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FOOD ENGINEERING CONCEPTS FOR BEGINNERS

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CHAPTER 1.

Rheological Properties of Foods

INTRODUCTION

Sensory evaluation as a scientific discipline represents a very unique technique that harnesses human behavioral instincts of perception, learning, cognition, psychophysics and psychometric for the evaluation of foods. The textural properties of a food are that group of physical characteristics that are sensed by the feeling of touch, are related to the deformation, disintegration and flow of food under application of force. Textural characteristics are an important factor in the overall quality of many food products. Unless these quality attributes meet the standards which the consumer expects, the product will be rejected regardless of its nutritional value.

Rheology is the science of flow and deformation of matter and describes the interrelation between force, deformation and time. It is the study of the manner in which materials respond to applied stress or strain. The term comes from Greek 'rheos' meaning to flow. The science of rheology is only about 76 years of age. It was founded by two scientists meeting in the late '20s and finding out having the same need for describing fluid flow properties.

The scientists were Professor Marcus Reiner and Professor Eugene Bingham.

PSYCHORHEOLOGY

Psychorheology of foods is the scientific study of man's perception of texture of foods. It may be devided into two major areas (i) Qualitative psychorheology work concerns the attributes of texture to which man responds, the structure of his mental lexicon of texture descriptors and the cluster of similar meaning texture descriptors. (ii) Quantitative work may consider mathematical relations between pairs of texture descriptors, or functions relating one or several subjective textural properties. The major thrust of quantitative psychorheology has been to ascertain the class of functions relating mechanical to subjective properties and through experimentations to quantify the parameters of those functions. Now it is well established that the psychorheological models are important in texture studies.

IMPORTANCE OF RHEOLOGY

Study of rheological properties is important in food science due to its utility in food processing operations and sensory characteristics. It gives information about the microstructure of a food. Rheology properties are manifestation of the rate and nature of the deformation that occurs when a material is stressed. These parameters can be used to predict how the fluid will behave in a process and in determining the energy requirement for transporting the fluid from one point to another in processing plant. Rheologyical parameters are also useful in defining the quality attribute of food products.

Rheology is very important in the following area in the food industry

- Mixing-Two or more material are blended manually or mechanically.
- Flow Control-Flowablity of material varies from very thin to highly viscous.
- Dispensing- Material comes out easily or with difficulty.
- Settling/ Floating – Material with different specific gravity either settle or float depending on viscosity of the material.
- Pumping- Liquids or semi-solids are forced through the pipe
- Coating- Spreading of one material as thin layer over other.
- Cleaning – Soil removal from the surface of the equipments and pipeline.
- Control of processing parameters- velocity, magnitude of pressure drop, piping design, pumping requirement for fluid transport system, power requirement of agitation, power requirement of mixing and blending, amount of heat generated during extrusion etc.
- Influence on unit operations – Heat transfer, Mass transfer, mixing, grinding, sedimentation, separation, filtration, evaporation and drying etc.
- Study of rheology helps to select proper method of harvesting and sorting of raw materials
- Study of rheology helps to select proper ingredients to manufacture processed foods.
- Study of rheology helps to select proper technology/equipment to manufacture processed foods with desirable sensory and rheological properties.

- Study of rheology helps in newer product development (e.g. dietetic ice cream, paneer, low fat mozzarella cheese etc.)
- Study of rheology helps in designing processing equipment, packaging machines, transportation system etc.
- Study of rheology helps to improve sensory quality of the products
- Study of rheology helps in marketing the products.

Importance of Rheological Studies in Dairy Industry

Rheological studies of dairy products are important at a juncture when the need for modernizing the manufacturing and marketing of Traditional Indian Dairy Products (TIDP) is being emphasized in India. It helps to evaluate ingredient for potential contribution to creaminess in fat-free dairy products. Rheological studies also helps to evaluate quality of cheese and applicability of cheese for various applications like suitability for pizza topping. Further, the Bureau of Indian Standards (BIS) is actively considering the views of describing the food products based on their structure and rheology. Most fluid foods including dairy fluids like cream, ice cream mix, stirred yoghurt and liquid infant foods shows complex flow behaviour at different stages of processing and it requires study of its flow behaviour for better control over the processing parameters. Viscoelastic characteristics of foods are of great importance to the manufacturer, the trade and the consumers as these properties affect 'eating quality', usage properties such as ease of cutting, spreading and melting characteristic as well as handling and packaging characteristics. Recent developments in rheological instruments hold out a definite scope for generating valuable informations on the basic rheological parameters of these products. In the context of Indian dairy industry, texture and rheology of certain solid and semi-solid dairy products such as paneer, khoa, chhana and milk sweets have been recognized to play an important role in their acceptance which has a great bearing on the success of their production in modern dairy plants.

SENSORY TECHNIQUES FOR EVALUATING MECHANICAL TEXTURE CHARACTERISTICS

- Hardness: Place sample between molar teeth and bite down evenly, evaluating the force required to compress the food.

- Cohesiveness: Place sample between molar teeth, compress and evaluate the amount of deformation before rupture.
- Viscosity: Place spoon with sample directly in front of mouth and draw liquid from spoon over tongue by slurping, evaluating the force required to draw liquid over tongue at a steady rate.
- Springiness: Place sample either between molar teeth (if it is solid) or between the tongue and the palate (if it is a semi-solid) and compress partially, remove force and evaluate the degree and quickness of recovery.
- Adhesiveness: Place sample on tongue, press it against the palate and evaluate the force required to remove it with the tongue.
- Fracturability: Place sample between molar teeth and bite down evenly until the food crumbles, cracks or shatters, evaluating the force with which the food moved away from the teeth.
- Chewiness: Place sample in the mouth and masticate at one chew per second at a force equal to that required to penetrate a gum drop in 0.5 seconds, evaluating the number of chews required to reduce the sample to a state ready for swallowing.
- Gumminess: Place sample in the mouth and manipulate with the tongue against the palate, evaluating the amount of manipulation necessary before the food disintegrates.
- Sensory texture profile is defined as the organoleptic analysis of the texture complex of a food in terms of its mechanical, geometrical, fat and moisture characteristics, the degree of each present, and the order in which they appear from first bite through complete mastication. The data on these parameters is generally collected using either interval or ratio scales.

Table-1.1: Definition of textural characteristics

Properties	**Physical**	**Sensory**
Primary		
Hardness	Force necessary to attain a given deformation	Force required to compress a substance between teeth
Cohesiveness	Extent to which a material can be deformed before rupture	Degree to which a substance is compressed between the teeth before it breaks
Springiness	Rate at which a material returns to its original condition	Degree to which a product returns to its original size
Secondary		
Fracturability/Brittleness	Force with which a material fractures	Force with which a sample crumbles
Chewiness	Energy required to masticate a food to a state ready for swallowing	Time required to masticate the sample to a state ready for swallowing
Gumminess	Energy required to disintegrate a semisolid food to a state ready for swallowing	Denseness that persists throughout mastication.

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CHAPTER -2

Rheology of Processed Foods

INTRODUCTION:

Rheology of process food is very important in the dairy products as it controls the body and texture of typical dairy products like cream, plastic cream, processed cheeses, traditional Indian dairy products (peda, burfi, halwasan, thabadi, sandesh, chhana podo etc.). Control of rheological properties is very much required in the development of new functional and health dairy products like low fat and low sugar ice cream, fat mimic products to avoid defects related to body and texture. Study of rheology is also important in the other food processing industries, like meat industries, fruits and vegetables processing, snack foods, bakery and confectionaries.

EXAMPLES OF APPLICATION OF RHEOLOGICAL STUDY IN THE FOOD INDUSTRY

- Meat products : To evaluate type of breed; its growth rate (tenderness); to evaluate effect of pickling, chilling, aging, preservation, etc. on rheological property of meat; for measurement of toughness and compactness of meat and meat products; establishment of quality grade for marketing and export.
- Fruits and vegetables : To evaluate variety of crop; for predicting the effect of storage and ripening period on process; prediction of storage and ripening period; in prediction of stage of harvesting and stage of maturing; used for sorting; measurement of\ textural variation, gives us an idea about growing practice; method of harvesting.
- Jams and jellies : helps to decide variety of blending ingredients, esp. pectin; deciding jelling quality of pectin as well as integrity of gel structure, helps in deciding ingredients.
- Snack foods : To evaluate formula for dough making and paste, particularly for extrusion; for measurement and adjustment of solids content; for measurement of textural properties like crispiness, hardness, softness and other properties to decide packaging and packing material; helps in predicting shelf-life of product under given storage conditions and history of product (method of harvesting, storage conditions,

pre-treatments and processing unit operations).

- Confectioneries : To evaluate the quality of raw material; to optimize the processing parameters; to decide the ingredient varieties to be used; for measuring properties like thickness of coating, chewiness, elasticity, brittleness and shelf life of product.
- Paste : (Tomato paste, spreads, relishes, puddings, gels, jams, jellies, etc.) – used to evaluate consistency of mixture used for measured viscometric parameters at different stages of processing; deciding the pectin retention and prediction of consistency of final products.
- Bakery : To evaluate dough consistency; to estimate floor time and rise time; effect of additives; prediction of shelf life.
- Dairy products : To evaluate the effect of ingredients i.e. creaming in fat-free dairy products, fat mimic products by using micro-fluidization of whey protein concentrate, desired quality of mozzarella.

TEXTURE AND STRUCTURE OF HEAT AND ACID COAGULATED INDIGENOUS MILK PRODUCTS

Characterization of various food products on the basis of their rheology and microstructure forms the backbone of the scientific approach to product process development and of quality assurance in modern industrial practices.

The current trends round the globe favour such studies to facilitate product description/specification for promoting process control and for international trade. Furthermore, the interest of researchers and manufacturers in the texture and structure of various milk products has been growing, as it is recognized that there are definite correlationship between the structure and other physical properties of the products. The physical manifestation of food materials is due to its chemical make-up and a micro structural study may yield the true insight into their textual attributes. Evaluation of geometrical properties of foods are important for their characterization; these properties refer to the arrangement of constituents of food including the size, shape and orientation of the particles. Electron microscopy is useful to study surface topology and to develop correlation between the structure of various food material and then physico –chemical properties .

At a juncture when the need for modernizing the manufacturing and marketing of traditional milk products is being emphasized in India, such rheological and electron microscopic studies would be sine qua non to obtain much needed information for product/process development. Further, the Bureau of Indian Standards (BIS) is actively considering the views of defining/describing the food products based on their structure. It is worthwhile to mention here that BIS has already made a headway in this direction in respect of some of the food products such as roasted chicory and coffee powder. In the past few years, some work has been directed to study the rheology of selected indigenous dairy products such as paneer, khoa, rasogoIla and sandesh. However, the area encompassing the micro structural studies has not received much scientific inputs so far in our country. Since rheology is determined by micro structure studies, study of rheological parameters would help us later to establish the relationship between microstructure and rheological properties. Keeping this in view, an attempt is made in this lecture to put forth the textural and structural aspects of some of the heat and acid coagulated indigenous milk products such as paneer, chhana and rasogolla.

Textural Properties of Paneer

Paneer is widely used in all vegetable dishes as well as for preparation of special foods, which requires to have rheological properties. The control of processing parameters during manufacture of paneer like temperature, pressure of press, control of pH, chilling and freezing during storage etc. are critical parameters, which requires study of its effect on the textural properties of paneer. The data on the objective textural properties of raw and fried and cooked paneers made from cow and buffalo milks has been shown in Table 2.1 It is evident from the table that primary parameters such as hardness and springiness differed significantly between cow and buffalo milk paneers. Cohesiveness, on the other hand, did not differ much between these two paneers. Since secondary parameters such as gumminess and chewiness are dependent on primary parameters, buffalo milk paneer revealed considerably higher vales for gumminess and chewiness compared to those recorded for cow milk paneer.

Table- 2.1: Instron texture profile analysis of paneer made from cow and buffalo milks

Attributes	Cow milk panner	Buffalo milk panner		
Raw	Fried & cooked	Raw	Fried & cooked	
Hardness, mN	25.59	8.66	40.72	9.31
Cohesiveness	0.67	0.70	0.64	0.70

Springiness, mm	7.50	9.38	7.70	9.59
Gumminess, mN	17.04	6.12	25.19	6.46
Chewiness, mN. Mm	131.27	54.27	206.36	63.32

Frying in oil and cooking- in salt water remarkably reduced the hardness, gumminess and chewiness and increased the cohesiveness and springiness of both the paneer.

Microstructure of Paneer

Scanning electron microscopy (SEM) reveals that in the raw state, both cow, and buffalo paneers possessed uniformly aggregated protein particles and fat globules are evenly distributed in the protein net work. Transmission Electron microscopy: (TEM) confirmed the existence of granular structure in paneer and also exhibited the internal structure of the protein particles. Raw cow milk paneer has uniformly packed small protein particles and resembled cottage cheese, while in raw buffalo milk paneer protein particles were more densely packed and fused. Core-and- lining structure, which is characteristic of curds obtained by coagulation of hot milk at pH 5.5 is well developed in both the paneers. The development of core-and-lining structure is influenced by the temperature and pH of coagulation.

Frying of paneer in oil severely changed its structure, resulting into compaction suppressing the smooth granularity of the protein matrix in cow milk paneer. The granularity totally vanished in the buffalo milk paneer. The compaction is more clearly evident in TEM ultragraphs. The compaction also caused the fat globules to acquire sharp and pointed outlines unlike their globular shape in raw paneer. Cooking of fried paneer in salt water restored both the granular structure and core-and- lining structure of the protein bodies. This restoration was more in case of cow milk paneer as compared to buffalo milk paneer.

Textural Properties of Chhana

Instron textural attributes of chhana made from cow and buffalo milks are given in table 2.2. It is evident that all the textural values were less for cow milk chhana compared to that of buffalo milk chhana. The secondary parameters such as gumminess and chewiness for buffalo milk chhana were more than two times to those values for cow milk chhana. However there was not much difference between cow milk and buffalo milk chhana as for as the adhesiveness was concerned.

Table-2.2: Instron Texture Profile Properties of Chhana

Attributes	Cow milk chhana	Buffalo milk chhana
Hardness, mN	11.60	19.50
Cohesiveness	0.59	0.67
Springiness, mm	3.60	5.00
Gumminess, mN	6.48	13.06
Chewiness, mN. mm	24.64	65.32
Adhesiveness mN	0.35	0.38

Microstructure of Chhana

SEM of a defatted cow milk chhana reveals conglomerated and compact protein material (casein and whey protein complexes with numerous small uniformly distributed pores of irregular shape. The protein particles coalesced and fused densely during coagulation and lost their natural identity of subunit' sizes as seen in milk. The coalesced, smooth protein bodies were joined with thick bridges. SEM of defatted buffalo milk chhana also shows a similar compact, coalesced protein net work with numerous globular and irregular voids throughout the matrix, but slightly more uneven as compared to cow milk chhana. The globular void spaces indicate that the casein-whey protein complexes are closely interspersed with numerous fat globules due to the usage of whole milk. Cow and buffalo milk chhana has been shown to contain fat globules embedded in coalesced casein micelles with some whey-filled spaces at the edge. The agglomerated large protein particles form continuous thick strands joined together forming somewhat uneven matrix with numerous void spaces in between. The fat globules are strongly cemented in these thick protein strands. The overall structure is more or less similar to that of cream cheese, in which the fat globules are found cemented together with the coalesced protein particles as seen in chhana.

Textural Properties of Rasogolla

Instron textural attributes of rasogolla are shown in Table 2.3. It is clear from the table that cow milk rasogolla has significantly lower hardness, springiness, gumminess and chewiness than that of buffalo milk rasogolla. The hardness of buffalo milk rasogolla in 2-3 times higher than that of cow milk rasogolla. Springiness of buffalo milk rasogolla (6.4 mm) is markedly higher than that of cow milk rasogolla (4.8 mm). Cohesiveness varied from 0.61 (cow milk rasogolla) - 0.70 (buffalo milk rasogolla). As the consequence of higher hardness and springiness in buffalo milk rasogolla, their gumminess and chewiness values also increased remarkably than that of cow milk rasogollas. No adhesive force, however, has been recorded for either of the rasogollas.

Table- 2.3: Instron texture profile properties of rasogolla

Attributes	**Cow milk rasogolla**	**Buffalo milk rasogolla**
Hardness, mN	5.85	16.82
Cohesiveness	0.61	0.70
Springiness, mm	4.80	6.40
Gumminess, mN	3.57	12.17
Chewiness, mN. mm	17.15	77.88

Microstructure of Rasogolla

Cooking of chhana in sugar syrup (for 15 min.) severely altered the structure of both the fat and the protein phases. The microstructure of rasogolla exhibits a distinctly different protein net work from, chhana at low magnification, a ragged and cracked protein matrix can be seen obscured with fat and several void spaces interspersed throughout. Higher magnification revealed that the fat globules are shrunken and ruptured, finally coalescing to a large mass and losing their natural identity as globular with a smooth surface as is found in chhana.

A defatted rasogolla sample showed a ragged porous, loose protein matrix with a folded thread-like structure. The clumped protein particles formed a corrugated edge around the void space. Higher magnification showed that the folded protein particles were interlinked with thick protein bridges forming a core type structure with numerous voids.

Similarly, the fat globule structure in buffalo milk rasogolla revealed drastic shrinkage of the fat globule membrane and globules partly detached from the protein bodies. The defatted protein matrix in buffalo milk rasogolla was more compact and ragged with lesser voids as compared to cow milk rasogolla.

Interrelationships between texture and microstructure of Chhana and Rasogolla

The denser protein network present in chhana reduced the mean free path of the coalesced casein micelles which reduced the capacity of the fat and protein phases to move in relation to each other. Where as in rasogolla the large voids between the coalesced protein gave the free access of the protein bodies to move freely during the instron testing, resulting its lower hardness but higher springiness. This higher springiness in rasogollas may be attributed to its loose, porous and ragged protein matrix.

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CHAPTER 3

Rheological Methods

INTRODUCTION

Generally rheological properties are judged by sensory panel, it has its advantages and disadvantages depending on the person selected for judging the products. To have unbiased scores as well as reproducibility of the values of rheological attributes, it is necessary to go for instrumental measurement. There are many instrumental methods are developed based on fundamental principle as well as experimental data. There are certain mathematical models developed by different scientist based on empirical methods, which are widely used for measurement of rheological properties of most of the food products.

TESTS FOR MEASUREMENT OF RHEOLOGICAL PROPERTIES

Instrumental methods for measurement of rheological properties are classified into two broad categories as follow: Fundamental tests which measure the properties that are inherent to the material and do not depend on geometry and shape of the sample, conditions of loading or type of apparatus used, e.g. relaxation time, Poisson's ratio, shear modulus and bulk modulus; Empirical tests (because data are based on comparison with sensory) or imitative tests (because these imitate the chewing in mouth). e.g. properties like puncture force, extrusion energy, cutting force required, pressing/compression force required for juice extraction, etc. – where mass of sample, geometry and speed of test will decide the magnitude of parameter estimated.

Generally fundamental tests are applied on solid foods and these are further classified into quasi-static and dynamic tests

The tests conducted under conditions of static/quasi-static loading are known as quasi-statictests while those conducted under dynamic loading conditions are called dynamic tests.

The use of Instron in determining the modulus of elasticity under compression is an example of quasi-static test while if the determination is done using a vibrating device of certain frequency (generally 200 Hertz), then the test is dynamic. You can say that rate of loading can be used to determine whether test is dynamic/quasistatic.

Quasi-Static Testing of Solid Food Products

Two types of behaviour can be studied – elastic behaviour of solid and another is pure viscous flow in case of liquids. Pure elastic behaviour is defined such that when force is applied to the material, it will instantaneously and finitely deform and when the force is released, the material will instantaneously come to the original form. Such materials are called 'Hooken solids' i.e. which follow Hook's law. The amount of deformation is proportional to the magnitude of the force. Rheological representation of this type of solids is a spring. The material of this nature can be given a rheological constant modulus of elasticity is ratio of stress/strain, where stress = force/area, and

strain=deformation due to force applied/original dimension. There are 3 types of moduli depending on type of force applied.

If force is applied perpendicular to area defined by stress and it is calculated as – modulus of elasticity(E)

If modulus is calculated by applying force parallel to area defined by stress i.e. a shearing stress, then it is called a shear modulus or modulus of rigidity(G or n) and

If force is applied from all directions (isotropic force) then change in volume over original volume is obtained that can be calculated by bulk modulus(B or K)

Creep : In an experiment if a constant stress is applied to sample and corresponding strain is followed as a function of time and results are expressed in terms of a parameter of compliance (J=strain/stress). The change in the strain of material can be measured, when stress is removed it known as creep curve. In short we can say that creep curve shows strain as a function of time at constant stress. Visco-elastic materials can often be characterized by a modulus and relaxation time, which can be determined by an analysis of strain curve with time.

Relaxation curve (stress relaxation) – It is the curve obtained when stress is applied as a function of time at a constant strain. That means that instead of applying constant force and measuring the change in strain with time, it is also possible to apply a constant strain and measure change in stress with time. This type of experiment is called relaxation stress and the curve is known as relaxation curve. These relaxation and creep experiments are known as

Transient experiments in which a constant force is applied to the material and resulting strain is measured as a function of time and vice-versa.

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Chapter -4

Measurement of Rheological Parameters

INTRODUCTION

The instrumental methods that have been used to evaluate the rheological properties of food may be empirical one or fundamental ones. Empirical methods include imitative ones, the Texture Profile Analysis (TPA) method employing the Texturometer as described by Friedman. The TPA has also been performed by many workers using Instron Universal Testing Machine. In these methods, mostly food samples are compressed between two plates using an Instron testing machine or a comparable apparatus and the force is recorded as a function of the compression. Until now no standardization of these tests has been made and many different executions of that have been described. Examples of differences are: shape and size of the test piece, treatments of the plates to increase or decrease the friction between the plates and the test piece, compression rate and temperature. One or more of the following parameters are usually derived from these tests:

- Force (or stress) at a given compression
- Force at the first maximum in the force-compression curve (often designated as fracture force)
- Initial slope (or modulus) of the force-compression curve
- Compression at the first maximum in the force-compression curve (often designated as fracture compression)
- Work done until a given compression
- Height recovered after deformation
- Adhesive force during ascending motion after compression

4.2 TEXTURAL PROFILE FROM INSTRON

The textural characteristics of the food samples can be interpreted from their respective force-distance compression curve obtained. A generalized texture profile curve obtained from the Instron Universal Testing Machine is shown in Fig:4.1 and the following textural parameters can be interpreted form the Instron Curve:

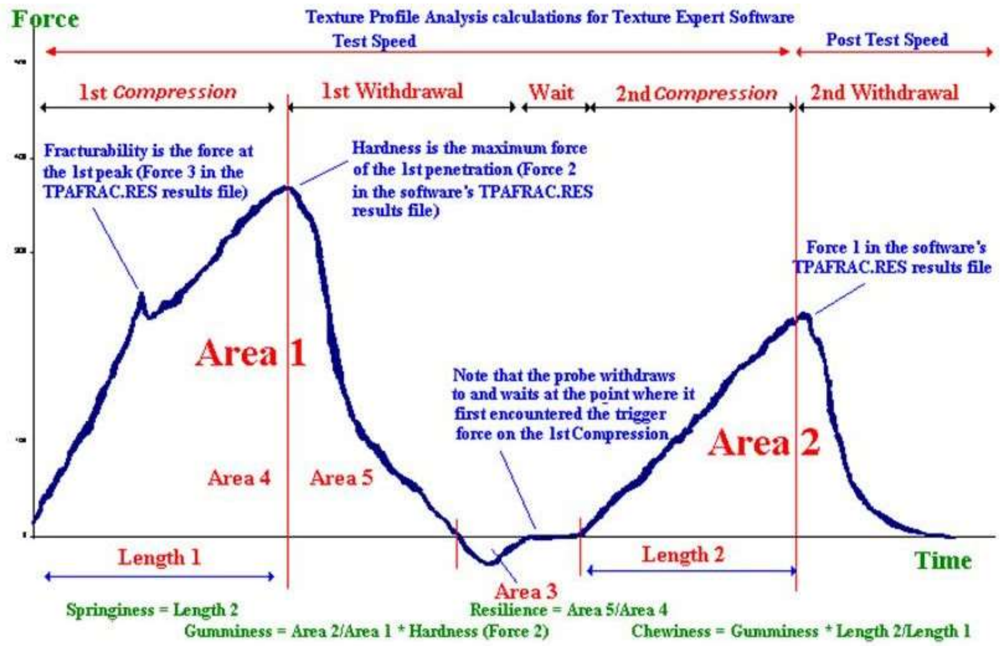

Fig-4.1: Generalized textural profile curve obtained from Instron universal testing machine

(i) Hardness (Kgf): The force necessary to attain a given deformation, i.e. the highest point of peak in the first bite curve (Fig-4.1).

Hardness= H1 , Kgf

(ii) Brittleness (Kgf): Force with which the sample crumbles, crackes or shatters Brittleness (or Fracturability) = H2, Kgf

(iii) Adhesiveness: It is the work necessary to overcome the attractive forces between the surfaces of the sample and the other materials with which sample comes in contact. It is negative force area for the first bite curve (Fig-1)

Adhesiveness = A3

(iv) Cohesiveness: The extent to which a material can be deformed before it ruptures Cohesiveness = A2/A1

A1 = Area under the first bite curve before reversal of compression A2 = Area under the second bite curve before reversal of compression

(v) Springiness (mm): The height of sample recovers between the first and second compression, on removal of the deformation force

Springiness = S, mm

(vi) Gumminess (Kgf): It is the energy required to masticate a sample to a state ready for swallowing a product of hardness and cohesiveness

Gumminess = Hardness x Cohesiveness x 100

(vii) Chewiness (kg-mm): It is the energy required to masticate a sample to a state ready for swallowing. It is a product of hardness, cohesiveness and springiness.

Chewiness = Hardness x Cohesiveness x Springiness

Table- 4.1: Definition of textural characteristics

Properties	Physical	Sensory
Primary		
Hardness	Force necessary to attain a give deformation	Force required to compress a substance between teeth
Cohesiveness	Extent to which a material can be deformed before rupture	Degree to which a substance is compressed between the teeth before it breaks
Springiness	Rate at which a material returns to its original condition	Degree to which a product returns to its original size
Secondary		
Fracturability	Force with which a material fractures	Force with which a sample crumbles
Chewiness	Energy required to masticate a food to a state ready for swallowing	Time required to masticate the sample to a state ready for swallowing
Gumminess	Energy required to disintegrate a semisolid food to a state ready for swallowing	Denseness that persists throughout mastication.

Rheological Properties of Fluid Foods

INTRODUCTION

It is necessary to study properties of fluid food products for designing and lay-outing of transport system (piping and pumping layout). For the fluid food products, the design of transport system mainly depends on the type and description of flow characteristics of the product. Some of the properties are interdependent and some are dependent on the fluid food composition and therefore it is necessary to measure dependant properties and we can predict its rheological properties.

Most important dependant fluid food property is viscosity i.e. resistance against flow, generally indicated by μ i.e. dynamic viscosity / ή kinematic viscosity (ή= μ/ ρ). In food industry μ is broadly used to describe a single

parameter known as ‘consistency’. But this approach may lead to confusion in many cases due to non-Newtonian behaviour of many fluid food products. The rheological classification of food is given in Fig-5.1. The stress and rate of shear diagram indicate varieties of food products classified under different categories, which is considered to be non-Newtonian as shown in the figure 5.2.

CLASSIFICATION

The fluids can be classified into following categories depending on the response to the applied shear force.

Newtonian Fluids:

Newtonian fluids are fluids which exhibit a linear increase in the shear stress with the rate of shear. These fluids exhibit a linear relationship between the shear stress and the rate of shear. The slope ' μ ' is constant therefore, the viscosity of a Newtonian fluid is independent of the rate of shear. These fluids exhibit a pure viscous flow i.e. the product begins to flow with the slightest force and the rate of flow is proportional to the magnitude of force applied. The examples of Newtonian fluids are milk, clear fruit juices, sucrose solution, most types of honey, corn syrup etc. The equation for characterizing Newtonian fluid is

$T = \mu (-dv/dx)$ (Eq-1)

Where, T = shear stress, μ = dynamic viscosity (η = μ/ρ) , -dv/dx = velocity gradient

Non-Newtonian Fluids:

A non-Newtonian fluid is broadly defined as one for which the relationship between shear stress and shear rate is not a constant. When the shear rate is varied, the shear stress doesn't vary in the same proportion. These fluids exibit either shear thinning or shear thickening behaviour and some exhibit a yield stress. The two most commonly used equations for characterizing non-Newtonian fluids are the power law model (Eq-2) and Herschel-Bulkley model (Eq-3) for fluids.

$T = K (\gamma)n$ (Eq-2)

$T = T0 + K (\gamma)n$ (Eq-3)

Where, T = shear stress, K = consistency constant, γ = shear rate, n = flow behaviour index, T0 = yield stress

There are several types of non-Newtonian flow behaviour, characterized by the way a fluid viscosity changes in response to variation in shear rate (Fig-5.2). The most common non-Newtonian fluids are:

(A) Time-independent flow of non-Newtonian foods:

The fluid foods whose viscosity is not influenced by the shearing time at a constant shear rate show two distinct patterns of stress – shear rate relationship i.e shear-thinning and shear-thickening.

(i) Pseudoplastic/shear-thinning fluids: - This type of fluids will display a decreasing consistency with an increasing shear rate. Probably the most common of the non-Newtonian fluids, psedo-plastic include emulsions and dispersions of many types. This type of flow behaviour is some times called shear-thinning. The shear stress ('T' or 'ς') versus shear rate (γ) curve is convex toward the stress axis. The shear thinning behaviour of a fluid or semi-solid food is expressed by the power law model or de Waele's model:

$T = K (\gamma)+n$ (Eq-4)

Where, T = shear stress, K = consistency constant (Pa s)n, γ = shear rate, n = flow behaviour index ('n' has a positive value between zero and unity)

Protein concentrates, skim milk concentrate, milk ultrafiltration retentates, concentrated fruit juice and vegetable purees and gum solutions are the examples of pseudo –plastic fluid food products.

(ii) Dilatant/shear-thickening flow behaviour:- This type of fluid will display an increasing viscosity with increase in shear rate. Dilatancy is frequently observed in fluids containing high level of deflocculated solids, such as candy compounds, cooked corn starch paste, certain types of honey etc. Dilatancy is also referred to as shear-thickening flow behaviour. The stress shear rate curve is concave toward the stress axis and the value of 'n' in the power law (Eq-4) is negative.

(B) Time-dependent flow of non-Newtonian foods:

Certain non-Newtonian fluids show a time-dependent stress-shear relationship which can be one of the following types:

(i) Thixotropy: - When at a constant shear rate, the stress decreases over a period of time due to structure breakdown until eventually it reaches a steady value, the product is said to be thixotropic. Aged condensed milk, cream and ice cream mix, egg white etc. revel thixotropy.

(ii) Rheopectic: - This essentially the opposite of thixotropic behaviour, in which the fluids viscosity increases with time as it is sheared at a constant rate. Rheopectic fluids are rarely encountered. Both thixotropic and rheopectic may occur in combination with any of the previously discussed flow behaviour, or only at certain shear rates.

(iii) Plastic: - This type of fluid will behave as a solid under static conditions. A certain amount of force must be applied to the fluid before any flow is induced, this force is called yield value. Tomato ketchup is a good example of

(iv) this type fluid, its yield value will often make it refuse to pour from the bottle until the bottle is shaken or struck, allowing the catchup to flow freely. Once the yield value is exceeded and flow begins, plastic fluids may display Newtonian, pseudoplastic, or dilatant flow characteristics.

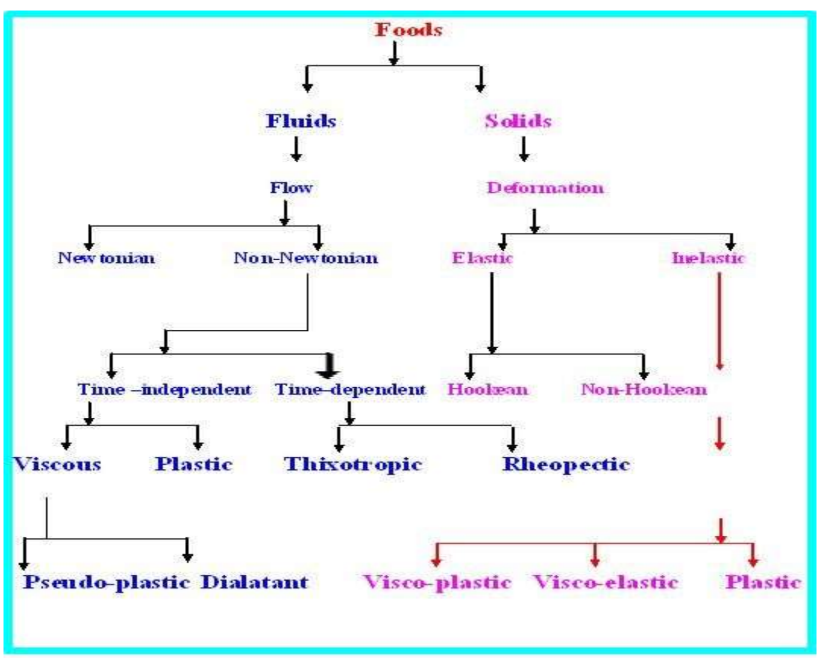

Fig 5.1 Rheological classification of foods

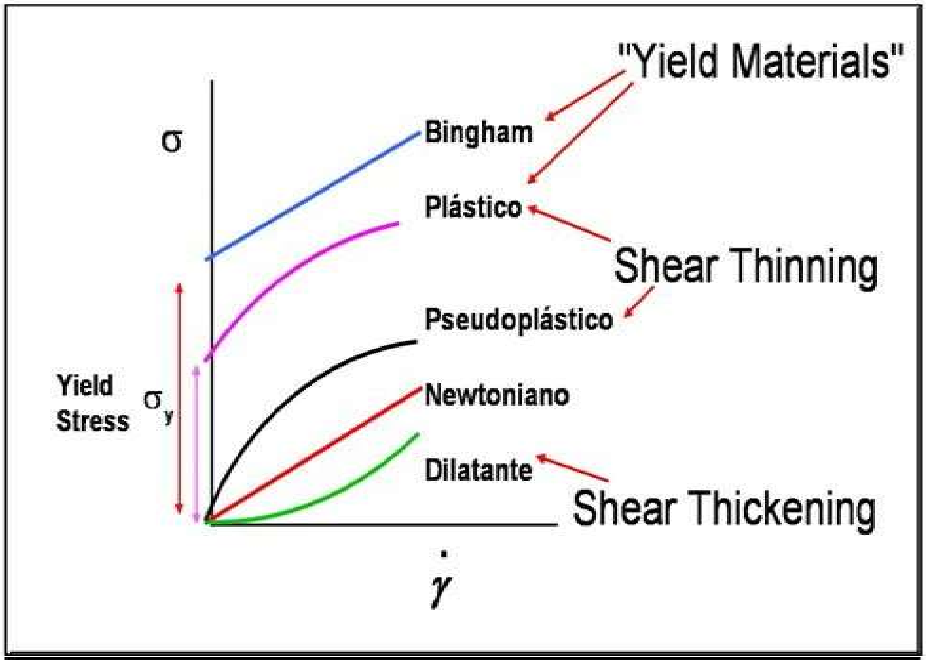

Fig-5.2: Stress-shear rate relationship in different rheological classes of fluids

IMPORTANT PROPERTIES OF FLUID FOODS

- Bounce: The resilience rate at which the sample returns to its original shape after partial compression.
- Chewiness: It is the number of chews (@1 chew/sec.) needed to masticate the sample to a state ready for swallowing.
- Coarseness: Degree to which mass feels coarse in the mouth.
- Cohesiveness: Degree to which the sample deforms before rupturing during biting.
- Denseness: It is a compactness of cross-section of the sample after complete biting.
- Dryness: Degree to which the sample feels dry in the mouth.
- Fracturability: Force with which the sample shatters/breaks. It encompasses crispiness, crumbliness, crunchiness and brittleness.
- Graininess: Degree to which a sample contains small grainy particles
- Gumminess: Energy required to disintegrate a semisolid food to a state ready to swallow.
- Hardness: Force required to deform the product to a given distortion. Generally the distortion is between tongue and palate.
- Heaviness: Weight of product perceived when first placed on the tongue.

- Moisture absorption (related to sensory): Amount of saliva absorbed by the product in the mouth.
- Moisture released: Amount of wetness and juiciness from the product.
- Mouth coating: Type and degree of coating in the mouth after mastication.
- Roughness: It is the degree of abrasiveness of product surface which is perceived by the tongue.
- Slipperiness: It is the degree to which the product slides over the tongue.
- Smoothness: It represents the absence of any particle, lumps, etc. in the product.
- Springiness/sponginess: Degree to which the product returns to its original position i.e. shape and size after partial compression (without failure). Here compression is between the palette and teeth.
- Uniformity: Degree to which the sample is even throughout.
- Uniformity of bite : Evenness of force applied on the product while biting.
- Uniformity of chew : The degree to which the chewy characteristics of the product are even throughout the mastication
- Viscosity : Force required to draw a liquid from spoon over to the tongue.
- Wetness : Amount of moisture perceived on the product surface.

Rheological Properties of Granular Foods and Powders

INTRODUCTION

Dry food products make up a considerable portion of the total amount of food products available. Like fluid food products they are handled in various ways in different parts of processing plant .The design of handling system for dried products requires knowledge of the flow properties of the product being handled and transported or conveyed. The manner in which granular foods or powder may flow into or out of container is of particular concern in processing plants. In addition to the density and particle size parameters, there are specific parameters which describe the flow properties of these types of food products. Two common parameters used for this purpose are the angle of response and the angle of slide. Both of these parameters lack theoretical considerations but do serve as a means of comparing different food powders. The angle of slide is a rather simply defined parameter in which the powder is placed on a horizontal plate and the angle of the plate is changed until the powder slides from the plate. The angle from the horizontal which is required for the powder to lose its position on the plate is measured and this angle will be a function of the type of surface on which the powder is placed.

Dry food products are handled in various ways in different parts of processing plants. The design of handling system for dry products requires knowledge of the properties of the product being handled.

DENSITY

Density is one of the basic properties of any material but in the case of granular food products, various types of densities have been defined:

6.2.1. **Bulk Density** (ρ_B): It is defined by following expression:

$$\rho_B = m / V \text{ -------------- } 1$$

Two types of bulk densities have been designated for dried products.

1) *Loose bulk density* (ρ_L): - measured after placing the product in constant volume container without vibration.
2) *Packed bulk density* (ρ_P) : is measured after the sample is placed in constant volume container which is vibrated until the volume seems to be constant. The bulk density value will be dependent on particle size characteristics and any factor which effects them.

Two additional properties of granular products, which relate to density, are *void* and *porosity*.

Particle shapes

All particles are not exactly of spherical shape, how far it is deviated from spherical shape is expressed by the term spherocity. The term spherocity ΦS which is independent of particle size is used to express shape of the particle.

$\Phi S = 6\ Vp / Dp\ Sp$

Where Dp equivalent diameter of particle Sp surface area of one particle

Vp volume of one particle

For a regular particle $\Phi S = 1$

For many crushed material ΦS =0.6 to 0.7

Particle Size and Size Distributions

A very important property of granular foods and powders is particle size and size distribution. One of the important factors to consider when discussing the mean diameter of a particle is the type of diameter being utilized. Mugele and Evans (1951) developed a generalized expression, which can be used to define all types of mean diameters.

This expression is d = Σ(dq N)

Σ (dp N)

Symbol	Name of Mean Diameter	p	q	Order
dL	Linear arithmetic	0	1	1
dS	Surface	0	2	2
dV	Volume	0	3	3
dM	Mass	0	3	3
dSD	Surface diameter	1	2	3
dVD	Volume diameter	1	3	4
dVS	Volume surface	2	3	5
dMS	Mass surface	3	4	7

for eg . Arithmetic or number diameter is DL = Σ d N / N

Which is obtained when p = 0 and q = 1. Another commonly used notation is volume surface diameter usually called sauter mean diameter.

DVS = Σ d3 N/Σ d2 N

Example: Compute the arithmetic, surface diameter and volume - surface mean diameter for particles in a dry food product with the following distribution of sizes.

Numbers sizes (microns)

140

430

2520

2015

1010

4 5

Solution:

Arithmetic mean diameter dL = Σ (d1 N) / Σ (d0 N)

= 40 X 1 + 30 X 4 + 20 X 25 + 15 X 20 + 10 X 10 + 5 X 4

1 + 4 + 25 + 20 +10 +4

= 16.9 μ

Surface diameter, dSD = Σ (d2 N) / Σ (d1 N)

= 40 X 1 + 30 2 X 4 + 20 2 X 25 + 15 2 X 20 + 102 X + 10 +52 X 4

40 X 1 + 30 X 4 + 20 X 25 +15 X 20 + 10 X 10 + 5 X 4

= 19.26 μ

Volume surface diameter: dVS = Σ (d 3 N)

Σ (d 2 N)

= 403 X 1 + 30 3 X 4 + 20 3 X 25 + 15 3 X 20 + 10 3 X 10 + 5 3 X 4

40 2 X 1 + 30 2 X 4 + 20 2 X 25 + 15 2 X 20 + 10 2 X 10 + 5 2 X 4

= 21.6 μ

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Chapter 5.

Properties of Solid Foods

INTRODUCTION

Solid foods are generally characterized in terms of stress - strain relationship. The stress may be of tensile, compressive, tangential (shear) or torsional (acting on a transverse cross section). The classification of solid foods is even more hazy than that of fluid foods. There are two major groups : elastic and non elastic. visco - elastic foods, mostly of semi - solid and solid nature, form an important group of non - elastic foods.

ELASTIC SOLIDS

1. Hookean or linear elasticity

Elasticity is defined as the tendency of the product to recover upon unloading the shape and dimensions it had before loading. If there is no permanent deformation after unloading, the elasticity is said to be complete elasticity. Ideal or Hookean elasticity is characterized by a linear relationship between force (or stress) and deformation (or strain) starting at the origin (Fig. 7.1a) The body instantaneously returns to its initial form with no residual strain upon unloading.

Further, the Linear relationship is retraced when the sample is unloaded. The ratio of tensile stress to strain for these so-called Hookean bodies is termed Young's modulus (E) or elongation modulus. The ratio between shear stress to shear strain in an ideal linear elastic solid is called shear modulus (G) or rigidity.

Non - Hookean or non - linear elasticity

In reality, most elastic solids exhibit a non-linear or non-Hookean elasticity, in which case the stress is not proportional to strain, and the linear dependence of stress on strain exists only at the lowest strain 'levels. In general, at higher strain levels the loading-and-unloading cycle yields two separate traces describing a hystersis loop (Fig. 7.1b). Since the stress-strain relationship is curvilinear, the modulus of elasticity is frequently given as the tangent modulus, which is the slope of the stress-strain curve at any specified stress or strain.

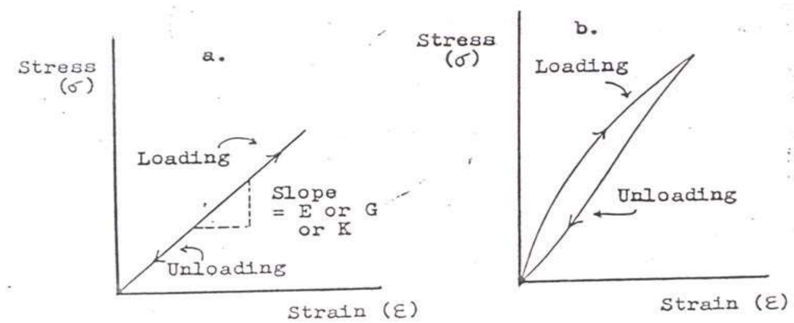

Fig-7.1: Linear (a) and Non-linear (b) elasticity: Stress-strain relationship

NON-ELASTIC SOLIDS

A material may show elasticity, linear or non-linear, if the applied stresses and corresponding strains are small. However, for large deformations most solids are non-elastic. Non-elastic products may exhibit failure when stress exceeds the strength of the body.

Failure

Failure may be seen as fracture or rupture.

(i) Fracture : Cracking of hard materials such as hard cheese at low temperature ultimately resulting in two or more separate pieces is termed fracture. Elastic fracture is fracture without or with a very limited amount of flow (only in the region just around the crack) of the material, as in unripe fruit flesh, tubers etc., whereas plastic fracture is fracture accompanied by flow of material as may be seen in certain soft or semi-hard cheeses.

(ii) Rupture : This term refers to tearing (in pieces) of soft materials. Rupture point is sometimes defined as a point on the stress-strain or force-deformation curve at which the axially loaded specimen ruptures. The failure in rupturing materials such as certain cheese gels, cooked egg white etc. is characterized by a multitude of failure planes.

PLASTIC SOLIDS

Certain non-elastic products may show yield value and tend to flow when the stress exceeds this point. Plasticity is found more frequently in semi-solid and soft products such as butter, spreads etc. rather than hard solids.

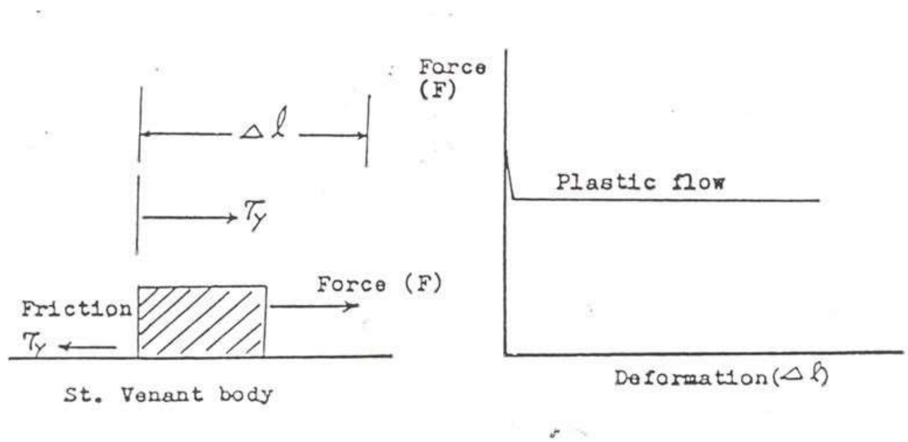

Fig-7.2: Ideal plastic behaviour

VISCOELASTIC FOODS

Failure resulting in rupture, fracture or plastic flow usually involves relatively large stresses and large deformation in solid foods. On the other hand, small deformation in most solids and semi-solid products may reveal what is known as viscoelasticity. Certain, shear-thinning fluids such as age thickened sweetened condensed milk also exhibits viscoelasticity.

The reaction of a viscoelastic body to stress (or strain) consists partly of a viscous component and partly an elastic one. Since stress and strain are time-dependent, the response of the material is rate dependent.

Viscoelastic Models

INTRODUCTION

The fluids can be classified into following categories depending on the response to the applied shear force. Visco- elastic models are developed for Newtonian and non-newtonian fluids by different scientist considering different elements like dashpot and spring in series, in parallel and in combination. Widely used rheological models are Kelvin model, Maxwell Model and Burgers Models, which are described here.

Newtonian fluids are fluids which exhibit a linear increase in the shear stress with the rate of shear. These fluids exhibit a linear relationship between the shear stress and the rate of shear.

The equation for characterizing Newtonian fluid is

T = μ (-dv/dx) (Eq-1)

Where, T = shear stress, μ = dynamic viscosity (η = μ/ρ) , -dv/dx = velocity gradient

A non-Newtonian fluid is broadly defined as one for which the relationship between shear stress and shear rate is not a constant. When the shear rate is varied, the shear stress doesn't vary in the same proportion. These fluids exibit either shear thinning or shear thickening behaviour and some exhibit a yield stress.

The two most commonly used equations for characterizing non-Newtonian fluids are the power law model (Eq-2) and Herschel-Bulkley model (Eq-3) for fluids.

T = K (γ)n (Eq-2)

T = T 0 + K (γ)n (Eq-2)

Where, T =shear stress, K = consistency constant, γ = shear rate, n = flow behaviour index, T0 = yield stress

RHEOLOGICAL MODELS

Several models have been developed to describe the viscoelastic behaviour of materials. There are two basic viscoelastic models viz Kelvin and Maxwell. Other complex viscoelastic behaviors are described by using combinations of these basic models (Fig-8.1 & Fig-8.2).

(i) Kelvin model

The Kelvin model employs the spring (elastic component) and dashpot (viscous component) in parallel. In this stress is the sum of two components of which one is proportional to the strain and the other is proportional to the rate of shear. Since the elements are in parallel they are forced to move together at constant rate. When a constant load is applied to Kelvin model, initially a retarded deformation is obtained followed by a final steady state deformation. When the load is removed the Kelvin model recovers completely but not instantaneously. The model is expressed mathematically as:

εt = ς0 / E [1 - e (-t/ Tret)+ (Eq-5)

where εt is strain at time t, ς0 is applied stress, E is elastic modulus and Tret is retardation time.

(i) Maxwell model

The Maxwell model employs a spring and dashpot in series. In this model the deformation is composed of two parts, one purely viscous and the other purely elastic, When a constant load is applied to Maxwell body, instantaneous elastic deformation will take place followed by continuing viscous flow, which will continue indefinitely as it is not limited by the spring component. When load is removed, the Maxwell body recover instantly but completely. The Maxwell body shows stress relaxation but Kelvin body does not. stress-strain-time relationship in Maxwell model can be given as:

$\varepsilon t = \varsigma 0 / Ed [1 - e (-t/ Tret)+ + E0$ .... (Eq-6)

where, ςt is stress at time t, ςo is fixed strain, Ed is elastic decay modulus and Tred is relaxation time and E0 is equilibrium modulus.

(ii) Burgers model

This 4-element model is one of the best known rheological model which has been used to predict the creep behaviour in a number of materials. The model is composed of spring and dashpot in series with another spring and dashpot in parallel. When a burger's body is subjected to constant load, there is instantaneous deformation (E0) is followed by retarded flow. When the load is removed there is instantaneous recovery followed by incomplete and slow recovery. The stress-strain time relationship can be given as:

$\varepsilon t = \varsigma 0 / Eo + \varsigma 0 / Et(1 - e(-t/ Tret)) + \varsigma 0 t / nv$ .... (Eq-7)

In terms of compliance function Jt which is reciprocal of Young’s modulus (E) the above equation can be given as:

$Jt = J0 + Jt (1 - e(-t/ Tret)) + t / nv$ ....(Eq-8)

Where, J0 is (l/E0) initial compliance, Jt is (l/Et) retarded compliance and t / nv is Newtonian compliance.

(iii) Generalized Maxwell model

A generalised Maxwell model is composed of n Maxwell elements with a spring in parallel with nth element. The elastic modulus E0 of last spring corresponds to the equilibrium modulus in the stress relaxation test. The stress- strain time relationship is given by :

εt = ς0 (Ed1 + e(-t/T1) + Ed2 e(-t/T2) + …………………..+ Edn e(-t/Tn) + Eo) .... (Eq-9)

where, T1, T2 ....Tn are relaxation times.

(ii) Generalised Kelvin model

Experimental data on may viscoelastic materials including biological materials have shown more than one relaxation time or retardation time. For these materials, complete behaviour cannot be represented by a singly Maxwell or single Kelvin model or elements model. Each or these models have only one time constant. To represent viscoelastic behaviour more realistically a chain of Kelvin models, each with its own time retardation is assumed and the model is called a generalized Kelvin model. It consists of Kelvin elements connected in series with an initial spring and final 'viscous element. The equation for generalised kelvin model is:

εt = { 1 / E0 + 1/Et1 (1 - e -t/T1) + 1 / Et2 (1-e -t/T2) + + 1 / E tn (1- e -t / Tn) + t / nv }

.............(Eq-10)

where, T1, T2 Tn are relaxation times.

(iii) Plasto - visco - elastic or Bingham model

A more common type of body is the plasto-visco-elastic or Bingham body. When the stress is applied which is below the yield stress the Bingham body reacts as an elastic body. At stress values beyond the yield stress there are two components. One is constant and is represented by the friction element and the other is proportional to the shear rate and represents the viscous flow element. In a creep ,experiment with stress not exceeding yield value, the creep curve would be similar to the one for a elastic body. When the shear tress is greater than the yield stress, the strain increases with time similar to the behaviour of a Maxwell body. Upon removal of stress at time the strain decreases instaneously and remains constant thereafter. The decrease represents the elastic components and the plastic deformation is permanent.

(iv) Psychorheological Models:

Psycho rheological models consist of a mathematical expression relating sensory rheological data to the corresponding mechanical data. These two sets of data are usually considered as output and input respectively. Associations between subjective and objective texture measurement may be expressed by grap1iieal or mathematic / statistical terms. Various con-elation coefficients quantify the relation between variables.

Using regression analysis, one can ascertain the relation it seIf beyond developing a measure of relatedness of two variables with the assumption of unilateral casuality. Regression analysis helps the experimentor to : (a) select a variables, and (b) to estimate the parameters of that equation by statistical analysis.

8.5. VISCOELASTIC CHARACTERIZATION OF MATERIALS

There are a number of tests which may be used to study viscoelastic materials and determine the relation among stress-strain-time for a given type of deformation and a given type of loading pattern. The most important tests include stress relaxation, creep and dynamic tests.

(i) Creep measurement (Fig-8.1)

In this test the stress is suddenly applied and held constant, and strain ('γ' or 'ε') is measured as a function of time. For a viscoelastic material the slope (dγ/ dt = γ) gives (from ς/ γ) an apparent Viscoelasticity. The deformation γ0 is a measure of the elastic part. From the instantaneous shear modulus G0 may be calculated (ς/y0) or the instantaneous compliance J0o / ς). The whole curve gives Jt, which, in principle, can be calculated to yield Gt. The rheological model to represent the creep behaviour is the Kelvin model and 4 elements Burgers model. Creep measurement are very useful for studying stand up properties of foods. (γ

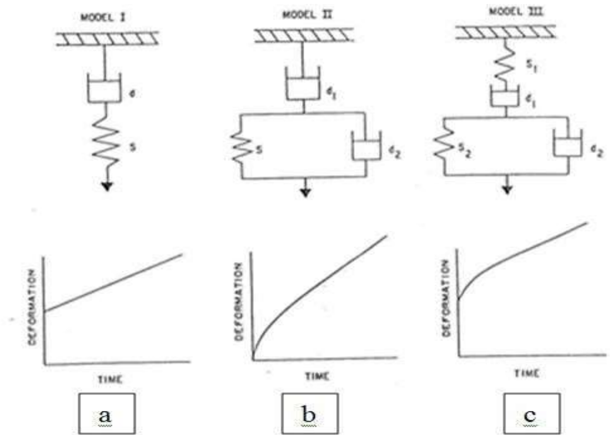

Fig-8.1: Typical creep curves for (a) Maxwell model (Model-I); (b) Kelvin Model (Model-II); (c) Burgers Model (Model-III)

Stress relaxation (Fig-8.2)

In stress relaxation test the specimen is suddenly brought to a given deformation (strain), and the stress required to hold the deformation constant is measured as a function of time. The results are expressed in terms of time dependent modulus Et in tension or compression, Gt in shear or Kt in bulk compression. The rheological models representing stress relaxation are Maxwell model and generalised Maxwell model. One of the most important viscoelastic parameters which can be obtained from stress relaxation test is the relaxation time. It is the time at which the stress in the body resembling a Maxwell model decay to 1/e of initial stress. It is the measure of the rate at which a material dissipates stress after receiving a sudden force. There are a number of methods for treating experimental data on stress relaxation and finding the relaxation time.

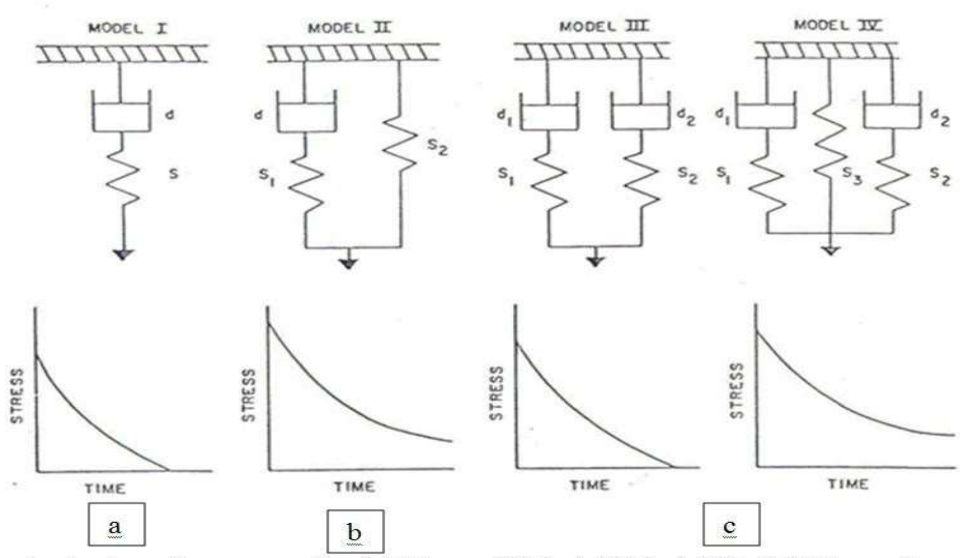

Fig. 8.2 Typical relaxation curves for (a) Maxwell Model (Model-I); (b) Three-element (Model-II); (c) Four-element Model (Model-III); Five-element (Model-IV)

(i) Dynamic Measurement

Despite the simplicity of creep and stress relaxation experiments, there are two disadvantage in these tests. The first disadvantage is that in order to obtain complete, information about viscoelastic behavior of the material, it is necessary to take measurements over many decades of time scales. This in addition to prolonging the experiment may cause chemical and physiological changes in the specimen which will affect the physical behavior of the material. The second disadvantage is the impossibility of having a truely instantaneous application of load or deformation at the beginning of the experiment. These disadvantages can be overcome by dynamic tests in which the specimen in deformed by stress which varies sinusoidally with time.

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CHAPTER 6

Measurement of Food Texture

INTRODUCTION

Texture is one of the major criteria which consumers use to judge the quality and freshness of many foods. When a food produces a physical sensation in the mouth (hard, soft, crisp, moist, dry), the consumer has a basis for determining the food's quality (fresh, stale, tender, ripe). The crispiness of a potato chip, the crunchiness of a pickle, the freshness of bread, cookies and crackers, the firmness of jam and preserve, the spreadability of butter, margarine and cheese and creaminess of puddings are just a few examples of texture and mouthfeel characteristics that make food appealing and satisfying to consumers.

In formulations of new foods, or modification of the existing products while maintaining the desirable sensory characteristics sensory evaluation plays a pivotal role. For instance arriving of minimum sensory standards in nutrient fortified foods for domestic as well as for export purposes, and the development of substitutes for consumers on special diets such as low-calorie, low-sodium, low-cholesterol or lactose-free foods. Sensory evaluation techniques have been used to assess the progress of the product development in the food industry. Many consumers purchase a product on the bases of the sensory experience which it delivers. Food technologist in general, and sensory analyst in particular, recognize the need to focus attention on measuring the perception of these characteristics. In similar manner, the textural measuring devices are helpful in evaluating the product quality.

TEXTURE TERMS USED IN SENSORY TEXTURE PROFILING

A major challenge facing food developers is how to accurately and objectively measure texture and mouthfeel. To develop new product or to modify existing product to have better sensory and rheological attributes developer should understand different texture terms used in sensory texture profiling. The different texture terms used in sensory texture profiling are listed below:

- Adhesiveness: Force required to remove the material that adhere to a specific surface (e.g. lips, palate, teeth).

- Hardness: Force required to deform the product to given distance, i.e. force to compress between molars, bite through with incisors, compress between tongue and palate.
- Cohesiveness: Degree to which the sample deforms before rupturing when biting with molars.
- Springiness: Degree to which the product returns to its original size/shape after partial compression (without failure) between the tongue and palate or teeth.
- Fracturability: Force with which the sample crumbles, crakes or shatters. Fracturability encompasses crumbliness, crispiness, crunchiness and brittleness.
- Chewiness: Number of chews (at 1 chew/sec) needed to masticate the sample to a consistency suitable for swallowing.
- Guminess: Energy required to disintegrate a semi-solid food to a state ready for swallowing.
- Bounce: The resilience rate at which the sample returns to the original shape after partial compression.
- Coarseness: Degree to which the mass feels coarse during product mastication.
- Denseness: Compactness of cross section of the sample after biting completely through with the molars.
- Dryness: Degree to which the sample feels dry in the mouth.
- Graininess: Degree to which a sample contains small grainy particles.
- Heaviness: Weight of product perceived when first placed on tongue.
- Moisture absorption: Amount of saliva absorbed by product.
- Mouth release: Amount of wetness/juiciness released from sample.
- Mouth coating: Type and degree of coating in the mouth after mastication (for example fat/oil).
- Roughness: degree of abrasiveness of product's surface perceived by the tongue.

- Slipperiness: Degree to which the product slides over the tongue.
- Smoothness: Absence of any particles, lumps, bumps, etc. in the product.
- Uniformity: Degree to which the sample is even throughout.
- Uniformity of chew: Degree to which the chewing characteristics of the product are even throughout mastication.
- Uniformity of bite: Evenness of force through bite.
- Viscosity: Force required to draw a liquid from a spoon over the tongue.
- Wetness: Amount of moisture perceived on product's surface.

Instruments for Rheological Measurement

10.1. INTRODUCTION

There are diverse range of instruments for measuring texture properties of dairy and food products. Some of the equipments are described as below:

(i) Wire Cutting Devices:

A wire driven at a Constant speed to cut the sample is used for certain daily products. An advantage is that the sample area in Contact with the wire is constant throughout the test which minimizes the effect of friction and adhesion between the product and the test cell surfaces.

(ii) Circular cutting devices

The Cherry- Burrel Curd tension meter is used in the dairy industry to determine curd tension of milk and firmness of cottage cheese. A circular blade is driven at a constant speed of 2.54 cm per 7.5 sec. to cut the curd.

(iii) Cone Penetrometer of varying dimensions

It consists of a cone of varying dimensions which is allowed to penetrate chhana, paneer,khoa or any other soft dairy product. The hardness values are read out on a mechanical linked graduated scale in terms of mm penetration.

(iv) Pea Tenderometer

It consists of a grid of shearing blades (test cell) rotated at constant speed through a second grid suspended, so that the force on the second, grid is counter balanced by a pendulum which is displayed by a pointer on a graduated scale. It is widely used by the pea industry.

(v) The Warner – Bratzler Shaler Test

A cylindrical sample usually 2.5 cm. in ilia. is placed ill a triangular hole in a thin blade of 0.25 cm thickness cut by pulling the blade through a slot and the sheer force indicated by a spring scale. It is widely used for meat products.

(vi) Kramer shear press

It consists of a hydraulic press where the ram speed can be selected to complete its down stroke in 15 to 100 seconds. The ram operated by a hydraulic pump drives the moving components of the texture test cell into stationary component supported by the press frame. It is based on the principle of a multi- blade shear compression cell. Because of limitation of control by ram speed, the instrument does not give precise and accurate reading of force exerted.

Sensory texture profile is defined as the organoleptic analysis of the texture complex of a food in terms of its mechanical, geometrical, fat and moisture characteristics, the degree of each present, and the order in which they appear from first bite through complete mastication. The data on these parameters is generally collected using either interval or ratio scales.

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Chapter 7.

Thermal Properties of Frozen Foods

INTRODUCTION

The food product properties of interest when considering the freezing process include density, specific heat, thermal conductivity, enthalpy, and latent heat. These properties must be considered in the estimation of the refrigeration capacity for the freezing system and the computation of freezing times needed to assure adequate residence times. The approach to prediction of property magnitudes during the freezing process depends directly on the relationship between unfrozen water fraction and temperature.

It is important to study thermal properties of foods because they affect the design of food processing equipment. The food products undergo changes in composition during such process as freezing, evaporation and dehydration. There are different methods available to measure the thermal properties of food, but the available data differ depending on the method used. The important thermal properties of food are as follows:

DENSITY

The density is mass per unit volume. Usually the density is expressed in grams per mL or cc. Mathematically a "per" statement is translated as a division. cc is a cubic centimeter and is equal to a ml Therefore,

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \ \text{g/ml}$$

The influence of freezing on food product density is relatively small but a dramatic change does occur at and just below the initial freezing temperature. This change can be predicted by the following equation, as discussed by Heldman (2001):

$$\rho = 1/ \sum (m_{si} / \rho_{si})$$

SPECIFIC HEAT

A measure of the heat required to raise the temperature of a substance. When the heat ΔQ is added to a body of mass m, raising its temperature by ΔT, the ratio C given in Eq. (1) is defined as the heat capacity of the body.

Cp = ΔQ/ ΔT

The specific heat capacity of a food product can be predicted, based on product composition and the specific heat capacity of individual product components. The following expression was proposed:

Cp = ∑ (C psi. m si)

where each factor on the right-side of the equation is the product of the mass fraction of a product component and the specific heat capacity of that component. The specific heat values for product components were estimated by

Choi and Okos (1986). The above equation can be used to predict the specific heat capacity of product solids by removing the term for the water fraction. These specific heat magnitudes for the product solids can be used in the prediction of product enthalpy and apparent specific heat.

Cp = 4.180 Xw + 1.711 Xp + 1.98 Xf + 1.547 Xc + 0/908 Xa, ; kJ/kg0C

……….Cho’s and Oko’s Model Where, Xw: water fraction Xp: Protein fraction

Xf: Fat fraction

Xc: Carbohydrate fraction XA: Ash fraction

THERMAL CONDUCTIVITY

Thermal conductivity (λ) is the intrinsic property of a material which relates its ability to conduct heat. Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole. Conduction takes place when a temperature gradient exists in a solid (or stationary fluid) medium. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature equates to higher molecular energy or more molecular movement. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide.

Thermal conductivity is defined as the quantity of heat (Q) transmitted through a unit thickness (L) in a direction normal to a surface of unit area (A) due to a unit temperature gradient (Δ T) under steady state conditions and when the heat transfer is dependent only on the temperature gradient. In equation form this becomes the following:

Thermal Conductivity = heat × distance / (area × temperature gradient)

$$\lambda = Q \times L / (A \times \Delta T)$$

The thermal conductivity magnitudes of most food products are a function of water content and the physical structure of the product. Many models suggested for prediction of thermal conductivity are based on moisture content and do not consider structural orientation. The Choi's and Oko's Model for prediction of thermal conductivity is as follows.

$$K = 0.58\, X_w + 0.155\, X_p + 0.25\, X_c + 0.16\, X_f + 0.135\, X_a \text{ , W/m °K}$$

X_c: Carbohydrate fraction X_a: Ash fraction

THERMAL DIFFUSIVITY

A measure of the rate at which a temperature disturbance at one point in a body travels to another point. It is expressed by the relationship K/dCp, where K is the coefficient of thermal conductivity, d is the density, and Cp is the specific heat at constant pressure. Very little thermal diffusivity data are available, but it can be determined using relationship of specific heat, thermal conductivity and mass density of the food product.

FREEZING POINT DEPRESSION

Probably one of the more reveling properties of water in food is the freezing point depression. Since all food products contain relatively large amounts of moisture or water in which various solutes are present, the actual or initial freezing point of water in the product will be depressed to some level below that expected for pure water.

The magnitude of this freezing point depression becomes a direct function of the molecular weight and concentration of the solute in the food product and in solution in the water.

The expression or expression which predicts the extent of freezing point depression can be derived from thermodynamic relationships based on equilibrium between the states of a system. The final form is given by

$$\Delta T_F = \frac{Rg * (Tao)^2 * Wa * m}{1000\ L}$$

Where ΔT_F is freezing point depression and m is molality in terms of moles of solute per kg solvent. L is the latent heat of fusion per unit mass. T_{AO} is the freezing point of pure liquid (A) (273°c in c.q.s. system)

W_a=molecular weight of component in solution

$$m = \frac{MB\ (\text{per 100 gm solvent})}{Wb}$$

(Wb = molecular weight of component in solution, MB = mass in kg) Rg is gas constant

Rg = w × WA = 0.462 × 18

Rg = 8.316 Joules/mole oc

WA = molecular weight of water = 18 moles/gm w = fraction of water

11.8. THERMODYNAMICS OF FOOD FREEZING

Freezing is one the more common processes for the preservation of foods. It is well known that lowering the temp reduces the activity of microorganisms and enzyme systems, thus preventing deterioration of the food products. In addition to the influence of temp reduction on m.o. and enzymes, crystallization of the water in the product tends

to reduce the amount of liquid water in the system and inhibit microbial growth or enzyme activity in the secondary action.

The engineering aspects of food freezing include several interesting areas. In order to design a refrigeration system that will serve a food freezing process, some indication of the refrigeration requirements or enthalpy change which occurs during product freezing is required. This aspect is related to the type of product being frozen. The second aspect of food freezing that is closely related to engineering is the rate at which freezing progresses. This aspect is related to the refrigeration requirement, but the temperature difference existing between the product and freezing medium are also of significance. The rate of freezing is also closely related to product properties and quality. Product properties resulting from very rapid freezing are significantly different from those obtained by slow freezing. This difference is dependent primarily on the manner in which ice is formed within the product structure. In addition, the rate of freezing will establish the rate of production for a particular food-freezing operation. For this purpose the most rapid rate of freezing is desirable provided that product quality is not sacrifice.

Examples:

Example 1:

A formulated food product contains the following components – water 80%, protein 2%, carbohydrate 17%, fat 0.1% and ash 0.9%. Predict the specific heat in W/kg K using Choi's and Oko's model.

Solution:

Cp = 4.180 Xw + 1.711 Xp + 1.98 Xf + 1.547 Xc + 0/908 Xa

= 4.180 (0.8) + 1.711 (0.02) + 1.98 (0.001) + 1.547 (0.17) + 0.908 (0.009)

= 3.651 kJ/kg0C

= 0.8726 kCal/kg0C

= 1.0147 W/kg0C

Example 2:

Calculate the thermal conductivity of milk using choi & OKOS model, if milk contains 87.5% water, 3.7% protein, 3.7% fat, 4.6% lactose and 0.5% ash at 100C.

Solution:

K = 0.58 Xw + 0.155 Xp + 0.25 Xc + 0.16 Xf + 0.135 Xa

= 0.58 (0.875) + 0.155 (0.037) + 0.25 (0.046) + 0.16 (0.037) + 0.135 (0.005)

= 0.49 + 0.005735 + 0.0115 + 0.00592 + 0.000675

= 0.51383 W/m ºK

Example 11.3

Compute the temperature at which ice formation begins in an ice cream mix with the following composition: 10% butter fat, 12% solids-not-fat, 15% sucrose and 0.22% stabilizer.

$$\text{Molality, m} = \frac{M_b \text{ (per 100 g solvent)}}{W_b}$$

The solute accounted for in the ice-cream mix is sucrose (W = 342) and lactose (W = 342), which represents 54.5 % of the SNF in the mix. – Molality is computed as:

Fraction solute = 0.15 + 0.545(0.12) = 0.2154 g/ g product

When expressed in terms of water fraction (62.78%), thus 0.2154/0.6278 = 0.3431 g solute/g solvent or 343.1 g solute / 1000g solvent

And m = 343.1/342 = 1.003

$$T_f = \frac{(0.462)(273)^2(18)(1.003)}{1000(333.22)} = 1.86 \text{ K}$$

Therefore initial ice formation will occur at (273-1.86) 271.14 K or - 1.86 0C

Prediction of Freezing Rates

INTRODUCTION

The most important consideration associated with food freezing rate is the rate of the process. This rate not only establishes the structure of the frozen product but the time required for freezing is the basic design consideration for the process. An analysis of current literature indicates significant variation in the definition of freezing rate.

Fennema, et.al(1973) have identified four methods to describe rate of freezing including: (a) Time-Temperature methods (b) velocity of ice front (c) Appearance of specimen and (d) Thermal methods. The most frequently encountered methods are time – temperature including (a) Temperature change per unit time or (b) time to transverse a given range of temperatures. The temperature change per unit time is the most appropriate indicator when the primary concern is structure of the frozen product and resulting influence on quality. It must be emphasized that temperature change per unit time will vary significantly during the freezing process and an average value has limited meaning.

The most appropriate indicator of freezing rate for purpose of process design is the time to transverse a given range of temperature. The international institute of refrigeration (1971) has proposed the following definition: The freezing rate of a food mass is the ratio between the minimum distance from the surface to the thermal center and the time elapsed between the surface reaching 0 ° C and the thermal center reaching 5 ° C colder than the temperature of initial ice formation at the thermal center. Where depth is measured cm & time in hour, the freezing rate will be expressed as cm/hr. A variation of the IIR definition is referred to as "thermal arrest time" and represents the time required for the slowest cooling point in the product to decrease 0 ° C to – 5 ° C. Long class used thermal wrest time to describe the rate of freezing in fish. The result of this research indicates two significant factors about the use of thermal arrest time. The first factor was the location of the temperature sensor. Small deviations in location of the temperature sensor from the slowest cooling or freezing point in the product resulted in considerable error in determining the thermal arrest time for a given product. The second factor was the influence of initial product temperature. Results reported by long (1955) indicated that an increase in initial product temperature decreased the thermal arrest time. In other words, the total freezing time was longer when the initial temperature was higher, but the time required to reduce the product temperature from 0 ° C to – 5 ° C was less, for purposes of the discussion which follows, the time required to reduce the product temperature at the slowest cooling location from the initial freezing point will be utilized as the time to describe freezing rate.

Although this definition is not without limitations, it seems to provide the best compromise when considering advantages & disadvantages of other methods.

Fennema and Powrie (1964) have listed four factors which influence freezing rates: (a) The temperature difference between the product & cooling medium (b) The modes of heat transfer to from & within the product (c) The size, type & shape of the package containing the product & (d) The size, shape & thermal properties of the product.

Although considerable information is available in heat transfer literature to assist in describing the rates of heat transfer in various shaped packages & products, the major limitation appears to be in the description of transient heat transfer with thermal properties being a function of temperature. The latter must be the case during the freezing of food products, since the apparent specific heat & thermal conductivity are both significant function of temperature in the freezing zone or below the initial freezing point of the product. Many of the methods utilized to obtain expressions for freezing time have involved simplifying assumptions which do not account for the thermal diffusivity being a function of temperature, in an effort to obtain a solution to a complete heat conduction problem.

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Chapter 8.

Planck's Equation and related Problems

INTRODUCTION

Freezing times are basic design criteria for freezing systems and represent the residence time for the food product within the freezing system required to achieve the desired level of freezing. The most widely accepted definition of freezing time is the time required to reduce the product temperature from some initial magnitude to an established final temperature at the slowest cooling location. An alternative definition changes the endpoint to the mass average enthalpy equivalent to the desired final temperature for the product. Freezing-time calculations are completed as a first step in the design of a food freezing system. The freezing time establishes the residence time for the product in the system. The final product temperature is established as the magnitude needed to maintain optimum product quality during storage. For a continuous freezing system, the resident time is dependent on the rate of product moves through the system and on the length of the system. More specific characteristics of the design will depend on the type of freezing system being considered.

FREEZING TIME EQUATION (PLANCK'S EQUATION)

The most straight forward expression available for computing freezing time was derived by plank. The equation utilized, for computation purpose be derived for various geometries of product. By reference to fig. given below, the case of one-dimensional freezing of a product slab can be illustrated the three basic equations utilized in a the derivation account for the first expression is the basic heat-conduction equation for the frozen product region which has a variable thickness x as follow:

$$q = \frac{A(T_S - T_F).k}{x} \text{..............(1)}$$

Where T_F is the initial freezing point of the product and represent the temperature which exists in all unfrozen region of the product & K is the thermal conductivity of the frozen material.
The second expression describes the heat transfer from the product surface to the surrounding medium can be expressive as:

$$q = h_C A(T_\infty - T_S) \text{ ....(2)}$$

Where H_C is a convective heat transfer coefficient at the product surface.

Eq. (1) & (2) can be combined into one expression to account for heat transfer in series as follows:

$$q = \frac{A(T_2 - T_F)}{1/h_c + x/k} \text{ .... (3)}$$

And eliminates the need for knowledge of the surface temperature.
The third equation, describing the rate at which heat is being generated at the freezing front is as follows:

$$q = AL\rho . \frac{dx}{dt} \text{ ....(4)}$$

Where the differential **dx/dt** represent velocity of the freezing front. **A**=Area, **L**=Latent heat, **ρ** = Density
By equating Eq. (3) & (4) and by integration between the appropriate limits the following expression for freezing time is obtained

$$t_F = \frac{\rho L}{T_F - T_\alpha}\left[\frac{a}{2h_C} + \frac{a^2}{8k}\right] \text{ .... (5)}$$

Where a represent the total thickness of the slab being frozen. By introduction of appropriate

constants, the most general form of plank's equation is obtained as follows:

$$t_F = \frac{\rho L}{T_F - T_\alpha}\left[\frac{Pa}{h_C} + \frac{Ra^2}{k}\right] \text{ ....(6)}$$

Numerous equations and approaches to freezing-time prediction have been proposed and utilized. The best known and most used of the prediction methods is based on Planck's equation (1913):

$$t_F = \frac{\rho L}{T_F - T_\alpha}\left[\frac{Pa}{h_C} + \frac{Ra^2}{k}\right]$$

where P and R are constants that depend on product geometry (Table 13.1).

The limitations to Planck's equation for estimation of freezing times for foods are numerous and have been discussed by Heldman and Singh (1981) and Ramaswami and Tung (1981). One of the concerns is selection of a

latent heat magnitude(L) and an appropriate value for the thermal conductivity (k). In addition, the basic equation does not account for the time required for removal of sensible heat from unfrozen product above the initial freezing temperature or for removal of frozen product sensible heat. There have been numerous attempts to modify Planck's equation or develop alternative expressions.

The modifications made in the expression by number of scientists.

Limitations of Planck's Equation:

Use of equation requires assumption of some latent heat value and doesn't consider the gradual removal of latent heat.The equation utilized only the initial freezing point and neglects the time required to remove sensible heat above the initial freezing point.

Constant thermal conductivity is assumed for the frozen portion. In fact thermal conductivity of the frozen region is temperature dependent and hence variable. Density values for frozen foods are difficult to measure. The initial and final temperature is not accounted for in the equation.

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Density values for frozen foods are difficult to measure.

The initial and final temperature is not accounted for in the equation.

Even with these limitations, Planck's equation becomes most popular method for freezing time prediction.

Assumptions of Planck's Equation

Freezing starts with all water in the food unfrozen but at its freezing point and loss of sensible heat is ignored. Heat transfer takes place sufficiently slowly for steady state conditions to operate.

The freezing front maintains a similar shape to that of the food. There is single freezing point.The density of food doesn't change.

The thermal conductivity and specific heat of the food are constant when unfrozen and then change to a different constant value when the food is frozen.

Table- 13.1: Constants for Plank's Equation

Geometry	***P***	***R***
Infinite slab	1/2	1/8
Infinite cylinder	1/4	1/16
Sphere	1/6	1/24

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Chapter 9.

Design of Food Freezing Equipment

INTRODUCTION

Freezing is one of the common processes for preservation of foods. Preservation of food by freezing occurs by several mechanisms. The reduction of temperature to levels below 0 0C causes a significant reduction in growth rates for microorganisms and the corresponding deterioration of product due to microbial activity. In addition to this enzymatic and oxidation reactions will be slow downed or arrested. In addition, formation of ice crystals with in the product changes the availability of water to participate in reactions. The engineering aspects of food freezing include:

- Design of food freezing system Design of refrigeration system
- Prediction of the rate at which freezing progresses.

FREEZING PROCESS

Actual freezing process in food products is somewhat more complex than freezing of pure water. In water the temperature decreases as heat is removed from the system until freezing point is reached. After small amount of sub cooling / super cooling, the temperature remains constant as latent heat is removed from the water system. Following this latent heat removal,

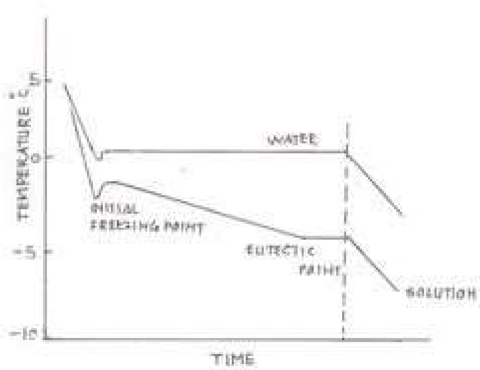

Fig- 16.1: Freezing point depression

the temperature deceases again.

In a food product removal of heat energy results in a temperature decrease until initial freezing point is reached. Initial freezing results in crystallization of a portion of the water, resulting in a concentration of the remaining solution and further reduction of the freezing point of that unfrozen portion. This results in additional decrease in temperature. This process continues till eutectic point of the solute present in the food product. In single solute

system, the removal of heat energy beyond this point does result in temperature decrease, but with crystallization of solute as well as ice crystal formation.

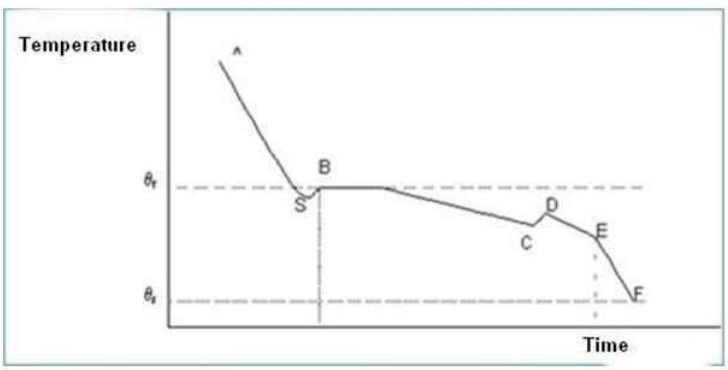

Fig-16.2: Freezing curve for food product with more than one solute

In actual food product system, it is very probable that more than one solute will be present. If the temperature is monitored atthermal center of a food (the point that cools most slowly) as heat is removed, the freezing curve obtained will be like

AS – The food is cooled to below its freezing point Tf, with the exception of pure water, is always below 0 0C. At point S the water remains as liquid, although the temperature is known as super cooling and may be as much as 10 0C below the freezing point.

SB – The temperature rises rapidly to the freezing point as ice crystals begins to form and latent heat of crystallization is released.

BC - Heat removed from the food at same rate as before. Latent heat is removed and ice forms, but the temperature remains almost constant. The freezing point is depressed as solute concentration increases and the temperature therefore falls slightly. It is during this phase that the major part of ice is formed.

CD – One of the solute becomes super saturated and crystallizes out. The latent heat of crystallization is released and temperature rises to eutectic temperature * for that solute.

DE – Crystallization of water and solute continuous. The total time, Tf taken is determined by the rate at which heat is removed.

EF - The temperature of the ice water mixture falls to the temperature of the freezer. A portion of water remains unfrozen at the temperature used in commercial freezers, the amount depends on type and composition of the food and temperature of storage.

Water contents and freezing points of selected foods:

Food	water content (%)	freezing point (^{0}C)
Vegetables	78-92	-0.8 to -2.8
Fruits	87-95	-0.9 to -2.7
Meat	55-70	-1.7 to -2.2
Fish	65-81	-0.6 to -2.0
Milk	87	-0.5
Egg	74	-0.5

* Temperature at which a crystal of an individual solute exists in equilibrium with the unfrozen liquid and ice.

ICE CRYSTAL FORMATION

The freezing point of a food is the temperature at which a minute crystal of ice exists in equilibrium with surrounding water. However before an ice crystal can form, a nucleus of water molecules must be present. There are two types of nucleation: homogeneous nucleation (the chance orientation and combination of water molecules) and heterogeneous nucleation (the formation of a nucleus around suspended particles or at cell wall). Heterogeneous nucleation is more likely to occur in foods and takes place during super cooling.

The length of super cooling period depends on the type of food and the rate at which heat is removed. High rates of heat transfer therefore produce a large number of small ice crystals. The rate of ice crystals growth is controlled by rate of heat transfer. The rate of mass transfer does not control the rate of crystal growth except towards the end of freezing period. The time taken for the temperature of a food to pass through the critical zone determines both the number and the size of ice crystals.

ENTHALPY CHANGE DURING FREEZING

One of the basic considerations in the design of a system for the freezing process is the refrigeration requirement for reducing the food product temperature to the desired level. The enthalpy changes required will reduce the product from some temperature above the freezing point to some temperature below the freezing point and can be represented by

$\Delta H = \Delta Hs + \Delta Hu + \Delta HL + \Delta HF$

where the terms on right hand side represent the sensible heat required to reduce the product solids temperature from initial to storage temperature (Δ Hs), the sensible heat removed to reduce the unfrozen portion of the product to the storage temperature(Δ Hu), the latent heat removed (Δ HL), and the sensible heat removed to reduce the frozen water portion of the product to the storage temperature(Δ HF).

Sensible heat Δ Hs is given by,

$\Delta Hs = M\ Cp\ (Ti-TF)$ where TF = freezing point temperature

Evaluation of other components is somewhat complex because of changing state of product below initial freezing point. Mass of unfrozen product and frozen product are changing and are temperature dependant. Enthalpy change required to reduce the unfrozen portion of the product to various temperatures below initial freezing point, TF is given by:

$\Delta Hu = Mu\ (T)\ Cp,u\ (T)\ (TF-T)$

Similarly,

$\Delta HF = MF\ (T)\ Cp, F\ (TF-T)$

these equations can be writen in differential form as:

$dHu = Mu\ (T)\ Cp,u(T)\ dT$ and $dHF = MF\ (T)\ Cp, F\ dT$

Latent heat portion is given by:

$\Delta HL = MF\ (T)\ L$

Unfrozen and frozen portions of product at any temperature below the initial freezing point can be calculated by $\ln XA = l\ '/Rg\ (1/TAo - 1/TA)$

Where, TAo - freezing point of pure liquid, K XA - is mole fraction of water in solution

Rg - gas constant , 8.314 kJ/ kg mol K.

TA - absolute temperature of aqueous solution, K

l ' - Latent heat of fusion, J/ mol (6003 J/ mol for dilute liquids)

After obtaining information on the frozen and unfrozen fractions as function of temperature and specific heat of unfrozen fraction the above equations can be evaluated by integration.

Volume changes:

The volume of ice is 9 % greater than that of pure water hence expansion of food after freezing is expected. The degree of expansion depends on:

1. Moisture content (higher moisture content produce greater changes)
2. Cell arrangement: Plant material with intra cellular air spaces will absorb internal increases in volume without large changes in their overall size.

Δ Hu = Mu (T) Cp,u (T) (TF-T)

Similarly,

Δ HF = MF (T) Cp, F (TF-T)

these equations can be writen in differential form as:

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1. Moisture content (higher moisture content produce greater changes)
2. Cell arrangement: Plant material with intra cellular air spaces will absorb internal increases in volume without large changes in their overall size.
3. The concentrations of solute: High concentrations reduce freezing point and do not freeze or expand.
4. Freezer temperature: This determines the amount of unfrozen water and hence the degree of expansion.

Prediction of Freezing Rates/ Time

Most important consideration in food freezing problems is the prediction of time required to accomplish a given freezing process. The concept of "thermal arrest time", which may be defined as the time required to reduce the temperature of the product to some stated temperature below the initial freezing point.

During freezing, heat is conducted from the interiors of a food to the surface and is removed by the freezing medium. The factors which influence rate of heat transfer are:

1. The thermal conductivity of food
2. The area of food available for heat transfer
3. The distance that the heat must travel through the food
4. The temperature difference between the food and freezing medium
5. The insulating effect of boundary film of air surrounding the food.

Prediction of Freezing Time is Complicated because of The Following Reasons:

1. Differences in initial temperature of the food
2. Differences in initial size and shape of pieces of food
3. Differences in the freezing point and the rate of ice crystal formation with in different regions of pieces of food.
4. Changes in density, thermal conductivity, specific heat, and thermal diffusivity with reduction in temperature of food.

Factors Influencing Freezing Time

There are several parameters that influence freezing time and that will influence the design of equipment used for food freezing.

Freezing medium temperature, where lower magnitude will decrease freezing time. Product size will influence freezing time.

Convective heat transfer coefficient, hc will influence freezing time significantly. The initial freezing point.

Product properties (TF,ρ, k,CP) will influence freezing time predictions.

Design Criteria For Selection Food Freezing Equipment

It should be of sanitary design. All product contact surfaces should be made of Stainless Steel. The equipment should be adaptable for different food products. It should have high efficiency. Quick freezing & continuous operation. Material of construction should be non-toxic, non-corrosive and odour less & taintless.

The equipment should be of simple design and easy to operate. Type of product processed. Reasonable freezing rates. Airflow rates should be uniform and air should make intimate contact with the product.

Changes in Food during Freezing

In any food freezing operation the amount of water getting frozen depends on

1. Initial water content

2. The way in which it is bound.

During freezing the water inside food is converted into the ice and freezing progresses i.e. the constituents like salts, acids, sugar etc., which are dissolved in the water, become more and more concentrated. This concentrated solution may adversely affect the properties of the product. Hence fast freezing is recommended. During rapid freezing the size of ice crystals will be small and the constituents are trapped inside them and almost in unchanged state. It is important to maintain lower temperature as frequent changes in temperature may lead to recrystallization of water in which the water molecules will migrate from the smaller ice crystals which have higher osmotic pressure, to larger ones which have lower osmotic pressure. Apart from rapid freezing, rapid thawing is also important to preserve biological value of foods. Rapid thawing by use of microwaves will prevent recrystallization.

Important Changes during Freezing

1. **Freezer burns:**

Due to irreversible drying of the surfaces leading to brown spots on the surface. This occurs due to changes in water vapour pressure in the product. This occurs mainly when the freezer is switched off –and- on frequently. Suppose during a particular interval of time the product has higher temperature which is the case when the freezer is switched on, the water from the product may come out and condense on colder surfaces. However when the temperature changes are reversed, the water does not return to original sites and this gives rise to freezer burns. This can be prevented by wrapping the food products in polyethylene films which are impervious to water vapor before freezing.

2. **Destruction of cells:**

This takes place during freezing. The cause is not clear yet but reasons may be manifold. Purely mechanical action of growing ice crystals may destroy cells.

Osmotic drying of cells due to increasing concentration of solution. Concentrated solution of acid/sugar/salt may damage the cells.

To prevent this, addition of sugars like sucrose at 10%, gelatin etc has been recommended especially in freeze drying of eggs.

1. Change in proteins: Precipitation of calcium caseinate commonly called as denaturation by cold may take place.
2. Enzymes: Enzymes are not destroyed completely during freezing. Peroxides are found to be active even at – 20 0C. Hence vegetables are given blanching treatment prior to freezing (either by steaming or boiling water). To prevent browning of fruits 0.1 % ascorbic acid or 0.1% citric acid solution is used. SO2 gas is also used to prevent browning.
3. Vitamins: No loss of A, B, D, E during freezing and some loss of C especially at below – 20 0 C may occur.
4. Microorganisms: They are inhibited – no growth. But psychotropic organisms may grow. Destruction of microorganisms by denaturation of protein is possible.
5. Metabolism: It is slowed down.

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Chapter 10.

Study of Batch and Continuos Ice cream Freezer

Introduction

Ice cream freezers, apart from freezing a portion of water of ice cream mix, also incorporates air in the mix to obtain a swell in volume or 'overrun'. To get different freezing and good overrun in the ice cream it is very essential that the optimum quantity of the mix should be taken in the freezer for freezing. This quantity varies from freezer to freezer. The function of the freezer are:

- To freeze a portion of the water of the mix to get a smooth product,
- To incorporate a predetermined amount of air uniformly into the mix to get proper overrun,
- To mix fruits and flavouring into the mix while being frozen.

Fast freezing is essential for a smooth product because ice crystals that are formed quickly are smaller than those formed slowly. Therefore, it is desirable to freeze and draw from the freezer in as short a time as possible. Failure to provide adequate refrigeration during freezing or hardening, results in formation of large ice-crystals in ice cream. Also, since freezing continues after the ice cream is placed in the hardening rooms; the ice crystals formed during the hardening period are larger because they form more slowly than in the freezer. For this reason, it is desirable to freeze the ice cream as stiff as possible and yet have it liquid enough to draw out of the freezer.

Factors influencing the freezing time are: the mechanical factors and factors inherent in the mix itself.

Mechanical factors are

- Type and make of freezer
- Condition of the freezer wall and blades
- Speed of the dasher

- Temperature and flow rate of the refrigerant
- Overrun desired and
- Rate of drawing the ice cream.

Characteristics of the mix influencing the freezing time are:

(i) Composition of mix

(ii) Freezing point of mix and method of processing the mix, and

(iii) Kind and amount of flavours added.

There are two types of ice cream freezers:

(I) Batch ice cream freezers and

(II) Continuous ice cream freezers.

(I) Batch Ice Cream Freezer

Construction

In the batch freezer a definite quantity of the mix is frozen at a time. It consists of a tubular chamber fitted with a rotating dasher (Fig-17(A). The chamber is fitted with a mix tank and hopper for adding fruits and flavours. The chamber is surrounded by a refrigerated jacket in which ammonia or other suitable refrigerant is evaporated to provide the cooling effect.

The freezing chamber is made of a liner, usually of nickel silver or stainless steel, pressed inside a steel or copper tube which forms the inside wall of the cooling jacket. If the jacket is cooled by brine, it is constructed of copper with narrow passageways to increase turbulence and heat transfer. The outside is insulated with cork and covered with an airtight metal housing. If the cylinder is to be cooled by direct expansion of a refrigerant, the outer jacket is usually built of steel and properly insulated.

The functions of the dasher are

(i) To scrape the frozen film from the cylinder wall, carry it to the centre, and circulate it from one end of the freezer to the other so that rapid and uniform cooling takes place,

(ii) To beat the mix and hold air into it,

(iii) To eject the frozen mix rapidly when the batch is finished.

The dasher consists of an outer frame carrying either two or more sets of scraper blades, which turn in one direction at a speed of 60-70 rpm. (Fig-17(B))The central part consists of beater having a series of longitudinal rods or paddles which rotate in opposite direction. The dasher is mounted on a shaft furnished with rotary seals, so that it can be completely taken apart for cleaning. It is important to have the dasher in proper alignment and the blades must be sharp.

Operation

A batch of mix is dropped into the chamber, the refrigeration is turned on and dasher is started. The temperature of the refrigerant is very important and should be from -240C to -290C in order to get a rapid formation of ice crystals. The mix is cooled down to a temperature of about -50C in 6-10 minutes at which the refrigeration is turned off by means of a quick shut off valve and dasher allowed to rotate for 1-2 min to allow the mix to partially congeal. The mix will not absorb much air until a temperature of about -50C is reached. At this point, it will rapidly absorb air of 100-120% of its original volume. The ice cream is then drawn out of the chamber and into cans or packages which are placed in a room at temperature between -24 to -300C for hardening.

A slide or pivot valve on the bottom portion of the front door allows the ice cream to be drawn into containers or bulk cans. The dasher is designed to propel the product toward the discharge port. Subsequent batches are made in the same manner. The size of the batch freezers varies from 18-40 liters of 100% overrun. If greater than 100% overrun is desired, the mix charge must be reduced enough to prevent overflow of ice cream during whipping.

The beaters promote whipping, but when freezing at temperatures below -50C, air is less readily incorporated, and some may even be expelled. Ice cream made with batch freezers has both larger ice crystals and bigger air cells than ice cream made with the same mix on continuous freezers. Overrun control to close tolerance is difficult with batch freezers, and it may vary by 80-100 from the beginning of drawing the batch to completely emptying the barrel. This occurs because whipping continues all during the drawing time.

FIG-17(A) Batch Ice Cream Freezer

FIG-17(B) Beater Assembly of Batch Ice Cream Freezer

Study of Continuous Ice cream Freezer

Continuous Ice Cream Freezer

The continuous ice cream freezer was developed in the early 1930's. The principle of operation is very similar to that of a batch freezer, except that the freezing is done under pressure (which increases the heat transfer rate) and the air is forced in or drawn into the freezing chamber continuously at a metered rate. The expanded and congealed ice cream is then forced out of the freezer cylinder, ready for filling in packages and containers. In a continuous freezer (Fig-18.1), about 30 second time is taken for partial freezing the mix. The ice crystal size is reduced to 45-55 µm and the air voids are in the range of 100-150 µm diameter.

The continuous freezer (Fig. 18.1) consists of a stainless steel shaft carrying a set of blades (dasher) rotating at 150- 200 rpm inside a chromium-plated nickel surface of the freezing cylinder (Fig-18.2). The blades made of spring steel continuously scrape off the thin film of ice which form on the inner wall or the tube and at the same time thoroughly mix the ice cream as it is formed. A special eccentrically placed beater operates inside the dasher frame and is rotated by re-action with the ice cream. The eccentric position of the beater gives a thorough mixing of the ice cream as it freezes and is moved from one end of the cylinder to the other. For cooling, evaporating coolants in the temperature range of -20 to -300C are used in the cooling jacket.

The mix is pumped into a cylinder, which is flooded with liquid refrigerant. The freezing process is very rapid and the layer of the frozen mix on the cylinder wall is continuously scraped off with a rotating blade equipped mutator inside the cylinder.

The required amount of air is supplied continuously whilst the ice cream is worked in the freezer, so that the air is worked into the mix at the same time. This gives the ice-cream the desired texture before it is fed from the freezer through a pipe to a forming or filling machine.

The advantages of the continuous or instant freezers are:

- Less stabilizer is needed because a larger amount of ice crystals can be formed and less viscosity is needed in the mix.
- A shorter ageing time is possible because less viscosity is needed and incorporation of air is less.
- Less flavoring material is needed because the smaller ice crystal melt more rapidly in the mouth and make the flavour slightly more pronounced.
- Smoother ice cream is obtained.

- There is less tendency towards sandiness because rapid freezing favours small lactose crystals.
- Ice cream consistency is uniform due to continuous production

Pumps

Pumps of ice-cream freezers are usually of the rotary type with the capability to pump against pressure of 7-14 kg/cm2(690-1380 kPa) with reasonable volumetric efficiency. There are two general pumping arrangements, both designed as a part of the overrun system. The first employ a pump (or a pair of pumps or compound pump) to pump or meter the mix into the freezing cylinder, which is provided by a hold-back valve at the ice cream discharge port. The hold-back valve may be spring loaded with manual adjustment, it may have an air operator with adjustable air pressure supplying the operating power. The hold-back valve permits imposing a pressure on the cylinder during freezing which compresses the air admitted with the mix for overrun. Cylinder pressure of 3.5-4.0 atmospheres keeps the volume of air in the freezing cylinder sufficiently small so that it does not significantly lower the internal heat transfer out from and through the mix. That pressure is sufficient for proper air dispersion and small air cell size. Higher pressures may be imposed on the cylinder, but in most cases, the improvement of heat transfer and air cell size is not great enough to offset the disadvantages of increased pumping cost.

Ice cream freezer pumps are driven by various means, but all of these provide for varying pump speed. Usually the set of pumps for each cylinder is powered by one drive. Drives are of three types

(i) Electric motor powering a mechanical variable speed;

(ii) Frequency inverters with electronic speed control for standard electric motors. A gear reducer is always used between motor and pump;

(iii) Hydraulic pumping systems connected to hydraulic motors on the pumps. The hydraulic pumping units may be located within the freezer housing or remotely outside the production room.

Controls and Automation

All continuous ice cream freezers have control for operation which include on-off switches for pump and dasher motors, and for air compressor motors (when these are part of the freezer), for solenoid valves on hot gas defrost lines, air lines and refrigerant supply lines, speed regulation of pumps, refrigeration supply and back pressure, pressure gauges for the refrigeration system and cylinder or air pressure and dasher motor ammeter, wattmeter or motor load indicator. In addition more sophisticated machines may have a viscosity meter and controller, and a programmable controller or micro-processor to operate and control most functions of the ice cream freezer.

The modern ice cream freezer consists of a micro-processor programmed to control all the function of operation including overrun, viscosity of product, cylinder pressure, all operating steps such as start up, routine or emergency shutdown, resumption of operation after an automatic shutdown when the reason for shutdown has been corrected. The micro-processor shows the time of day, mix flow rate, percentage of overrun, product rate, hours of operation, accumulated production in that time interval, the program step in operation, and various warnings. In case of an impending freeze-up, the warning is displayed and corrective action is taken. If a freeze-up should occur, the micro processor automatically causes defrosting of the cylinder and operation to be resumed when conditions are satisfactory. The display can be in one or more of several common languages.

The micro-processor programmed operation assures that all functions are performed in the proper sequences, and under the conditions envisioned by the designer of the freezer. This is especially beneficial to the ice-cream maker in preventing damage to the freezer in emergency situations, thus avoiding the incidental unplanned down time in production.

Fruit & Nut Feeder:

Flavouring materials are added after the mix has been made. These may be added at the ageing or holding tanks, or in flavour tanks located just upstream of the ice cream freezer. Fruit juices, flavour extracts, colour and similar materials are added at these points. Pieces of fruit and purees should not be added to the mix prior to freezing in continous freezers, as they tend to settle out in the tank with subsequent poor distribution in the frozen ice cream.

Further, seeds in fruit or other gritty content harm the close-fitting pumps, the dasher bearing and seal, and dulls the scraper blades.

The ingredient feeders often referred to as fruit feeders have a hopper for the ingredient, an auger or other means for metering or proportioning the fruit, a rotator or plunger for inserting the ingredient.

1. Packing, Extrusion and Moulding:

Ice cream is packed in cups, cones and containers (1 to 6 liters) in a rotary or in-line filling machine. These can be filled with various flavours, and the products may be decorated with nuts, fruits and chocolate. The packs are lidded before leaving the machine, after which they are passed through a hardening tunnel where final freezing down to -20 0C takes place. Before or after hardening the products can be manually or automatically packed in cartons or bundled.

Moulding of ice cream or water ices bars are made in special machines, also called stick novelty freezers, with pockets in which the ice cream or water ice is moulded. Ice cream is supplied direct from the continuous freezer at a temperature of approx. -30C. The filled moulds are conveyed stepwise through a brine solution having a temperature of -40 0C, which freezes the ice cream or water ice solution. Sticks are inserted before the moulds are completely frozen. The frozen products are removed from the moulds by passing them through a warm brine solution which melts the surfaces of the products and enables them to be removed automatically by an extractor unit. After extraction of bars (novelties) may be dipped in chocolate before being transferred to the wrapping machine. Since the products are fully frozen, they can be taken straight to the cold store after wrapping and cartoning, otherwise go for hardening it in a hardening tunnel before wrapping and cartoning.

2. Hardening & Cold Storage:

The manufacture of ice cream is not complete until it has been thoroughly harden at a temperature of around - 20 0C. For products produced in an extrusion line or a stick novelty freezer, the hardening operation is included in the process. Products packed immediately after freezing must however be transferred to a hardening tunnel, The faster the hardening, the better the texture. After hardening the products are transferred to the cold store where they are stored on shelves or pallet racks at a temperature of -25 0C. The storage life of ice cream depends on the type of product, the packaging, and maintenance of a constant low temperature. The storage period of ice cream at -18 0C ranges from 0 to 9 months in the ice cream cold storage.

FIG-18.1 Continuous Ice Cream Freezer

FIG-18.2 Dasher of Continuous Ice Cream Freezer

Chapter 11.

Care and Maintenance of Ice Cream Freezers and Hardening Cabinets

Introduction:

Care and Maintenance of Ice Cream Freezers and Hardening Cabinets:

Primary requirement for satisfactory performance of ice cream freezers and hardening cabinets are their careful installation, proper operation and regular maintenance. The batch freezer consist of refrigerator cylinder and a rotating dasher assembly to scrap, beat and mix the frozen ice cream in the cylinder. The continuous freezer employs the same fundamental principles except that here the ice cream mix flows under pressure. The freezing cylinder is made up of a stainless steel liner pressed inside a steel or copper tube which forms the inside wall of the cooling jacket. The dasher inside the freezing chamber, carrying the scraper and beaters, is directly coupled to the driving unit. An airtight metal housing is provided on the refrigeration space around the freezing chamber which in turn is provided with insulation and protective cover to prevent moisture ingress into insulation layer. To achieve the best freezer performance the refrigeration must be good, the blades must be sharp and free from burrs , the mix must be right and the freezer must be properly operated. The following criteria are intended to furnish convenient guidelines to facilitate the regular maintenance programme for the freezer and hardening cabinets.

Dasher and Scraper assembly:

Scraper blades must function well to get the highest efficiency of the freezers. If the frozen film is not properly scraped off, the heat transfer will be low and the capacity of the freezer will suffer. The simple directions for care, maintenance and repair of scrapers involve the following:

- Dull blades causes slow freezing because they do not remove the frozen film from the freezing cylinder. The scraper blades should be kept free from burr and should be sharp and straight.

- The burr formed on the upper side edge of the blade could be removed by drawing a fine file or stone lightly along the edge of the blade at an angle of 30º. This operation is necessary for two or three times week depending upon service performed by the freezer.
- If the blade is worn down its heel become wider. The excess heel is removed by means of hand filing with a file held parallel to the main flat side of the blade. Some power operated blade-sharpener grinders are fitted with fixture to automatically hold the blade at the correct angle. The heel should be brought down to 1/32 of an inch in width for batch freezers and practically eliminated for continuous freezers.
- The front edge of the blade should never be touched by the file.
- If the service is available it is most advantageous to send continuous freezer blades to the nearest dairy equipment service agency for professional sharpening.
- If the blades are not sharp, the temperature of the refrigerant should be raised in order to allow them to scrape cleaner.
- Rubber friction ring of the rotary seal for mutator shaft should be kept in good condition. Replace it whenever necessary.
- Do not switch on the dasher and beater without any feed mix inside the freezer. It will result in the damage of blades.
- Do not change the alignment of the dasher, it may damage the freezing cylinder

Refrigeration System:

Refrigeration system should be cheked often to avoid any undue wear and tear on the system. By replacing the parts at the proper time the system is as good as the new system which not only adds to its life but keeps operating costs and capital expenditure to a minimum. The important maintenance criteria are as follows:

- Pressure gauges are the main visible means to tell how the refrigeration system is operating. After being in use for some time the needle of these gauges may either stick or show too high pressure. False readings may lead to adjustment which will affect many things throughout the system. Most gauges have a screw, which will reset the needle to zero after allowing air to surround the stem. If the dial of gauges become rusty and hard to read, replace them, as the cost is very small when compared to cost of false adjustment.

- Thermostatic expansions valve should be checked once a month. Under normal conditions, these valves are set for 5ºC to 6ºC super heat, but if through normal wear or because of large particles of dirt, the valve opens wider, flooding occurs which will cause a frost back to the compressor.
- The float control valves are used in ammonia refrigeration system which serve to keep the liquid ammonia in the evaporators at proper level. If this valve is sticking closed, the evaporator is being starved of liquid, which cuts its capacity and increases the necessary time for compressor operation. If valve is allowed to be flooded with too much liquid, then there is a flooding of the suction back to the compressor which causes damage to compressor. Float controls should be checked very often and cartridge replaced if they do not respond to the adjustment.
- Back pressure regulating valves regulate the pressure on the suction line coming from the evaporator. A pressure gauge is attached to it for adjustment of back pressure through a regulating valve. This gauge should be checked quite often for its accuracy.
- Defrost the evaporator coils as often as required because if frost or ice accumulates, the heat transfer is cut and efficiency of the entire system suffers.
- A refrigeration system is theoretically a vacuum system, and air and non-condensable gases can infiltrate in many ways. These tend to accumulate at the top of the condenser or other high points in the systems. Whether the system has non-condensable gases or not can be detected by installing a thermometer in the high pressure vapour line near condenser. If the temperature of gas does not correspond to the pressure on condensing pressure gauge it means system contains non-condensable gases or air which needs to be purged off. Thereafter, charge the system with correct refrigerant charge.
- The compressor will start to show wear after several years of operation. The simplest test is to check the compressor for over heating. Get the condition of the compressor checked as soon as the wear has been little more than normal. Do not wait until the compressor breaks down before replacing worn parts.

- Loose compressor mounting bolts or vibrating unit tubing causes high level of noise and produces undue stress in the system. Tight the bolts and gently reform tubing to eliminate vibration. Check for the lubricating oil if the noise still persist.
- Over charging raises the temperature and pressure above the desirable limits. Unit draws more current and consumes more power. With under charging lower than normal evaporator temperatures are maintained. The compressor motor gets overheated due to reduction in effective cooling by suction vapour. Motor winding finally burns out due to over heating. Recharge the unit with proper amount of refrigerant.

Electric Motor and Controls:

The contemporary electric motor is one of the most efficient machine known today. Although they can operate with a minimum of attention, systematic motor care means not only fewer motor failures but also lower repair costs.

- Every effort should be made to keep water in liquid form from dripping on, splashing on or flooding on the motor unless the motor is of splash proof design. Whether the air-born moisture has produced a harmful condition in the motor can be determined by testing insulation resistance. When the resistance has dropped to a dangerous point the motor should be dried out without damage to the insulation.
- Excessive bearing wear can produce misalignment and cause motor vibration. Even when the alignment is perfect vibration in the driven machine may be transmitted to the motor. Excessive vibrations can shake motor parts and electric connections loose, crystallize metal and multiply frictional wear. Vibrations should always be tracked down and it's cause eradicated.
- To protect the compressor over load protector(OLP) is provided, which starts within a few seconds and trips off, due to very high or very low voltage. Use the voltage stabilizer, if necessary. If the OLP is under sized replace it with correct size OLP.
- If the unit hums and shuts off it may be due to the low voltage or the inoperative relay. At low voltage current drawn by the motor is not sufficient to keep plunger of relays on and it drops earlier. At normal voltage if relay is of oversize, the start winding is not kept in circuit by relay for sufficient time. Use voltage stabilizer and the correct sized relay.

- Inoperative thermostat or incorrect thermostat setting may sometimes results in too cold cabinet temperature. Correct the setting or use the lower setting of thermostat. The thermostat may be re-calibrated by varying cut in and cut out temperatures.

In order to achieve the desired performance objectives, it is necessary to determine periodically the performance of each item of the ice-cream freezers and hardening cabinets and auxiliary equipment under actual operating conditions and correct any digression from the established norms. Immediately after new equipment is placed in service it begins to deteriorate. Even under idealized conditions the efficiency and performance of equipments progressively decreases with normal usage. Through periodic checks the actual performance can be determined. The laxity of operating and supervising personnel also needs to be detected and corrected. Set up a convenient file containing all manufacturers specifications, instructions, drawings and performance data for the units. No mal- performance should go unheeded or uncorrected. This would help the plant to remain in optimum performance condition at all times. Electric motor should be provided with soft starters and other means to maintain power factor above 0.95.

Air Blast Freezers

INTRODUCTION

Air-blast freezers are the most common type of food freezer. Individual product items are placed in a recirculation air stream within a room or tunnel. The air is circulated by fans, which are often associated with the evaporator coils providing cooling. These freezers can be simple, operating in batch mode with manual loading and unloading of the product (Fig. 22.1, 22.2) or more complex, with automated continuous operation (Fig. 22.3, 22.4).

Continuous freezers are best suited to processing large volumes of product. They have lower labor costs, and generally provide more uniform freezing conditions, but are less flexible.

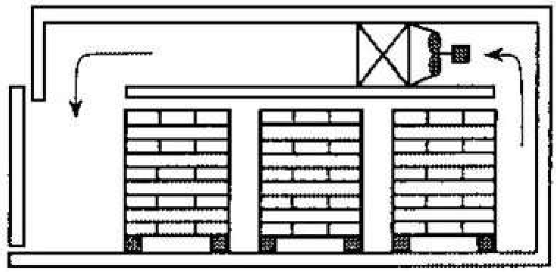

Fig-22.1: Schematic diagram of a batch air-blast tunnel freezer with racks of product and horizontal air flow

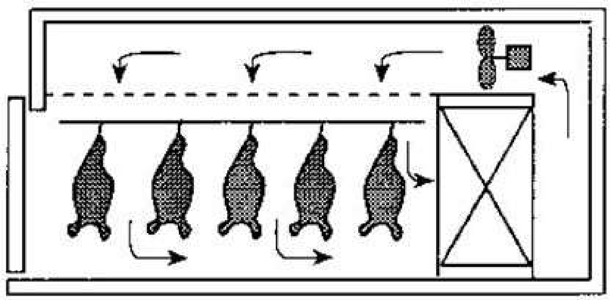

Fig-22.2: Schematic diagram of a batch air-blast carcass freezing room with vertical air flow through a distribution plenum.

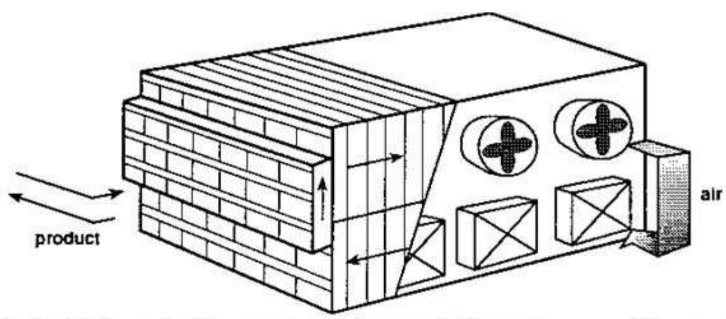

Fig- 22.3: Schematic diagram of a continuous air-blast carton tunnel freezer with cross-flow of air.

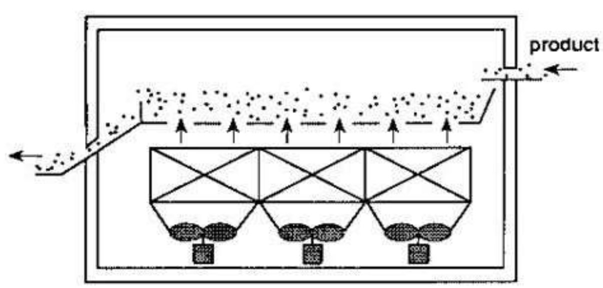

Fig-22.4: Schematic diagram of a continuous spiral belt freezer with vertical air flow.

Many different air and product flow configurations can be used. Horizontal air flow is probably most common, but there are a number of designs using vertical air flow, often to avoid air bypassing the product (Fig. 22.5). In continuous systems, air and product flows can be cocurrent, countercurrent (Fig.22.5) or cross-flow (Fig. 22.3, 22.4). The latter two configurations are most common as air temperature rise is small, so the temperature driving force for cooling and thus the rate of heat transfer are maximized. Methods to present the product to the air depend on the size, shape and packaging of the product, and include trays, racks, trolleys, hooks, conveyors, and belts. A wide range of product types, sizes, shapes, and packaging types can be handled by such freezers.

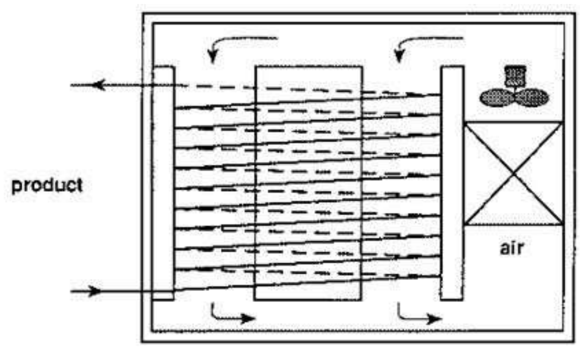

Fig-22.5: Schematic diagram of a continuous spiral belt freezer with vertical air flow

The major advantages of air-blast freezers are their simplicity and flexibility. The disadvantages are that using air limits the rate of heat transfer at the product surface, requires the use of substantial fan energy, and to achieve uniform air distribution can be difficult. Also, further disadvantages are that: evaporative weight loss can be significant from unwrapped product; bulging of packaged product can occur; defrosting evaporator coils or other means of frost prevention is required which can disrupt freezer operation; and the refrigeration system must operate with a low suction condition due to the air-to-refrigerant heat exchange.

Still Air Freezers

The simplest type of freezer is one in which the product is placed in a refrigerated room that is usually used to store frozen product. The process is historically referred to as sharp freezing. The shelves on which the product is placed within the room may be directly refrigerated, and the product may be bulk-stacked. Air flow over the product is minimal and the freezing rate is slow. Also, heat removal from the freezing product may cause undesirable temperature fluctuations in adjacent stored product.

Air-Blast Room and Tunnel Freezers

These freezers are commonly used for medium to large products where the rate of freezing is limited by the size of the product. The product does not need to be regular in shape. The product is placed on trays in racks or suspended so that air flow is possible around each individual product item. In continuous tunnel freezers, it is usual to have a mechanical system moving racks through the tunnel in a cyclic manner, with device for automatic loading and unloading of the product. Belt freezers are similar but product is transported on a perforated conveyor belt.

Schematic diagram of a continuous spiral belt freezer with vertical air flow. racks, and product arriving and leaving on a conveyor system (Fig. 22.3). For batch freezers, the racks are manually loaded and positioned in the room or tunnel (Fig. 22.1, 22.2). In a tunnel system, the air is confined to flowing in the cross-section where the product is located. Also, the product is spaced evenly so that uniform air distribution and high air velocity is more easily achieved for a low total air flowrate and fan power. While most continuous tunnel freezers are restricted to one product size and shape in order to optimize the product loading configuration and air flow distribution, a range of products can be processed in the same tunnel if a variety of rack sizes and tray spacing are used. In a blast room there is often less strict control of the air flow pathway and bypassing of the air around the product can more easily occur.

Belt Freezers

Belt freezers involve the product passing continuously through a tunnel freezer on a perforated belt (Fig. 22.4). The air flow is directed vertically up through the belt and product layer. There may be multiple belt passes. Such freezers are commonly used for small unwrapped products with uniform shape in which a free-flow individually quick frozen (IQF) product is desired. The air velocities are typically in the range 1 to 6 m/s and the layer of product can be partially fluidized. This creates high rates of heat transfer between the air and product. Even distribution of the product across the belt is important to achieve uniform air distribution and freezing rate. Product transfers from one belt to another and/or mechanical devices are sometimes installed to reduce clumping and to redistribute the product. The belt speed can be varied to cope with changing production rates but care must be taken to maintain a uniform thickness of product on the belt.

Spiral Belt Freezers

Spiral freezers are a specialized type of belt freezer in which a continuous belt is stacked in a spiral arrangement up to 50 or so tiers high (Fig. 22.5). They allow very long belts (long product residence times) in a compact area as long as sufficient overhead space is available. Therefore, they are suitable for processing products with longer freezing times compared with other belt freezers (e.g., larger products and packaged products for which the packaging

impedes heat transfer). The size of the product is limited by the distance between each spiral tier and the total height of the stack. Air flow can be either horizontal across or vertical through the belts. Recent design improvements have included self-stacking belts to reduce mechanical wear and maintenance, and cleaning-in-place of the belt and freezer.

Fluidized Bed Freezers

Fluidized bed freezers are only suitable for small unwrapped IQF products of uniform size and shape, such as fruits and vegetables for which the energy requirements for fluidization are not excessive. In a manner similar to belt freezers, air is directed up through a perforated plate and bed of the product but at a flow rate high enough to fluidize the product (Fig.22.4). The product is fed in at one end and overflows out of the freezer at the other.

Fluidization

achieves good distribution of the product and prevents clumping, even with very wet incoming product, and the surface heat transfer is significantly enhanced. The product moves by flowing within the fluidized bed, but this can be aided by vibrating and/or sloping the air distribution plate. Individual items reside for different periods depending on the flow pattern in the bed. The average residence time is fixed by the feed rate and the volume of the bed, which is controlled by the height of the overflow weir. Fluidized bed freezers can be very compact because the small product size and high rates of convective heat transfer keep freezing times short.

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