZOD
6. TABER TYPE ABRASION TESTER
7. ELMENDORF TYPE INTENSITY TEARING TESTER
8. MULLEN TYPE BURSTING TESTER
9. ROLL COATER
10. HEAT SEAL TESTER MODEL 1 TYPE
11. SPECTROPHOTOMETERS INFRARED PERKIN-ELMER X 99 SERIES
12. DIFFERENTIAL SCANNING CALORIMETER PERKIN-ELMER WITH THERMOMECHANICAL ATTACHMENT
13. CONSTANT TEMPERATURE AND HUMIDITY CABINET WITH REFRIGERATOR
14. MOISTURE PERMEABILITY OVEN

ANNEX II

THE STERILIZABLE FLEXIBLE PACKAGE (RETORT POUCH).

1. INTRODUCTION.

The history of the preservation of foods by heat sterilization now covers close to two hundred years. During most of this period the only materials which met the extreme requirements of heat and pressure of this process were glass and metallic containers provided with coatings to minimise chemical reaction with the food (tinplate and organic lacquers).

The past sixty years have seen the development of food preservation by retorting into a science as well as a technology. Rule of thumb processes have been improved by application of heat transfer theory, biochemistry of foods and microbiology so that a high degree of control of the critical factors for quality and safety has been achieved (Appendix 1).

Not all problems have been solved for this major source of stabilised foods. Among those still requiring attention are the deterioration of foods by corrosion of the metals and the fragility of glass. Economic factors of container weight and volume have assumed increased importance as the cost of energy for process and transport has risen exponentially in recent years.

The cost of transport is particularly important as not only has there been drastic increases in the distances between areas for food production and its consumption, but that the areas for further increases in world food supply, such as the subtropics, are often distant from the natural resources needed to produce metallic containers. Production of either metal cans or glass jars requires major capitalization for new installations which could place an untoward financial burden on developing nations.

Increased attention is now being given to alternatives to the rigid metal or glass food container. Amongst these are those fabricated from flexible barrier materials which provide for minimum bulk shipment from the producing plants to food production centres as they are in the form of rolls or flat stock. Package forms such as pouches also require less volume and container weight per unit of food. According to Silverman ( ), two truck loads of empty pouches will contain the same amount of foods as seventy-two truck loads of empty #10 cans.

Claims are also made for better quality and less energy input for the pouched versus canned foods ( ). The thinner profile of the pouch compared to the cylindrical shape of the can does shorten the process time for equivalent microorganism destruction (Appendix 2). Lower brine/food ratios in pouches also contribute to the decreased energy requirement along with better nutritional quality.

A major disadvantage of the pouch has been in its relatively slow filling speed - about 1 per second for pouches compared with up to 10 per second on the better can packing lines for containers of less than 500 grams. Where larger volumes are being packed however, e.g. 3 kg or more, the filling speed is limited mainly by the pumping rate of the product, and line output per kilo of product on a #10 can line and one filling 30 x 45 cm^2 pouches is approximately equal as the pouch, with an average filled thickness of 3 cm, holds 25% more product than the can.

On the overall basis - capital investment, transportation and package material costs per unit of food, and food quality - the larger size pouches provide a very good investment for developing a new processed food industry, especially in new food production centers such as Mexico and Latin America. Even in highly developed

nations such as the United States of America a rapid shift from larger cans to pouches is forecast ( ).

While economics appear to favor the development of flexible alternatives to rigid food containers, the technological problems are less favorable. The canning industry is mature, closely regulated and already highly capitalized. The technical knowledge of its materials and food processes are well developed with extensive production experience.

The retort pouch concept has been made recently possible by new materials and new technology and lacks the depth of experience in the critical process of heat sterilization (Appendix 3) Experience has taught caution in too rapid expansion of industrial technology without proper controls against new and unforeseen factors which grow in importance in proportion to total production. The danger here is especially critical for non-acid food products where errors can lead to deaths from microbial toxins such as botulin from improperly processed or damaged packages. The reduction in brine ratio, for example, may be less favorable for microbial control although of benefit nutrionally.

The major hurdle to the growth of the reort pouch is, therefore, the need for complete standardization of the process from materials. package formation and filling, sterilization and distribution. Defects will have to be of the order of less than one per ten thousand as delivered to the ultimate consumer to compare with present canned food standards which, on long experience, correspond to essentially zero risk of post-sterilization invasion of canned foods by toxic bacteria.

2. CRITICAL FACTORS IN RETORT POUCH PRODUCTION.

2.1. Retort process.

Since sterility is the ultimate factor in this product, the factors affecting the process should be given first consideration. Amongst these are:

Residual gas content.
Retort design.
Pouch materials.

2.1.1. Residual gas content.

The volume of residual gas affects seal integrity by the stress produced by pressure changes during the retorting cycle. A temperature rise of 150°C is equivalent to a pressure increase of 0.55 atmospheres per unit area. Since area is proportional to residual gas volume so will be the total stress on the seals from the expansion of the air space in the pouch.

The horizontally processed pouch with residual gas will also develop an insultating layer free of product. Since agitation may not be feasible for pouches as it is for cans, the transmission of heat by conduction can be so greatly reduced as to require as much as 35% increase in processing time ( ).

The relative merits of the various heat transfer media - steam and water - have been debated with results largely dependent on the specific retort system. The main problem is in the over-riding pressure which must be supplied to prevent seal rupture during the external decrease in temperature after completing the heat rise phase. Air over water and steam air mixtures are used in different retort designs.

2.1.2. Retort design.

The main differences between the can and the pouch retort are in the mechanics of loading and the geometric stability of the package during processing.

The more easily deformed pouch requires special racks to support and confine it during processing. Metallic racks also can facilitate heat transfer by direct conduction using circulation of superheated steam or water through hollow rack walls.

The water circulation system in the FMC type retort is of special utility since it enables minimization of process water volume and conservation of heat energy by recirculation from a heated reservoir. Steam is usually vented with consequent heat loss. The control of pouch temperature, however, can be more critical with minimal heat transfer fluid.

Rack designs are also being suggested to allow for pouch agitation despite the weakness of the thermoplastic seals at maximum retort temperature.

From the foregoing it is clear that considerable development in retort pouch technology is required as new package sizes and shapes are developed beyond those used in the present commercial experience which is mainly Japanese.

2.1.3. Pouch materials.

Whereas can materials have been well standardized the pouch, as yet, does not have a set of standardized, proven quality control specifications and test.

The most widely used pouch construction is a three ply laminate of polyester, aluminium foil and polypropylene, and is thus more complex in construction than a tinplate can. The food surface contact problems, however, are not as critical for the thicker, homogeneous, relatively inert polymer compared to the metal coatings of tin or lacquers.

The main problems for the pouch quality are the properties of the individual components and the degree of bonding to each other. The bond strength and coverage of the adhesives must also meet the additional complications from stresses induced by the extremes of temperature and pressure encountered during processing.

While the thermoset urethane adhesives of the linear polyester/isocyanate types have proved operationally successful, the use of toluene di-isocyanate (TDI) as the crosslinking agent has failed, as yet, to win approval by the US Federal Food and Drug Administration (FDA). The regulations based on the Delaney clause prohibit the presence in the food of any potential carcinogen such as the aromatic amines formed from unreacted TDI monomer. Proof is demanded by the FDA that this adhesive will not transfer such residues in the manufactured pouch to the packaged food. Since the absence of such residues is dependent on the convertor's process the proof must be based on the laminating process and its control.

These legalistic considerations make questionable the future use of this adhesive system in the United States of America. The psychological and political effects on other countries of the use in other countries of materials not approved by the FDA cannot be overlooked.

The presently approved pouch material in the USA has a preformed polymeric adhesive such as amorphous polypropylene. This material can be subjected to strict control for undue toxic residues such as catalysts prior to use by the convertor as an

FDA "food approved" adhesive. The urethane system on the other hand requires polymer formation as part of the laminating process.

It is quite likely that any other system which will be approved will also use preformed polymeric adhesives, or at least high molecular weight intermediates not capable of migration into food.

The urethane system is easily adaptable to the most widely used dry bond laminating equipment of the convertor as a gravure solution application. The extrusion or hot melt lamination of the FDA approved system requires special equipment now available only to certain major convertors. This advantage over competition has resulted in a lack of enthusiasm by the major USA convertors for continuing the battle with the FDA for approval of the urethane system.

2.2. Quality control of incoming materials.

Incoming pouch material must be tested as either roll stock or preformed pouches. Roll stock presents a difficult sampling problem since variances within the roll cannot be inspected prior to use. Devices for inspection during unreeling are presently too costly and of questionable accuracy.

The critical factors of incoming materials are :

(i) Composition.
(ii) Bond strength.
(iii) Resistance to delamination by process and food contact.
(iv) Interaction with food directly or by mass transfer.
(v) Barrier properties.
(vi) Absence of undue residual toxic material which could become an indirect food additive unregulated by the FDA.
(vii) Sealability and seal strength.

The last item is best tested on pouches without food. Thus the main advantage of the purchase of preformed pouches to the food processor is a much simpler quality control system since the entire lot can be sampled by a reasonable number of pouches in an AQL procedure for a qualified supplier.

The same tests could be used with form, fill and seal roll stock but this would require rapid testing in coordination of a sequential interruption of filling to provide samples for a Shewart type of continuous quality control (accepted deviation limits and randomization with time) to predict any trends toward the production of defective pouches.

The available time for testing and the degree of quality assurance is thus much greater for preformed pouches.

Filled pouches, whether from roll stock or preformed, require additional testing which will be covered in a later section.

3. PRODUCTION CONTROL ON POUCHED FOODS.

3.1. Incoming materials.

A food processor must initiate control of incoming materials. Exclusive of the food ingredient phase, the packaging material tests must be made on empty, formed packages. Thus for a new operation, the Japanese system of purchase of preformed and tested pouches is preferable to the high speed continuous operations developed by the Natick Laboratories of the USA Army. The apparent economies in material

and labor costs of the high speed operation should be considered only in terms of future expansion of an established market.

While the food processing control is the sole responsibility of the food manufacturer it is quite probable that the major pouch suppliers will provide technical assistance for pouch food processing at least as equivalent to that provided in the past for can retorting.

3.2. Process control.

The standards presently used for cans will generally be required for pouches. Records must be kept of all process variables including viscosity and time/temperature cycles. Bacteriological positive controls (innoculated packs) are mandatory. Test pack incubation must be done prior to release of any batch for sale. Checks on composition and nutritional quality will be required at least for any major market.

3.3. Shipping and storage requirements and control.

These will be stricter for the pouch. Some of the economies of material and space of this form of package may have to be sacrificed for the stability provided by cartoning the pouches. The high speed Klik-Loc system widely used in Japan in consumer marketing also allows for more effective graphics for consumer appeal.

While the institutional pouch will require specific designs for its transport the economies allow for wider latitude in design.

Much remains to be developed in the physical problems of marketing. The Japanese experience is largely confined to distribution in short time/distance chains. Countries like the USA and Mexico will require storage and transport systems adapted to their own situation, particularly in the case of Mexico where export markets may dominate.

4. SELECTION OF FOODS FOR RETORT POUCH PRODUCTION.

4.1. Classification of foods.

4.1.1. Stability factors.

Foods can be classified as either perishable or non-perishable under ambient storage conditions. Each class can be further divided into sub-classes according to lipid content. In general the degree of perishability is directly related to moisture content. Thus sugar, wheat and corn flours, dried legumes etc. are primarily non-perishable, or low moisture content. The principal packaging requirement is protection against moisture gain and from insect and rodent damage. Since microbial deterioration is prevented by adequate moisture barriers sterilizable containers are not needed.

When these foods are processed by cooking to gelatinize starches they enter the perishable class and would require either re dehydration or retortable packaging.

Fresh produce is an example of highly perishable food. While some delay in spoilage can be achieved by controlled atmosphere storage or package gas permeability, satisfactory shelf life requires processing such as dehydration (potato granules), canning with retorting, or freezing. All of these processes are designed to minimize or eliminate microbial deterioration.

4.1.2. Secondary foods.

Secondary foods are those representing mixtures of different foods. Stews, sauces

etc. are examples of such types. and much food is consumed in this form rather than in its original, more stable, state. Secondary foods are the prime candidates for the use of flexible reortable packages.

4.1.3.Commodity items.

The commodity items - peas, carrots, chili. tomato pastes. cooked fruits (pineapple, peaches, citrus segments) etc. - are also important candidates for the use of flexible rather than rigid (can) retort preservation. The better keeping quality of non-metallic contact of such foods can be a considerable advantage in addition to material and process energy savings.

4.2. Selection of candidate foods.

Three major classes of food emerge as potentials for the reort pouch project.

4.2.1. Commodity items.

Commodity items in institutional as well as consumer size packages, including many of the fruit and vegetables commonly marketed in tinplated cans. The individual rating would depend on the following:

(i) Amount, location and economic values of Mexican production.
(ii) Quality factors more favorable to the pouch system than to the can (metal pick-up, discoloration, corrosion etc, reduced brine requirement).
(iii) Nutritional and hedonic factors.

4.2.2. Speciality items.

Sauces and condiments as added ingredients to other foods. Guacomole and enchillada sauces could be examples of such stablized adjuvents to more calorie dense foods.

Main food entrees such as beef stews. steaks in mushroom sauce, meat pies and much of the frozen food specialities could benefit from the better quality from less thermal input than in canned versions. While the quality may not equal the best frozen equivalents after long storage times at ambient temperatures, the energy cost differences alone will promote the retorted flexible system.

4.2.3. Bulk food ingredients.

A major agricultural development of today is the bulk shipment of food ingredients from rural areas to urban centers of final food preparation, or to act as ingredients for formulations using non-indigenous compounds. Mushrooms, onions, and tomato pastes are now transported in international trade in bulk quantities. This is particularly true for developed countries such as the USA and Western Germany where high industrial development and reduced agriculture has created demands for speciality food items such as dehydrated mushrooms which are now principally imported from Taiwan where production costs are much lower. Mexico, particularly with expansion of irrigation facilities, is already in competition for such markets on the basis of climate and a large farming oriented population.

5. SUMMARY.

The replacement of metallic sterizable containers by flexible materials offers a major economic benefit to Mexico from reduced costs for materials and transportation. The development of petrochemical materials particularly favors the flexible alternative to the tinplate can.

There are also major advantages in Mexico for food production in rural areas.

Minimal investment in package production and in transport to rural food production will increase indigenous supplies of food stablized against spoilage, as well as lessening seasonal fluctuations in availability. Urban waste reduction and better byproduct utilization will accrue from packaging at farm production centres.

Development of the report pouch concept on a commercial basis should be confined to preformed pouches shipped to food production centers equipped with proper retort and cartoning facilities. The better quality control possible with centralized production can be achieved without the extra cost of transport of empties as for cans.

The major problems for Mexico are the food related ones such as filling, sealing and retorting. The principal initial obligations of IMAI appear to be in setting standards for pouch materials and for the food processing and packaging aspects of the total system. The development of economically and socially desirable food types and their processing is also part of this overall function.

ANNEX III

CONTROL DE CALIDAD EN ENVASES FLEXIBLES ESTERILIZABLES

(RETORT POUCH)

LAS DETERMINACIONES PARA EL CONTROL DE CALIDAD SE DIVIDEN EN: PRUEBAS A MATERIALES Y PRUEBAS AL ENVASE.

ENTRE LAS PRUEBAS QUE SE DEBEN REALIZAR A MATERIALES ESTAN:

I./ PRUEBAS DE IDENTIFICACION A MATERIALES. Determinación por espectroscopía infrarojo de los diferentes materiales plásticos q ue componen la laminación.

1.- ESPECTRO INFRAROJO DE POLIESTER
2.- " " DE NYLON
3.- " " DE POLIPROPILENO
4./ " " DE POLIETILENO ALTA DENSIDAD

2./ EN LA PARTE CENTRAL DE LA LAMINACION SE ENCUENTRA LA HOJA DE ALUMINIO A LA CUAL SE LE DEBE DETERMINAR:

1.- ESPESOR
2.- EL NUMERO DE PUNTOS O PERFORACIONES QUE TIENE LA HOJA POR METRO CUADRADO.

3./ EN LA PARTE INTERNA DE LA LAMINACION SE ENCUENTRA EL POLIPROPILENO o'POLIETILENO ALTA DENSIDAD, A LOS CUALES ADEMAS DE IDENTIFICARLOS POR INFRAROJO SE LES DETERMINA:

1.-SOLUBILIDAD
2.-TEMPERATURA DE PUNTO DE FUSION
3.- FUERZA DE SELLADO POR CALOR

4./EN LA PARTE INTERNA DE LA LAMINACION IDENTIFICAR: URETANOS(ADHESIVOS)

1.- ESPECTRO INFRAROJO DE URETANO

2./ SOLUBILIDAD EN XILENO CALIENTE

3.-RESIDUOS VOLATILES COMO TDI (estabilidad al calor de los residuos volátiles por el método HOT JAR)

5./EN LA HOJA LAMINADA ANTES DE FORMAR EL ENVASE SE DEBE DETERMINAR :

PERMEABILIDAD A GASES Y VAPOR DE AGUA POR AMBOS LADOS DE LA LAMINACION

LAS PRUEBAS PARA EL ENVASE SE DEBEN REALIZAR CONSTRUYENDO UNA BOLSA TAMAÑO ESTANDAR.(DISEÑO DEL ENVASE)

1.-DETERMINAR TEMPERATURA OPTIMA DE SELLADO.

2.-RESISTENCIA AL REVENTAMIENTO DE LA BOLSA

3./PRUEBA DE CARGA ESTATICA

4./ DEFECTOS DEL SELLO

5./ EXTRACCION DE COMPUESTOS NO VOLATILES E IDENTIFICACION POR ESPECTRO INFRAROJO

6./ EXTRACCION DE COMPUESTOS VOLATILES E IDENTIFICACION POR CRO/ MATOGRAFIA DE GASES.

7./ PRUEBAS DE VIBRACION

8./ PRUEBAS DE CHOQUE

9./ PRUEBAS DE SESION DEL SELLO (fractura, ruptura y pérdidas del sello)

10.-DELAMINACION

I1./PRUEBA DE PRESION INTERNA

I2 ./ PRUEBAS DE PENETRACION DE CALOR (ESTERILIDAD)

I3.-FUERZA DEL SELLO POR LOS CUATRO LADOS

I4.-PRUEBAS DE ESTABILIDAD DEL PRODUCTO(DETERMINACION DE VIDA DE ANAQUEL) A DIFERENTES CONDICIONES.

I5./PRUBAS DE SIMULACION DE TRANSPORTE

ANNEX IV

FOOD PRESERVATION BY USE OF HIGH TEMPERATURES

The use of high temperatures to preserve food is based on their destructive effects on microorganisms. By high temperatures are meant any and all temperatures above ambient. With respect to food preservation, there are two temperature categories in common use: pasteurization and sterilization. *Pasteurization* by use of heat implies either the destruction of all disease-producing organisms (e.g., pasteurization of milk) or the destruction or reduction in number of spoilage organisms in certain foods, e.g., the pasteurization of vinegar. The pasteurization of milk is achieved by heating at 145°F for 30 minutes, or at 161°F for 15 seconds (high temperature short time—HTST method). These treatments are sufficient to destroy the most heat-resistant of the nonsporeforming pathogenic organisms—*Mycobacterium tuberculosis* and *Coxiella burnetii*. Milk pasteurization temperatures are sufficient to also destroy all yeasts, molds, gram negative bacteria, and many gram positives. The two groups of organisms that survive milk pateurization are placed into one of two groups: thermodurics and thermophiles. *Thermoduric* organisms are those that can survive heat treatment at relatively high temperatures but do not necessarily grow at these temperatures. The nonsporeforming organisms that survive milk pasteurization generally belong to the genera *Streptococcus* and *Lactobacillus*, and sometimes to other genera. *Thermophilic* organisms are those that not only survive relatively high temperatures but *require* high temperatures for their growth and metabolic activities. The genera *Bacillus* and *Clostridium* contain the thermophiles of greatest importance in foods.

Sterilization means the destruction of all viable organisms as may be measured by an appropriate plating or enumerating technique. Canned foods are sometimes called "commercially sterile" to signify that no viable organisms can be detected by the usual cultural methods employed, or that the number of survivors is so low as to be of no significance under the conditions of canning and storage. Also, micro-

organisms may be present in canned foods that cannot grow in the product by reason of undesirable pH, Eh, or temperature of storage.

FACTORS THAT EFFECT HEAT RESISTANCE IN MICROORGANISMS

It is well known that equal numbers of bacteria placed in physiologic saline and nutrient broth at the same pH are not destroyed with the same ease by heat. Some 11 factors or parameters of microorganisms and their environment have been studied for their effects on heat destruction and are presented below (Hansen and Riemann, 1963).

1. Effect of Water. The heat resistance of microbial cells increases with decreasing humidity or moisture. Dried microbial cells placed into test tubes and then heated in a water bath are considerably more heat resistant than moist cells of the same type. Since it is well established that protein denaturation occurs at a faster rate when heated in water

Table 11-1. The effect of the medium upon the thermal death point of *Escherichia coli** (Carpenter, 1967)**

Medium	*Thermal death point* (°C)
Cream	73
Whole milk	69
Skim milk	65
Whey	63
Bouillon (broth)	61

* Heating time: 10 minutes.
** Courtesy of W. B. Saunders Co., Philadelphia.

than in air, this suggests that protein denaturation is either the mechanism of death by heat or is closely associated with it (see Chapter 19 for further discussion of the mechanism of heat death). The precise manner in which water facilitates heat denaturation of proteins is not entirely clear, but it has been pointed out that the heating of wet proteins causes the formation of free —SH groups with a consequent increase in the water-binding capacity of proteins. The presence of water allows for thermal breaking of peptide bonds, a process which requires more energy in the absence of water and consequently confers a greater refractivity to heat.

2. Effect of Fat. In the presence of fats, there is a general increase in the heat resistance of some microorganisms (see Table 11-1). This is sometimes referred to as fat protection and is presumed to increase

heat resistance by directly affecting cell moisture. Sugiyama (1951) demonstrated the heat-protective effect of long-chain fatty acids on *C. botulinum*. It appears that the long-chain fatty acids are better protectors than short-chain acids.

3. Effect of Salts. The effect of salt on the heat resistance of microorganisms is variable and dependent upon the kind of salt, concentration employed, and other factors. It has been observed that some salts have a protective effect upon microorganisms while others tend to make cells more heat sensitive. It has been suggested that some salts may decrease water activity and thereby increase heat resistance by a mechanism similar to that of drying, while others may increase water activity (e.g., Ca^{++} and Mg^{++}) and consequently increase sensitivity to heat. It has been shown that supplementation of the growth medium of *B. megaterium* spores with $CaCl_2$ yields spores with increased heat resistance, while the addition of L-glutamate, L-proline, or increased phosphate content decreases heat resistance (Levinson and Hyatt, 1964).

4. Effect of Carbohydrates. The presence of sugars in the suspending menstrum causes an increase in the heat resistance of microorganisms suspended therein. This effect is most likely due to the decrease in water activity that is caused by high concentrations of sugars.

5. Effect of pH. Microorganisms are most resistant to heat at their optimum pH of growth, which is generally about —7.0. As pH is lowered or raised from this optimum value, there is a consequent increase in heat sensitivity (Figure 11-1). Advantage is taken of this fact in the heat processing of high acid foods where considerably less heat is applied to achieve sterilization compared to foods at or near neutrality. The heat pasteurization of egg white provides an example of an alkaline food product that is neutralized prior to heat treatment, a practice which is not done with other foods. The pH of egg white is about 9.0. When this product is subjected to pasteurization conditions of 60–62°C for 3.5–4 minutes, coagulation of proteins occurs along with a marked increase in viscosity. These changes affect the volume and texture of cakes made from such pasteurized egg white. Cunningham and Lineweaver (1965) have reported that egg white may be pasteurized the same as whole egg if the pH is reduced to about 7.0. This reduction of pH makes both microorganisms and egg-white proteins more heat-stable. The addition of salts of iron or aluminum increases the stability of the highly heat-labile egg protein conalbumin sufficiently to permit pasteurization at 60–62°C.

6. Effect of Proteins and Other Substances. It is well known that proteins in the heating menstrum have a protective effect upon microorganisms. Consequently, high protein-content foods must be heat processed to a greater degree than low protein-content foods in order to achieve the same end results. For identical numbers of organisms, the presence

of colloidal-size particles in the heating menstrum also offers protection against heat. For example, under identical conditions of pH, numbers of organisms, etc., it would take longer to sterilize pea purée than nutrient broth.

7. Effect of Numbers of Organisms. The larger the number of organisms, the higher is the degree of heat resistance. This is well illustrated in Table 11-2. It has been assumed that the mechanism of heat protection by large microbial populations was due to the production of protective substances excreted by the cells, and some authors claim

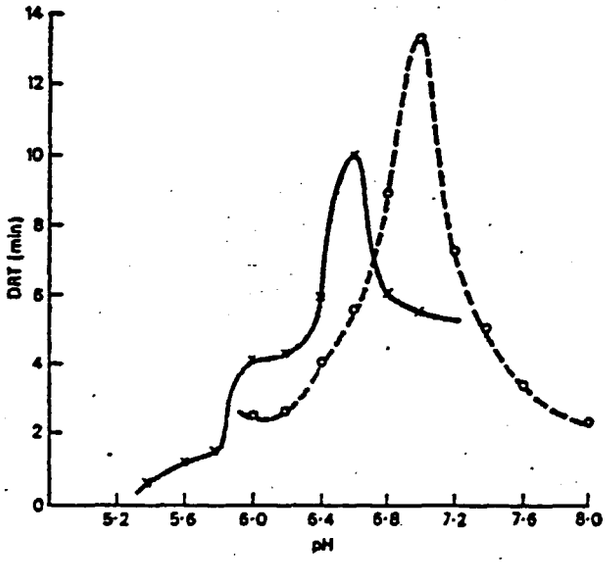

FIGURE 11-1. The effect of pH on the DRT of *Strep. fecalis* (C & G) exposed to 60° in citrate-phosphate buffer (crosses) and phosphate buffer (circles) solutions at various pH levels (White, 1963).

to have demonstrated the existence of such substances. Since proteins are known to offer some protection against heat, many of the extracellular compounds in a culture would be expected to be protein in nature and consequently capable of affording some protection. Of perhaps equal importance in the higher heat resistance of large cell populations over smaller ones is the greater chance for the presence of organisms with differing degrees of natural heat resistance.

8. Effect of Age of Organisms. Bacterial cells tend to be most resistant to heat while in the stationary phase of growth (old cells) and less resistant during the logarithmic phase. Heat resistance has been reported to be high also at the beginning of the lag phase but decreases

to a minimum as the cells enter the log phase. Old bacterial spores have been reported to be more heat resistant than young spores. The mechanism of increased heat resistance of less active microbial cells is undoubtedly complex and at this time not well understood.

9. Effect of Temperature of Growth. The heat resistance of microorganisms tends to increase as the temperature of incubation increases. Lechowich and Ordal (1962) showed that as sporulation temperature was increased for *B. subtilis* and *B. coagulans*, the thermal resistance of spores of both organisms also increased. Although the precise mechanism of this effect is unclear, it is conceivable that genetic selection

Table 11-2. Effect of the number of spores of *Clostridium botulinum* on the thermal death time at 100°C (Carpenter, 1967)*

Number of spores	*Thermal death time (minutes)*
72,000,000,000	240
1,640,000,000	125
32,000,000	110
650,000	85
16,400	50
328	40

* Courtesy of W. B. Saunders Co., Philadelphia.

favors the growth of the more heat-resistant strains at succeedingly high temperatures.

10. Effect of Inhibitory Compounds. As might be expected, a decrease in heat resistance of most microorganisms occurs when heating takes place in the presence of microbial inhibitors such as heat-resistant antibiotics, SO_2, and others. The use of heat + antibiotics and heat + nitrite has been found to be more effective in controlling the spoilage of certain foods than either alone. The practical effect of adding inhibitors to foods prior to heat treatment is to reduce the amount of heat that would be necessary if used alone.

11. Effect of Time and Temperature. One would expect that the longer the time of heating, the greater is the killing effect of heat. All too often, though, there are exceptions to this basic rule. A more dependable rule is that the higher the temperature, the greater is the killing effect of heat. This is illustrated in Table 11-3 for bacterial spores. As temperature increases, time necessary to achieve the same effect decreases.

These rules assume that heating effects are immediate and not mechanically obstructed or hindered. Also important is the size of the heating vessel or container and its composition (glass, metal, plastic, etc.). It should be obvious that it would take longer to effect pasteurization or sterilization in large containers than in smaller ones. The same would

Table 11-3. Effect of temperature upon the thermal death times of spores (Carpenter, 1967)*

Temperature	*Clostridium botulinum (60,000,000,000 spores suspended in buffer at pH 7)*	*A thermophile (150,000 spores per ml. of corn juice at pH 6.1)*
	Minutes	
100°C	360	1140
105°C	120	
110°C	36	180
115°C	12	60
120°C	5	17

* Courtesy of W. B. Saunders Co., Philadelphia.

be true of containers with walls that did not conduct heat as readily as others.

RELATIVE HEAT RESISTANCE OF MICROORGANISMS

In general, the heat resistance of microorganisms is related to their optimum growth temperatures. Psychrophilic microorganisms are the most heat sensitive of the three temperature groups, followed by mesophiles and thermophiles. Sporeforming bacteria are more heat resistant than nonsporeformers, while thermophilic sporeformers are in general more heat resistant than mesophilic sporeformers. With respect to gram reaction, gram positive bacteria tend to be more heat resistant than gram negative, with cocci in general being more resistant than nonsporeforming rods. Yeasts and molds tend to be fairly sensitive to heat with yeast ascospores being only slightly more resistant than vegetative yeasts. The asexual spores of molds tend to be slightly more heat resistant than mold mycelia. Sclerotia are the most heat resistant of these types and sometimes survive and cause trouble in canned fruits.

The heat resistance of bacterial endospores is of special interest in the thermal processing of foods. These structures are produced by *Bacillus* and *Clostridium* spp. usually upon the exhaustion of nutrients essential for continued vegetative growth although other factors appear to

be involved. Only one spore is produced per cell, and it may occur in various parts of the vegetative cell and possess various shapes and sizes, all of which are of taxonomic value. The endospore is not only resistant to heat but to drying, cold, chemicals, and other adverse environmental factors. It is a highly refractive body that resists staining by ordinary methods. The refractivity is due in part to the spore coats which consist of at least two layers—outer (exine) and inner (intine). Heat resistance is due also in part to the dehydrated nature of the cortex and spore core. Endospores are known to contain DNA, RNA, water, various enzymes, metal ions, and other compounds, especially dipicolinic acid (DPA). Although the precise mechanism of heat resistance of endospores is not yet fully understood, numerous authors have related this resistance to spore DPA and calcium contents. DPA may constitute from 5–15 percent of the dry weight of endospores, while these bodies may contain from 2–10 times more calcium than the corresponding vegetative cell. There is a general increase in heat resistance as the ratio of cations to DPA increases (Lechowich and Ordal, 1960; Levinson *et al.*, 1961). The addition of chelating agents with high affinities towards calcium and manganese has been shown to decrease the heat resistance of endospores (Amaha and Ordal, 1957), while the addition of calcium and manganese generally restores thermal resistance (El-Bisi and Ordal, 1956). The thermal death of endospores is accompanied by a release of DPA, divalent cations, and ninhydrin-positive material into the medium (El-Bisi *et al.*, 1962).

THE THERMAL DESTRUCTION OF MICROORGANISMS

In order to better understand the thermal destruction of microorganisms relative to food preservation and canning, it is necessary to understand certain basic concepts associated with this technology. Below are listed some of the more important concepts, but for a more extensive treatment of thermobacteriology, the excellent monograph by Stumbo (1965) should be consulted.

1. Thermal Death Time (TDT). This is the time necessary to kill a given number of organisms at a specified temperature. By this method, the temperature is kept constant and the time necessary to kill all cells is determined. Of less importance is the *thermal death point*, which is the temperature necessary to kill a given number of microorganisms in a fixed time, usually 10 minutes. The following 7 methods have all been proposed for determining TDT: tube, can, "tank," flask, thermoresistometer, unsealed tube, and capillary tube methods. The general procedure for determining TDT by either of these methods is to place a known number of cells or spores in a sufficient number of sealed containers in order to get the desired number of survivors for each

test period. The organisms are then placed in an oil bath and heated for the required time period. At the end of the heating period, containers are removed and cooled quickly in cold water. The organisms are then placed on a suitable growth medium, or the entire heated containers are incubated if the organisms are suspended in a suitable growth substrate. The suspensions or containers are incubated at a temperature suitable for growth of the specific organisms. Death is defined as the inability of the organisms to form a visible colony.

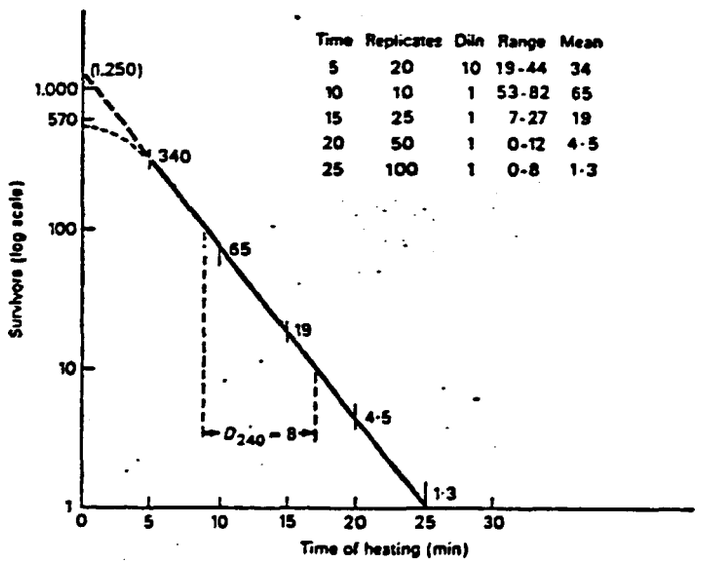

FIGURE 11-2. Rate of destruction curve. Spores of strain F.S.7 heated at 240°F in canned pea brine pH 6.2 (Gillespy, 1962, courtesy of Butterworth Publishers, London).

2. D Value. This is the decimal reduction time, or the time required to destroy 90 percent of the organisms. This value is numerically equal to the number of minutes required for the survivor curve to traverse one log cycle (see Figure 11-2). Mathematically, it is equal to the reciprocal of the slope of the survivor curve and is a measure of the death rate of an organism. When D is determined at 250°F, it is often expressed as D_r. The effect of pH on the D value of *C. botulinum* in various foods is presented in Table 11-4.

3. z Value. The z value refers to the degrees Fahrenheit required for the thermal destruction curve to traverse one log cycle. Mathematically, this value is equal to the reciprocal of the slope of the TDT curve (see Figure 11-3).

Table 11-4. Effect of pH on D values for spores of *C. botulinum* 62A suspended in three food products at 240°F (from Xezones and Hutchings, 1965)*

	D Value (in Min.)		
pH	*Spaghetti, tomato sauce, and cheese*	*Macaroni creole*	*Spanish rice*
4.0	0.128	0.127	0.117
4.2	0.143	0.148	0.124
4.4	0.163	0.170	0.149
4.6	0.223	0.223	0.210
4.8	0.226	0.261	0.256
5.0	0.260	0.306	0.266
6.0	0.491	0.535	0.469
7.0	0.515	0.568	0.550

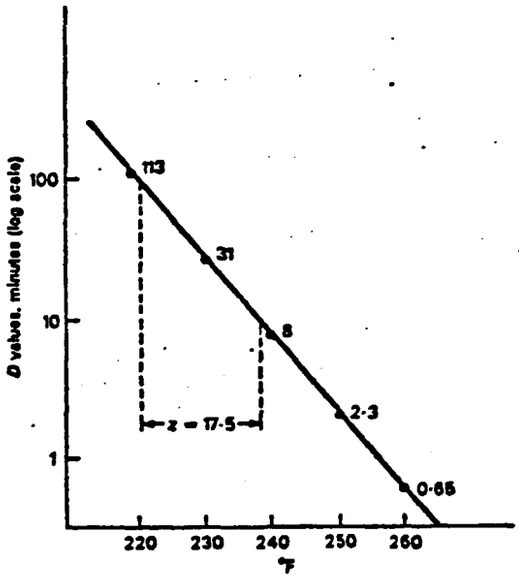

FIGURE 11-3. Thermal death time curve. Spores of strain F.S.7 heated in canned pea brine pH 6.2 (Gillespy, 1962, courtesy of Butterworths Publishers, London).

4. F Value. This value is the equivalent time, in minutes at 250°F, of all heat considered, with respect to its capacity to destroy spores or vegetative cells of a particular organism. The integrated lethal value of heat received by all points in a container during processing is designated F_s or F_o. This represents a measure of the capacity of a heat process to reduce the number of spores or vegetative cells of a given organism per container. When we assume instant heating and cooling throughout the container of spores, vegetative cells, or food, F_o may be derived as follows:

$$F_o = D_r(\log a - \log b)$$

where a = number of cells in the initial population, and b = the number of cells in the final population.

5. Thermal Death Time Curve. For the purpose of illustrating a thermal destruction curve and D value, data are employed from Gillespy (1962) on the killing of flat sour spores at 240°F in canned pea brine at pH 6.2. Counts were determined at intervals of 5 minutes with the mean viable numbers indicated below:

Time (Min.)	*Mean viable count*
5	340
10	65
15	19
20	4.5
25	1.3

The time of heating in minutes is plotted on semi-log paper along the linear axis, and the number of survivors is plotted along the log scale to produce the TDT curve presented in Figure 11-2. The curve is essentially linear, indicating that the destruction of bacteria by heat is logarithmic and obeys a first order reaction. Although difficulty is encountered at times at either end of the TDT curve, process calculations in the canning industry are based upon a logarithmic order of death. From the data presented in Figure 11-2, the D value is calculated to be 8 minutes, or $D_{240} = 8.0$.

D Values may be used to reflect the relative resistance of spores or vegetative cells to heat. The most heat-resistant strains of *C. botulinum* types A and B spores have a D_r value of 0.21, while the most heat-resistant thermophilic spores have D_r values of around 4.0–5.0. Putrefactive anaerobe (P.A.) 3679 was found by Stumbo *et al.* (1950) to have

PRODUCT RECALLS

How to Avoid a Recall

The best way to avoid a speeding ticket is to drive within the posted speed limits. And the best way to avoid a recall is to operate in accordance with FDA regulations. These involve many different matters and packers need to become acquainted with them. Some of the conditions that may trigger recalls are: pathogenic microorganisms in the product, pesticide residue levels above tolerances, use of un-approved additives, contamination with heavy metals or other objectionable substances, processing to a potentially unsafe level, inaccurate labeling, failure to comply with FDA regulations for standards of quality, identity and fill of container, and failure to operate with FDA's good manufacturing practice regulations. A further means of eliminating the possibility of a recall would be for the quality control supervisor to be directly answerable to top management, such as the president, or a vice-president of the firm.

To help avoid recalls, it is desirable to seek and follow the advice of a reliable source of information about FDA regulations such as the National Canners Association. In 1974 the NCA revised and up-dated its Bulletin 34-L, entitled "Organizing a Product Recall Program." U.S. Food and Drug Administration has advised NCA that Bulletin 34-L meets requirements of Part 90 rules of the Good Manufacturing Practice Regulations for a recall program. Copies of Bulletin 34-L may be obtained for a nominal fee by writing to:

National Canners Association
1133 20th St., N.W.
Washington, D.C. 20036

MICROBIOLOGY OF CANNED FOODS

Basic Considerations on pH Value

One of the most important properties associated with food chemistry and with microbiological food spoilage is the intensity of the acidity, or the pH of the product. This intensity factor, of pH value, is not to be confused with the amount of acid present in the food. In order to state this intensity of the acidity in simple numerical terms a mathematical notation was developed and named the pH scale. This scale runs from 0 to 14. The neutral point at which a substance is neither acidic nor basic is at pH 7.0. The smaller values of pH denote greater acid intensities and the larger numbers denote the less acidic or the basic intensities.

pH of foods depends upon many factors, some of these being maturity of the product, variety, and growing conditions. For these reasons, the pH of food is usually within a range of values.

Influence of pH on Food Microbiology and Spoilage

Different species of microorganisms are characterized by a specific pH value for optimum growth. Other chemical and physical characteristics of the food are also factors that affect the growth rate of bacteria, yeasts, and molds. One important effect of pH is its influence upon resistance of bacteria to heat. The lower the pH value, i.e., the higher the acid intensity, the lower the resistance of bacteria and bacterial spores to heat at a given temperature. When there are several species of bacteria, yeasts, and molds in a food, the pH value of the food is one of the most important factors determining which of those types of microorganisms will multiply faster, and within the types, the species that will prevail. That

characteristic of pH is important both in industrial fermentations and in food spoilage considerations.

Effect of Temperature on Growth of Microorganisms

While in the actively growing stages, most microorganisms are readily killed by exposure to temperatures near the boiling point of water. Bacterial spores are more heat resistant than their vegetative cells.

Mean pH Values of Selected Foods

pH Value	
2.3	Lemon juice (2.3)*, Cranberry sauce (2.3)
3.0	Rhubarb (3.1) Applesauce (3.4), Cherries, RSP (3.4) Berries (3.0 – 3.9), Sauerkraut (3.5) Peaches (3.7), Orange juice (3.7) Apricots (3.8)
4.0	Cabbage, red (4.2), Pears (4.2) Tomatoes (4.3) Onions (4.4)
4.6	Ravioli (4.6) Pimientos (4.7)
5.0	Spaghetti in tomato sauce (4.9) Figs (5.0) Carrots (5.2) Green Beans (5.3), Beans with pork (5.3) Asparagus (5.5), Potatoes (5.5)
6.0	Lima beans (5.9), Tuna (5.9, Tamales (5.9) Codfish (6.0), Sardines (6.0), Beef (6.0) Pork (6.1), Evaporated milk (6.1) Frankfurters (6.2), Chicken (6.2) Corn (6.3) Salmon (6.4) Crabmeat (6.8), Milk (6.8) Ripe olives (6.9)
7.0	Hominy (7.0)

*Mean pH Value

MICROBIOLOGY OF CANNED FOODS

Bacteria can be classified according to their temperature requirements for growth. Bacteria growing at temperatures between 75° and 100° F are called *mesophiles*. Other species of bacteria have optimum growth temperatures between 50° and 65° F and are called *psychrophiles*. Psychrophiles may grow, usually slower, at temperatures down to 35° F. Those that grow best between 120° and 150° F are *thermophiles*. Thermophiles may grow slowly up to 170° F.

There is an important difference between the optimum temperatures for growth of bacteria and their resistance to heat, i.e., to the effect of high temperatures. Highly heat resistant bacteria are called *thermoduric*. Mesophilic organisms can be thermoduric due to the high heat resistance of their spores, as can the spores of thermophilic bacteria.

Foods have associated microfloras. Certain microorganisms are usually found in certain food groups. These organisms gain entrance to the food during the canning operation either from the soil, from ingredients, or from equipment. On the basis of acidity classification of foods, it is possible to make general statements relative to the microorganisms which are potentially capable of producing spoilage in canned foods.

Acidity Classification of Canned Foods

Low-Acid Foods. Because *C. botulinum* will not grow at pH levels of 4.6 or below, foods in which it will grow have been categorized as "low-acid foods." In food processing regulations, low acid foods are defined as "any commercially processed food with a finished equilibrium pH value greater than 4.6 and a water activity greater than 0.85, but not including alcoholic beverages, and shall also include any normally low-acid vegetables or vegetable products in which for the purpose of thermal processing the pH value is reduced by acidification."

Meat, fish, poultry, dairy products, and vegetables except tomatoes, generally fall into a pH range of 5.0 to 6.8. While they are relatively non-acid, they do fall in the acid range of pH values. Figs and pimientos, as well as some manufactured foods such as spaghetti products, have pH values between 4.6 and 5.0.

High-Acid Foods. Foods with pH values of 4.6 and below are classified as "high-acid foods." High acid foods include fruits, tomatoes, rhubarb, berries, and fermented foods such as pickles and sauerkraut.

BOTULISM

Botulism is an intoxication caused by a toxin produced in foods by the microorganism called *Clostridium botulinum*. This organism is a rod-shaped, spore forming bacillus. It originally lives in and comes from the soil in all parts of the world. *C. botulinum* is an anaerobic bacterium. It does not grow in the presence of free oxygen nor on surfaces which support the growth of many other types of bacteria. This bacterium produces an exotoxin which is the most deadly neuro-paralytic toxin known.

Six types of *C. botulinum* have been described and are well known, i.e., Types A, B, C, D, E, and F. Each type produces a specific and somewhat different exotoxin, but each toxin produces similar type symptoms. Anti-toxins or serums are specific to the particular type of toxin, but polyvalent vaccines are available.

The intoxication is caused by ingestion of the exotoxin produced by the organism *C. botulinum*. It is not caused by the organism itself. The toxins are inactivated by heat in 10 minutes at 212° F. Types A, C and D are proteolytic, that is, they produce an extremely foul and putrid odor. Types B and E do not produce this odor.

C. botulinum is a gas producing organism but it is not a prolific gas former. Cans of food in which there are living organisms do not usually produce a "hard swell." Normally the type of swell is a "soft swell" or a "springer." In some cases, the cans may not swell at all. The optimum growth temperature of the botulism organism for the development of toxin is from 65° to 85° F. Five to ten percent salt content in a product, such as salt-cured meats and fish, will prevent the growth of *C. botulinum*.

Botulism Symptoms

Most outbreaks of botulism are dramatic, in that symptoms appear suddenly and progress rapidly. Symptoms usually appear within 8 to 72 hours after ingesting the toxin. Typical symptoms involve the nervous system and result in double vision, difficulty in swallowing, impaired speech, difficulty in breathing, and paralysis of the extremities. Death results usually from paralysis of the respiratory muscles and asphyxia. In addition, some botulism victims have shown symptoms of nausea, vomiting and constipation.

The illness is difficult to diagnose because at the onset, the symptoms of botulism are often confused with symptoms of other diseases and few physicians are familiar with the diagnostic techniques. By the time the nature of the illness becomes apparent it is usually too late for therapy. In botulism the only therapy known is the early administration of anti-toxin serum. Mortality varies with different outbreaks but the average in the U.S. is 25% at present, down from about 60% up to 1945.

Since 1925, four deaths have been reported from consumption of foods commercially canned in the United States. One death occurred in 1941, two in 1963, and one in 1971. These four fatalities occurred over a period during which consumers ate the contents of nearly 800 billion containers of canned food. This record supports the fact that properly processed canned foods are safe. The few exceptions, however, have been so tragic in their occurence and consequences that increased effort and diligence by the canner in preventing botulism outbreaks are mandatory. Adherence to the Good Manufacturing Practice regulations and good plant sanitation in processing low-acid canned foods constitute a safeguard against botulism outbreaks.

Botulism in Home-Canned Foods

Several deaths occur each year from botulism contracted through consumption of improperly home canned foods. Over 450 such deaths have occurred since 1920. Because botulinum spores are killed by heat, the culprit in home canning is under-sterilization, either by not using a high enough temperature or by processing for too short a time, or a combination of these conditions.

MICROBIOLOGY OF CANNED FOODS

CHARACTERISTICS OF CANNED FOOD SPOILAGE MICROORGANISMS

Low-Acid Canned Foods

Flat sour producing thermophilic bacteria. Aerobic and facultative anaerobic. Spores highly heat resistant. Occur more in canned vegetables and in products high in starch content for which quality considerations necessitate a minimum of heat processing. Produce acid but not gas. Cans do not swell. Type species: *Baccillus stearothermophilus.*

Thermophilic anaerobic bacteria. Very heat resistant. Obligate anaerobic. Gas and acid producers. Cans swell. Type Species: *Clostridium thermosaccharolyticum.*

"Sulphide spoilage" thermophilic bacteria. "Sulfur stinkers." Food turns dark due to production of H_2S and formation of sulfide with iron containers. Cans usually remain flat due to solubility of H_2S in water. Type species: *Clostridium nigrificans.*

Putrefactive anaerobic bacteria. Mesophilic, spore-formers and gas-formers. Type species: *Cl. botulinum, Cl. butiricum,* etc. Destruction of spore of *Cl. botulinum* is minimum standard for processing low acid foods. Most species of this group are more heat resistant than *Cl. botulinum.*

Aerobic mesophilic sport-formers. As a group, they are less important than putrefactive anaerobes, due to (a) vacuum in canned foods which inhibits their growth, and to (b) inability to produce marked changes in foods. However, some species of this group have shown considerable heat resistance. Several species of *Bacillus* belong to this group.

Yeasts, molds, and non-spore-forming bacteria. Spoilage with these microorganism is very uncommon in low acid canned foods. Their presence would indicate: (a) gross understerilization; (b) contamination due to defective seam. These organisms are readily controlled by relatively short processes at temperatures below 212° F.

Acid Foods

Spore-forming bacteria. Among the most important are: (a) *Bacillus thermoacidurans*, which is aerobic, not very heat resistant, thermophilic, produces "flat sour", (b) *Cl. pasteurianum*, which is spore former, anaerobic, saccharolytic, gas-producing.

Non-sporing bacteria. Lactic acid producing bacteria: *Lactobacillus* and *Leuconostoc* sp. Some are gas producing. Develop best under conditions of reduced oxygen tension.

Yeasts. Due to their very low heat resistance, yeast cause spoilage in canned foods only in cases of gross under-processing or can leakage.

Molds. Molds are in general of insignificant importance in all canned foods. However, there is one exception in *Byssochlamys fulva*, which is an important factor in spoilage of canned fruits. It breaks down pectinous material, disintegrating fruit; sometimes it produces gas. Heat resistance: 30 minutes at 190° F, or 16 minutes at 212° F. This mold is unusually heat resistant in comparison to other molds.

BASIC INFORMATION ON CANNING

Spoilage Resulting From Can Leakage

The organisms which cause spoilage in the event of leakage are the heterogeneous free-living forms not subject to orderly classification in relation to canned food groups. There is, however, an important biological differentiation between spoilage from under-sterilization and from leakage, as in the case of low-acid foods. In this group when spoilage occurs from under-sterilization it is due usually to a single spore-forming type. Where leakage is concerned, on the contrary, it is customary to find mixed cultured of nonsporing bacteria which could not have survived the process and which, therefore, must have entered the can after process. This differentiation does not exist in a clean-cut way in the case of the acid products because the aciduric organisms which cause spoilage may have been present in the product at the time of canning or may have entered subsequent to the process. Some guidance as to the cause of spoilage, however, may be had from observations as to whether spoilage occurred from one or a few or many bacterial types. In the latter instance leakage is indicated.

Commercial Sterility in Canned Foods

The very basis for the preservation of foods by canning is the use of heat to destroy bacteria which are generally capable of spoiling the product. Food poisoning bacteria are readily destroyed by heat. As a practical example of this fact, the pasteurization temperature for milk is about 143° F for 30 minutes, or 161° F for 15 seconds. The usual process or heat treatment given low acid canned foods of pH 4.6 or higher is equivalent to at least 3 minutes at 250° F. This heat treatment is more than sufficient to destory any food poisoning bacteria. It is also equivalent to more than 6 hours at 212° F and frequently affords much more lethality.

Acid foods of pH 4.6 or below will not support the growth of food poisoning bacteria. Tests have shown that not only are the food poisoning bacteria incapable of reproducing in acid foods but that large numbers deliberately added to such acid foods actually die in relatively short periods of time. Acid foods are not subjected to as much heat as low acid foods. However, they are heated sufficiently to destroy all vegetative bacterial cells, yeasts, and molds which could, if not destroyed, cause spoilage.

For all practical purposes, it may be considered that when a food is hermetically sealed in a container there will be included microorganisms which, unless they are subsequently destroyed, will thrive under the environmental conditions afforded and cause spoilage of the food. The destruction by heat of the organisms naturally present in the sealed container is the fundamental operation of food preservation by canning. The operation is known as processing to commercial sterility. The time and temperature combination at which the product is heated is known as the process.

The process is determined from a study of the rate of heat penetration for the product and from a study of the heat resistance of significant spores. A theoretical process is then calculated and tested by inoculation of product with a known spore load.

An example is the determination of a process for canned corn. Since it is known that flat sour and sulphide thermophiles as well as putrefactive anaerobic mesophiles cause spoilage of corn, it is necessary to study the conditions under which these agents are destroyed. After preparing a spore crop of each test

organism, a heat resistance determination is made. By using thermocouples, the rate of heat penetration into canned corn is determined. Employing a mathematical correlation between heat resistance and heat penetration, we arrive at what is known as a "theoretical" process. To test this theoretical process, packs of corn are inoculated with the test organisms. The packs are processed at various temperatures for varying periods of time, ranging about the "theoretical process," and then incubated to determine the spoilage levels.

The inoculated pack technique valuable especially for products, such as spinach, which exhibit rather gross variations in their rate of heat penetration. If the inoculated pack results confirm the mathematically derived theoretical process, the mathematical methods can usually be applied to the product in a variety of can sizes, thus precluding the need for studying the effects of the process on experimental packs in each can size.

The process so determined will produce a COMMERCIALLY STERILE canned food product with the greatest retention of quality.

Commercial sterility in low-acid foods may be defined as "that process by which all *Clostridium botulinum* spores and all other pathogenic bacteria have been destroyed, as well as more heat resistant organisms which, if present, could produce spoilage under normal conditions of non-refrigerated canned food storage and distribution." If the number of organisms in the product is excessive, recommended processes may not be adequate to prevent spoilage. Therefore, it is essential to exercise strict principles of sanitation while the agricultural commodities are prepared for canning.

There are some thermophilic or heat-loving bacteria which produce spores of such high resistance to heat that they cannot be destroyed in some products without processing to such a degree that the canned product would be unmarketable.

Fortunately, the thermophilic bacteria are not infectious or poisonous and are therefore of no significance with respect to public health, since we know that large numbers are ingested in coffee sweetened with table sugar. When such thermophilic spores survive the process in canned foods, they are unable to germinate and cause spoilage at storage temperatures of 100° F or lower. Prompt cooling of processed cans to an average temperature of 100° F and avoidance of high temperature storage safeguards against spoilage by thermophilic bacteria. Incubation of low acid canned foods at 131° F will quite obviously allow germination with recovery of vegetative cells.

Microbial decomposition of canned foods may result from lack of commercially sterile conditions, or from contamination of can contents after processing.

MICROBIOLOGICAL STANDARDS FOR INGREDIENTS

In the analysis of ingredients, a wide variety of thermophilic and mesophilic bacteria are encountered. Relatively few of the mesophilic bacteria, however, are considered significant from the standpoint of food spoilage. In general, yeasts, molds and thermophilic bacteria are the significant spoilage types of organisms.

The types of thermophilic low-acid food spoilage spore forming bacteria which may be found are characterized into 3 groups—those which produce flat sour

spoilage, i.e., *Bacillus stearothermophilus*, those which produce gas but not hydrogen sulfide, i.e., the thermophilic anaerobe *Clostridium thermosaccharolyticum*, and the thermophilic anaerobes which produce hydrogen sulfide spoilage, i.e., *Clostridium nigrificans*.

In general, there are no microbial standards by which the suitability of ingredients for use in canning may be measured. An exception to this are the standards suggested by the National Canners Association for thermophilic spore contamination of sugar and starch to be used in low-acid, heat processed canned foods. Those standards follow.

Standards for Starch and Sugar (National Canners Association)

A. Total thermophilic spore count: Of the five samples from a lot of sugar or starch none shall contain more than 150 spores per 10 g, and the average for all samples shall not exceed 125 spores per 10 g.

B. Flat sour spores: Of the five samples none shall contain more than 75 spores per 10 g, and the average for all samples shall not exceed 50 spores per 10 g.

C. Thermophilic anaerobe spores: Not more than three (60 percent) of the five samples shall contain these spores, and in any one sample not more than four (65 + percent) of the six tubes shall be positive.

D. Sulfide spoilage spores: Not more than two (40 percent) of the five samples shall contain these spores, and in any one sample there shall be no more than five colonies per 10 g (equivalent to two colonies in the six tubes).

CONTAINERS FOR CANNED FOODS

Canners of low-acid foods should comply with the requirements of Part 128b, Good Manufacturing Practices, promulgated by the U.S. Food and Drug Administration.

Under the regulations, the definition of an "hermetically sealed container" is as follows: "Hermetically sealed container means a container which is designed and intended to be secure against the entry of microorganisms and to maintain the commercial sterility of its contents after processing".

The container is an essential factor in the preservation of foods by canning. After canned foods are sterilized, it is the container that protects the canned food from spoilage by recontamination with microorganisms. It is then most important for the success of the canning operation to use good quality, reliable containers and properly adjusted capping machines. Thus, the seams and closures produced will be within the strict tolerances necessary to prevent access of microorganisms into the container during the cooling operation and during the shelf life of the product.

The food processor must adhere closely to can manufacturers recommendations on tolerances for can seam dimensions. He must also carefully control the finish and closure dimensions of the glass containers used, to make sure that they agree with the measurements that have been found to produce tight and safe glass containers. Container manufacturers assist food processors in the selection of the most efficient container for specific food products, and in the selection, operation, and maintenance of closing machines.