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SADC REGIONAL POSTGRADUTE COURSE IN DAIRY SCIENCE AND TECHNOLOGY

MODULE MAV 411 DAIRY PROCESSING

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SADC-UNIVERSITY OF ZIMBABWE REGIONAL POSTGRADUATE PROGRAMME IN DAIRY SCIENCE AND TECHNOLOGY

MODULE MAV 411

Dairy Processing

January 2010

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HARARE,
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MEMBER STATES OF THE SOUTHERN AFRICAN DEVELOPMENT COMMUNITY



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Study Unit 1
**INTRODUCTION TO DAIRY PROCESSING AND
MARKETING**

1.1 Developments in the Dairy Industry

Study Aims: After studying this unit, the student should be knowledgeable about the following:

1. At least 3 special features of the dairy industry that make it unique compared to other agricultural industries
2. Global and current trends in dairy processing and marketing
3. Formal and informal dairy processing and marketing in Africa
4. The dairy processing industry in Zimbabwe; a historical perspective
5. The small scale dairy production and processing sector with special reference to DDP-ARDA
6. Factors that have led to current milk shortages
7. The impact of milk shortages and potential for growth
8. Milk testing, its importance and the role of the Dairy Services

1.1.1 Special features of the dairy industry

i. The specific properties of milk as a raw material

Milk is a liquid consisting of 90% water and this means that it is a bulky and heavy commodity. Milk is also produced on a daily basis. As a result, milk requires high cost transportation and there is a cost limit on the range over which it can be sold. It will only keep for a few days, which places a time limit on the period during which it can be used or processed and transformed into more shelf stable products. Milk is also highly perishable and can easily be adulterated whilst the quality of the milk is highly dependent on farm management. Strict and comprehensive dairy regulations are therefore customary and necessary.

ii. The socio-economic position of dairy producers

Dairy production is characterised by a high percentage of fixed costs and this means that they are only able to adjust to changes in the market in a limited and gradual way. On the other hand its high labour intensity and daily production provide employment opportunities in the transport and processing of milk as well as the supply of inputs. As result, dairy industries tend to be the sector with the highest degree of protection. The import of cheaper dairy products can threaten this.

iii. The role of cooperatives in processing

Individual farmers are usually small and therefore not able to influence the price of milk. They can only keep their product for a few days not however, defer selling their product compared to, as an example, grain farmers. Cooperatives can play an important role in the marketing and processing of milk. Economic liberalisation, privatisation, globalisation and internationalisation can affect the contribution of the small scale farmer to dairy production. This in turn affects the amount of milk available for processing.

iv. The value of milk

Milk is a valuable and at the same time very expensive raw material. It can be used to make a wide range of products which are nutritious, palatable and at the same time high quality. On the other hand, the high cost price makes it necessary to make products which have high added value. Dairy processing becomes an important sector. Processing operations have to satisfy high technical and quality standards. This can sometimes deter small dairy producers if their milk fails to meet these standards.

1.1.2 Developments in dairy processing in western countries

A] General trends in the food market

- i. Health will continue to be a very important issue and is looked at under the following subdivisions; ingredients, appreciation of freshness, nutritional value and purity.
- ii. Consumers will maintain or intensify their efforts to reduce fat consumption.
- iii. Greater willingness to try new products; the life cycle of products will become shorter.
- iv. The trend towards convenience.

B] Trends in the consumption of dairy products

- i. Cheese consumption is increasing
- ii. The consumption of butter is falling
- iii. Sales of liquid milk have remained unchanged or declined slightly (100 kg per capita per annum)
- iv. Decline in home deliveries of liquid milk

- v. Demand for food produced in an environmentally friendly way
- vi. Higher priority for freshness

1.1.3 Developments in dairy processing in sub-Saharan Africa

Milk production in 1996 in Africa was 25 kg *per capita per annum* (compared to 32 and 97 kg *per capita per annum* in Asia and America respectively.) In 1996 imports of dairy products were 30-40% in West Africa and less than 10% in East Africa, Zaire and Zimbabwe.

Market oriented dairy farms are concentrated near or within urban consumption centres. The milk produced is delivered to dairy processing plants where it is added to imported reconstituted milk.

In small holder production systems, informal raw milk marketing is often the general rule with producers selling milk directly to the consumers. Some of the raw milk is also sold through informal traders, small shops, kiosks and larger grocery stores.

Surplus milk is usually fermented to give sour milk which is popular in many countries. Examples of sour milk products are *amasi* in Southern Africa, *irgo* in Ethiopia and *nono* in Northern Nigeria. *Cucu* or *wara* is a soft, wet, feta type cheese made from whole milk in West Africa. *Ayib* is a cottage type cheese made and consumed in Ethiopia. Butter making is an important industry in Ethiopia.

1.1.4 Developments in dairy processing in Zimbabwe

A historical perspective

- i. 1953; The Dairy Marketing Board established and responsible for milk production. The parastatal was responsible for;
 - a) setting of the producer price
 - b) setting of the consumer price
 - c) to the conditions of service of employees
- ii. 1978; Surge in demand for milk and milk products (imbalance in milk supply due to price distortions)
- iii. 1981/82; EU intervention programme (milk powder and butter oil importations to augment milk production. Chipinge dairy established to process reconstituted skim milk)
- iv. 1987; DDP initiated to spearhead milk production by smallholder farmers-10 projects established in all 10 provinces country-wide. DDP transferred to ARDA

- v. 1990; South Africa, Kenya and Zimbabwe produce 2.3 billion litres of milk per year (South Africa producing 1.8 billion litres and the balance being shared between Zimbabwe and Kenya) - Commercialisation, Economic structural adjustment programme initiated.
- vi. July 1994; Commercialisation completed
- vii. July 1997; Privation of Dairibord Zimbabwe Limited (DZL)
- viii. *Current status*; Decline in milk production (253 million litres in 1995 compared to 108 million litres in 2003). Total regional output is 2.5 billion litres per annum. South Africa produces more than 2.3 billion litres of milk per annum. The balance shared between the rest of the SADC countries.
- ix. *Result*; Milk deficit. Processing companies operating below capacity (2005; Dairibord- <20%, Nestle- <30%, others- below capacity. N.B. processing capacity is still intact at 350-400 million litres per annum)

Effects of shortages of milk

- i. Failure to meet domestic and export requirements
- ii. Loss of market share to regional (and other competitors)

Impact on the processing industry

- i. Plant closure, loss of employment and below capacity operations. There are at least 40 companies subcontracted by DZL with about 5000 employees.
- ii. Loss of nutritional value and shortages of products on the market
- iii. Loss of market share to side marketing
- iv. Competition from imported dairy products.
- v. Reduced foreign currency earnings.
- vi. Future recovery of the dairy industry.

Small Scale Dairy Production in Zimbabwe

The Dairy Development Programme (ARDA-DDP)

- i. Established in 1982 under the then Dairy Marketing Board (DMB) to spearhead dairy production on communal, small scale commercial and resettlement farms.
- ii. The specific objectives were to increase milk production, processing and marketing by small scale farmers.
- iii. The first project was Marirangwe in Mashonaland East. Other projects include Chikwaka, Chipinge And Guruve.
- iv. The programme contributes 5% to national milk production. Milk production on the decline
- v. 30% of the milk retained for home consumption and local sales. The rest sold for processing

The role of Dairy Services in Milk Testing

Milk is a carrier of many diseases. To safeguard public health, the dairy Act and Dairy Regulations were put in place. This legislation makes it possible to ensure that dairy products are pure, wholesome and unadulterated.

Dairy regulations stipulate requirements such as water quality, pasteurisers, cleaning chemicals. Dairy Services is mandated to monitor that the regulations are being effected.

Dairy Services is also responsible for monitoring the quality of milk and dairy products. The Regulations and Standards are covered under section 25 of the Dairy Regulations. The basic requirements are butter fat (min- 3.0 %), Solids Non Fat (min- 8.0%), acidity (0.19% Lactic Acid Equivalent), Harmful organisms- nil, Preservatives or foreign substances- nil and total bacterial count <500 000 CFUs/ml), somatic cell count <650 000/ ml and negative to the milk ring test for Contagious Abortion.

Way forward

- i. Processors can become involved in milk production (“the developed country route”)
- ii. Invest in smallholder dairy development
- iii. Imports of milk powder as a short term measure

Self test questions

- i. Explain 3 features of the dairy industry that set it apart compared to other agricultural systems?
- ii. Discuss the changes that have occurred in dairy processing and marketing in the last 50 years. How have they affected (i) the small scale processor and (ii) the large processor?
- iii. What challenges has the dairy processing industry been facing in Zimbabwe over the last 30 years?
- iv. What has been the impact of changes that occurred in the last 10 years on the availability of dairy products on the market in Zimbabwe?
- v. Why are regulations and standards important?
- vi. List the tests that are carried out on raw milk

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1.2 Milk Reception and Testing

Study aims: After studying this unit, students should be knowledgeable about the following aspects;

1. Milk storage on the farm
2. The importance of maintaining the cold chain from the farm to the factory
3. Quality tests and why they are important
4. Milk reception and storage at the factory

Milk storage at the farm

Milk should be chilled to $\pm 4^{\circ}\text{C}$ immediately after milking and be kept at this temperature all the way to the dairy. If the cold chain is broken somewhere e. g. during transportation, the microorganisms in the milk will multiply. This will result in the development of various metabolic products and enzymes. Subsequent chilling will arrest this development but the damage has already been done. The bacterial count is higher and the milk contains substances that will affect the quality of the end product.

Delivery of milk to the dairy

Milk can be delivered in churns or in insulated road tankers. The milk must be kept well chilled and free from air. It must be treated gently and containers must be well filled in order to prevent sloshing.

With DDP/ARDA funded small scale dairy schemes such as at Chikwaka and Marirangwe, collection centres have been established since producers do not have direct access to the dairy centres, individual milk quantities are too small and there is no water/electricity at the farms

Milk from diseased cows must not be delivered to the dairy together with milk from healthy cows. Milk from stock treated with antibiotics must be kept separate from other milk. Such milk cannot be used for products based on bacterial cultures as the antibiotic strain will kill the bacteria. This applies to cultured milk products, cheese, yoghurt and butter. Minute amounts of milk containing an antibiotic can render enormous quantities of otherwise suitable milk unusable.

Testing milk for quality

- i. **Taste and smell:** Milk with significant deviations in taste and smell can be rejected by the processor.
- ii. **Cleaning checks:** The inside surfaces of farm tanks are carefully inspected. Milk residue is evidence of inefficient cleaning.
- iii. **Sediment tests:** This applies only to churns. A quality deduction can be made if visible impurities are retained by the filter.
- iv. **Hygiene or Resazurin test:** The bacteria content of milk is a measure of its hygienic quality. Resazurin is a blue dye which becomes colourless when it is chemically reduced by the removal of oxygen. When it is added to a milk sample, the metabolic activity of the bacteria present has the effect of changing the colour

of the dye at a rate which bears a direct relationship to the number of bacteria in the sample. Two hygiene tests use this principle;

- a. If the milk sample changes colour immediately after adding the dye, the milk consignment can be rejected for processing.
 - b. The milk sample is stored in the refrigerator overnight before the dye is added. The sample is incubated in water at 37.5 ° for 2 hours. This can be used as routine hygiene test.
- v. **Somatic cell count:** A large number (more than 500 000/ml of milk if somatic cells in the milk indicates that the cows are suffering from udder diseases. The cell count is determined with specially designated particle counters such as the Coulter counter.
- vi. **Bacteria count:** A simplified form of bacteria count can be used to assess bacterial count. In the Leesment method, the bacteria are cultivated in a 0.001 ml milk sample with a nutritive substrate. The bacteria count is determined with a special screen.
- vii. **Protein content:** Farmers can be paid according to the protein content of the milk delivered. This is analysed using instruments operating with infrared rays.
- viii. **Fat content:** Fat content can also be a basis for paying farmers. The Gerber method is the most widely used test for whole milk.
- ix. **Freezing point:** Many dairies check the freezing point of the milk to determine if the milk has been diluted. Milk of normal composition has a freezing point of – 0.54 to –0.59°C. The freezing point will rise if water is added to the milk.

Milk reception

The first thing done at reception is to determine the quantity of the milk. This is done by volume or by weight.

1. **Measuring by volume:** This method uses the flowmeter. It also registers the air in the milk so the results are not always reliable. It is therefore important to prevent air from entering the milk. The method can be improved by fitting an air eliminator before the flowmeter.
2. **Measuring by weight:** Bulk collected milk can be weighed in two ways;
 - i. By weighing the tanker before and after unloading and then subtracting one value from the other.
 - ii. By using special weigh tanks with load cells in the feet. The cells supply an electric signal which is always proportional to the weight of the tanks.

Tanker cleaning

Tankers are cleaned everyday, as a rule after a collection round. Cleaning should be done by connecting the tanker to a cleaning system while in the reception area or delivering it to a special cleaning station.

Chilling the incoming milk

The milk should be chilled to below 4°C in a plate heat exchanger before being stored in a silo tank to await processing.

Raw milk storage

The untreated whole milk is stored in large vertical silo tanks which have capacities from about 25 000 to 150 000 l. Smaller silo tanks are often located indoors while large ones are placed outdoors to reduce building costs. Outdoor silo tanks are of double wall construction, with insulation between the walls. The inner tank is made of stainless steel polished on the inside and the outer tank is usually of welded sheet metal.

Agitation in silo tanks

These large tanks must have some form of agitation to prevent cream separation by gravity. The agitation must be very smooth. Violent agitation causes aeration of milk and fat globule disintegration. This exposes the fat to attack from the lipase enzymes of the milk. Gentle agitation is therefore a basic rule in the treatment of milk.

Tank temperature indication

An ordinary thermometer can be used. It is becoming more common to use an electric transmitter which transmits signals to the central monitoring station

Self test questions

1. What precautions should be taken when milk is stored at the farm prior to transportation to the dairy plant?
2. What is the cold chain and why is it important in milk quality?
3. Why is it important to test the quality of milk?
4. List the tests that can be carried upon reception of milk at the plant?
5. Explain the principle behind each test

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1.3 Dairy Chemistry and Microbiology

Study Aims: After studying this unit, the student should be knowledgeable about the following:

1. Mechanisms of the spoilage of various components of milk (milk, fat, protein, lactose) with examples of microorganisms.
2. Factors that affect the shelf life of raw milk and other dairy products.
3. The relationship between growth of micro organisms, the storage temperature and the water activity of the product for various classes of microorganisms
4. The components of milk and the role that each plays in dairy processing
5. Define what a starter culture is.
6. Explain the 3 types of fermentation (homofermentation, heterofermentation and mixed acid fermentation) and how they are used to produce different kinds of dairy products.

Introduction

Milk is an extremely nutritious food.. It is an aqueous medium that contains proteins, fats and carbohydrate. It also contains vitamins and minerals.. It has a pH of about 7 and is an excellent growth medium for humans, animals as well as microorganisms

The composition of milk

About 87% of milk is water. Casein contributes 2.5% to the composition of milk. It is a protein that exists as calcium caseinate a white compound which gives milk its colour. Casein is important in the manufacture of cheese. Lactalbumin is a whey protein which remains in the clear fluid during fermentation. It is often used to produce processed cheese. Lactose (also known as milk sugar) is the main carbohydrate in milk and it makes up to 5% of milk Bacteria ferment lactose to produce lactic acid which contributes to the flavour of yoghurt. It can contribute to milk spoilage

Butterfat is a mixture of fats that can be churned into butter. It makes up 4% of the milk and is removed in the preparation skim or low fat milk. Bacterial enzymes such as lipase breakdown milk fat to produce fatty acids which make milk unfit to drink. Controlled lipolysis may be desirable in some types of cheese

Types of spoilage

1. *Lactobacillus* or *Streptococcus spp* multiply slowly and ferment the lactose in milk to produce large quantities of lactic and acetic acids. The acid changes the structure of the protein and causes it to curdle. The Lactobacilli and Streptococci that cause it may have survived pasteurisation. The acidic curd produced is usually referred to as a sour curd
2. *Bacillus*, *Proteus* and *Micrococcus* breakdown casein and as the weak hydrogen bonds break, the casein loses its structure and curdles. The reaction is referred to as sweet curdling because little acid production occurs. It is an essential step in the production of cheese.

3. Milk may be contaminated by Gram negative rods of the coliform group of bacteria including *Escherichia coli* and *Enterobacter aerogenes*. These bacteria produce acid and gas from lactose. The acid curdles the protein and the gas forces the curds apart.
4. Ropiness in milk is caused by capsule producing organisms such as *Alcaligenes*, *Klebsiella* and *Enterobacter*. These Gram positive rods multiply in milk even at low temperatures and deposit gummy material that appears as stringy threads and slime.
5. Some *Pseudomonas* and *Achromobacter spp* produce the enzyme lipase which breaks down milk fat into glycerol and free fatty acids. This gives milk a sour taste and a putrid smell. A similar problem may develop in butter.
6. Acid conditions stimulate mould decay in cheese products and yeast decay in yoghurt.

Milk borne disease

Milk is an unusually good vehicle for the transmission of pathogenic microorganisms because its fat content protects organisms from stomach acid and because being a fluid remains in the stomach a relatively short period of time.

1. Bovine tuberculosis is caused by *Mycobacterium bovis*. In humans the bacillus passes from the intestines through the blood and infects organs. Good herd health management can eliminate the threat of this disease.
2. Brucellosis is a disease that affects any organs in the cow including the placenta. It can be transmitted to humans through milk. The causative agent *Brucella abortus* infects blood rich organs and causes malaise with recurrent periods of fever.
3. Q-fever is an influenza like disorder caused by the rickettsia *Coxiella burnetii*. It multiplies in the respiratory tract of cows and humans where it induces lesion formation. Bronchitis and pneumonia may develop in humans. It is among the most heat resistant of non spore forming bacteria and pasteurisation processes are commonly designed to destroy it.
4. Salmonellosis is caused by *Salmonella typhimurium*. It affects individuals who consume unpasteurised (raw) milk and dairy products.
5. Campylobacteriosis is caused by the Gram negative rod *Campylobacter jejuni*
6. Listeriosis is caused by *Listeria monocytogenes*. It has been isolated in cheese and yoghurt. Listeriosis is accompanied by blood invasion and meningitis. It is particularly acute in pregnant women because it can lead to miscarriage and stillbirth

What is fermentation?

It is a form of anaerobic respiration which does not use oxygen as the final electron acceptor. An organic molecule, usually an intermediary of the process, accepts the electrons.

Example: Streptococcus lactis uses pyruvic acid to remove the electrons and proton from NADH. An enzyme reaction converts pyruvic to lactic acid. When controlled this process is used to make yoghurt or buttermilk from milk

Types of fermentation

1. *Homolactic acid fermentation*; Lactic acid is the major end product of this reaction. It is characteristic of most Lactic acid bacteria (LAB) including the genera *Streptococcus* and *Pediococcus* and some *Lactobacillus* spp.
2. *In alcoholic fermentation* which is characteristic of yeasts grown anaerobically, pyruvic acid is converted to carbon dioxide and acetaldehyde. Acetaldehyde is reduced to ethanol by the enzyme ethanol dehydrogenase.
3. *Mixed acid fermentation* is characteristic of most enteric bacteria (Enterobacteriaceae) including the genera *Escherichia* and *Salmonella*. The end products are acetic, lactic and succinic acids as well as some carbon dioxide, hydrogen and ethanol.
4. *Propionic acid fermentation* is characterised by the production of propionic and acetic acids. *Propionibacteria* are Gram positive rods important primarily in the ripening of Swiss cheese.
5. *Heterolactic acid fermentation*; LAB metabolise lactose to produce a mixture of end products including ethanol, acetic acid and carbon dioxide. The heterofermentative LAB include the genus *Leuconostoc* and several spp of *Lactobacillus*. These bacteria are important in flavour production in fermented dairy products.

What is a starter culture?

These are bacteria that are used in the manufacture of yoghurt, kefir and other cultured dairy products as well as in cheese and butter manufacture. The starter is deliberately added to the product and allowed to grow under controlled conditions.

Why use a starter culture?

In the course of the resulting fermentation, the bacteria produce substances which give the cultured product its characteristic aroma, flavour, acidity and consistency. The drop in pH which takes place when bacteria ferment lactose to lactic acid has a preservative effect on the product while the nutritional value and digestibility of the product are improved.

Types of starter cultures

Starter cultures are classified according to their preferred temperature of growth

- i. *Mesophilic bacteria*; optimal growth temperatures of 20-30°C e.g. *Lactococcus lactis* spp *cremoris* used in the manufacture of cheddar cheese.
- ii. *Thermophilic bacteria*: optimal growth temperatures of 40-45°C e. g. *Streptococcus salivarius* spp *thermophilus* used to make yoghurt

The cultures may be of:

- i. *Single strain type*; containing only one strain of bacteria
- ii. *Multiple strain type*; a mixture of several strains, each with its own specific effect

Self test questions

1. What are the most important reasons for the spoilage of different types of dairy products?
2. How can spoilage be controlled?
3. Name 4 constituencies of milk and the role that each plays in milk processing
4. Name 5 pathogens that cause food borne illness in dairy and milk products.
5. What is a starter culture.
6. What is the difference between a mesophilic and a thermophilic starter culture?

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Study Unit 2

THE BUILDING BLOCKS OF DAIRY PROCESSING

2.1 Milk separation and milk fat standardisation

Study aims: After studying this unit, students should be knowledgeable about the following aspects;

1. Sedimentation by gravity
2. Factors affecting sedimentation
3. Separation by centrifugal force
4. Factors affecting the rate of separation by centrifugal force.

2.1.1 Sedimentation by gravity

Up to a century ago, the technique used to separate milk was the natural process of sedimentation by gravity. Milk was left in a vessel and after some time the fat globules aggregated and floated to the surface where they formed a layer of cream on the top of the milk. This could then be skimmed off.

Requirements for sedimentation

The liquid to be treated must be a dispersion i. E. a mixture of two phases, one of which continuous. Fat is dispersed in milk as globules with variable diameters of up to 15 μ m. Milk also contains a third phase, consisting of dispersed solid particles such as udder cells, pulverised straw and hair. The phases must not be soluble in each other. Substances in solution cannot be separated by sedimentation. Dissolved lactose cannot be separated by centrifugation. It can, however, be crystallised. The lactose crystals can then be removed by sedimentation. The phases to be separated must have different densities. The phases in milk satisfy this requirement. The solid impurities have a higher density than skim milk and the fat globules have a lower density.

How does sedimentation work?

Density

When an object is dropped in a liquid, it is the density of the object relative to the density of the liquid, which determines whether it will sink or float. If the density of the object is higher than that of the liquid, it will sink but will float if the density is lower.

Sedimentation and flotation velocity

A liquid droplet moving through a viscous fluid medium under the influence of gravity will eventually attain a constant velocity. This is called the sedimentation velocity. If the density of the particle is lower than the fluid medium, the particle will float at a floatation velocity. The magnitude of the sedimentation/sedimentation velocity is determined by the following physical quantities;

- i. particle diameter d (m)
- ii. particle density ρ_p kg/m^3
- iii. density of the continuous phase ρ_1 kg/m^3
- iv. viscosity of the continuous phase η kg/m,s
- v. gravitational attraction of the earth $g = 9.81 \text{ m/s}^2$

If the values of these quantities are known, the sedimentation/floatation rate can be calculated by means of the following formula which is derived from Stokes' law:

$$1) \dots\dots\dots [d^2 (\rho_p - \rho_1) / 18 \eta] g$$

This formula shows that the sedimentation/floatation velocity of a particle or droplet;

- i. increases as the square of the diameter i. e. a particle of diameter 2 cm will rise/settle 4 times ($2^2 = 4$) faster than a particle of $d = 1$.
- ii. Increases with increasing differential density between the phases
- iii. Increases with diminishing viscosity of the continuous phase

Flotation velocity of a fat globule

With fresh milk in a vessel, the fat globules will begin to move upwards towards the surface. The flotation velocity can be calculated with the formula one. The following average values apply at an ambient temperature of 35° C:

$$D = 3\mu\text{m} = 3 \times 10^{-6} \text{ m}$$
$$\rho_p - \rho_1 = (980 - 1028) = -48 \text{ kg/m}^3$$
$$\eta = 1.42 \text{ cP (centipoise)} = 1.42 \times 10^{-3} \text{ kg/m, s}$$

Substituting these values in formula 1:

$$V_g = [\{ (3 \times 10^{-6})^2 \times 48 \} / \{ 18 \times 1.42 \times 10^{-3} \}] \times 9.81$$
$$= [(9 \times 10^{-12} \times 48) / \{ 18 \times 1.42 \times 10^{-3} \}] \times 9.81$$

$$\begin{aligned} &= 0.166 \times 9.81 \\ &= 10^{-6} \text{ m/s} \\ &= 0.166^{-3} \text{ mm/s} \\ &= 0.597 \text{ mm/h} \end{aligned}$$

As indicated above, fat globules rise very slowly. The velocity of a fat globule which is 2x the size of the above globule will be $2^2 \times 0.6 = 2.4$ mm/h. In reality, fat globules cluster into larger aggregates and flotation therefore takes place more rapidly.

i. Batch separation by gravity

Figure 1: Sedimentation vessels holding the same volumes but with different sedimentation distances (h_1 and h_2)

In Figure 1 vessel A, assuming that the diameter of the globules is uniform, the milk must be left long enough for globules to starting from the bottom to reach the surface. The flotation distance is h_1 m.

The time to complete separation can be reduced if the sedimentation distance is reduced. The height of vessel B is reduced and the area increased so that it still holds the same volume. The floatation distance (h_2) is reduced and the time required for complete separation is also reduced.

ii. Continuous separation by gravity

Figure 2: vessel for continuous separation of solids from liquids

Figure 2 shows a simple vessel that can be used for continuous separation of particles of non-uniform diameter. Milk is introduced at one end of the vessel and flows towards an outflow outlet at the other end. On the way, the particles settle at different levels at different rates due to their different diameters. The surface area of the separator can be increased by inserting horizontal baffle plates.

2.1.2 Separation by centrifugal force

A field of centrifugal force is generated if a vessel is filled with a liquid and spun. The centrifugal acceleration [a] is not constant like the gravity [g] in a stationary vessel. The centrifugal acceleration increases with distance from the axis of rotation (radius r) and the speed of rotation expressed as angular velocity ω . The acceleration can be calculated by the formula 2.

$$2) \dots\dots\dots A = r \omega^2$$

The following formula 3 can be obtained if the centrifugal acceleration a is substituted for the gravitational acceleration [g] in equation 1:

$$3) \dots\dots\dots V_c = \{d^2 (\rho_p - \rho_l) / 18 \eta\} r \omega^2$$

Flotation velocity of a fat globule

When equation 1 was used it was found that the flotation velocity of a single fat globule 3 μ m in diameter was 0.166 x 10⁻⁶ m/s or 0.6mm/h under the influence of gravity. Equation 3 can now be used to calculate the flotation velocity of a fat globule of the same diameter at a radial position of 0.2 m in a centrifuge rotating at a speed of n = 5 400 rpm. The angular velocity can be calculated as;

$$\omega = (2\pi \times n) / 60 \text{ rad/s (radians per second)}$$

giving $2\pi =$ one revolution and

n = revolutions per minute (rpm)

with a rotating speed (n) of 5 400 rpm the angular velocity (ω) will be

$$\omega = 564.49 \text{ rad/s}$$

The flotation velocity (v) will be:

$$V = \{[(3 \times 10^{-6})^2 \times 48] / (18 \times 1.42 \times 10^{-3})\} \times 0.2 \times 564.49^2 = 0.108 \times 10^{-2} \text{ m/s}$$

i.e. 1.08 mm/s or 3 896 mm/h

Dividing the flotation velocity in a centrifugal force field by the flotation velocity in a gravity field gives the efficiency of centrifugal separation compared with sedimentation by gravity. The sedimentation velocity in the centrifuge is 3 896/0.6 = 6 500 times faster.

Continuous centrifugal separation of milk

i. Clarification

In a centrifugal clarifier, the milk is introduced into the separation channels at the outer edge of the disc stack, flows radially inwards through the channels towards the axis of rotation and leaves through the outlet at the top (Figure 3).

Figure 3: An example of a centrifugal clarifier bowl

On the way through the disk stack, the impurities are separated and thrown back along the undersides of the discs to the periphery of the clarifier bowl. There, they are collected in the sediment space. As the milk passes along the full radial width of the discs, the time of passage allows very small particles to be separated. The most typical difference between a centrifugal clarifier and a separator is the design of the disc stack- clarifier without distribution holes and the number of outlets-clarifier one and separator two.

ii. Separation

In a centrifugal separator, the disc stack is equipped with vertically aligned distribution holes (Figure 4).

Figure 4: An example of a separator

The milk is introduced through vertically aligned distribution holes in the discs at a certain distance from the edge of the disc stack. Under the influence of centrifugal force the sediment and fat globules settle radially outwards or inwards in the separation channels according to their density relative to that of skim milk.

High density impurities in the milk will quickly settle outwards towards the periphery of the separator and collect in the sediment space. Sedimentation of solids is assisted by the fact that the skim milk in the channels in this case moves outwards towards the periphery of the disc stack.

The cream, i.e. the fat globules has a lower density than the skim milk and therefore moves inwards in the channels, towards the axis of rotation. The cream continues to an axial outlet.

The skim milk moves outwards to the space outside the disc stack and from there through a channel between the top of the disc stack and the conical hood of the separator bowl to a concentric skim milk outlet.

Skimming efficiency

The amount of fat that can be separated from milk depends on the design of the separator, the rate at which the milk flows through it and the size and distribution of fat globules. The smallest fat globules (<1 µm) do not have time to rise at the specified flow rate but are carried out of the separator with the skim milk. The remaining fat content of the skim milk lies between 0.04 - 0.07 %. The skimming ability of the machine is then said to be 0.04 – 0.07.

The flow velocity through the separation channels will be reduced if the flow rate through the machine is reduced. This gives the fat globules more time to rise and be discharged through the cream outlet. The skimming efficiency of a separator consequently increases with reduced throughput and vice versa.

Fat content of the cream

The milk passing through the separator is discharged as skim milk and cream, of which cream represents 10% of the total throughput. The proportion discharged as cream determines the fat content of the cream. If the whole milk contains 4% fat and the throughput is 20 000 l/h then the total amount of fat passing through the fat is:

$$(4 \times 20\,000)/100 = 800 \text{ l/h}$$

Assuming that cream with a fat content of 40% is required. This amount of fat must be diluted with a certain amount of skim milk. The total amount of liquid discharges as 40% cream will be:

$$(800 \times 100)/40 = 2000 \text{ l/h}$$

800 l/h is pure fat and the remaining 1 200l/h is skim milk

Solids ejection

The solids that collect in the sediment space of the separator bowl consist of straw, hair, udder cells, white blood corpuscles (leucocytes), red blood cells, bacteria etc. The total amount may be 1kg/ 10 000 litres.

Methods of filtration

1. Conventional filtration

Also known as dead end/traditional filtration it is usually used to separate suspended particles larger than 10 μm . The filters used are thick and have open structures. The material commonly used is paper. Gravity is the main force affecting particle separation. Pressure may be applied only to accelerate the process. The flow of feed is perpendicular to the filter medium and filtration can be conducted in open systems.

2. Membrane Filters

Membrane technology is a proven separation method used on the molecular and ionic levels. Since the beginning of the 1970s this technique has been adapted for the dairy industry. Membrane filtration separates substances of molecular weight sizes less than 10^{-4} μm . The membrane filters used are thin and of fairly controlled pore size. The use of pressure is essential as the driving force for separation and a cross flow or tangential flow design is followed. The feed solution runs parallel to the membrane surface and the permeate flows perpendicular to the filtration membrane. Filtration must be carried out in a closed system.

Frequently used expressions in membrane technology

1. *Feed*; the solution to be fractionated or concentrated
2. *Flux*; the rate of extraction of permeate measured in litres per square metre of membrane surface per hour (l/m²/h)
3. *Membrane fouling*; deposition of solids on the membrane, irreversible during processing
4. *Permeate*; the filtrate, the liquid passing through the membrane
5. *Retentate*, the concentrate, the retained liquid
6. *Concentration factor*; the volume reduction achieved by concentration i.e. the ratio of initial volume of feed to the final volume of concentrate
7. *Diafiltration*; a modification of ultrafiltration in which water is added to the feed as filtration proceeds in order to wash out feed components which will pass through the membrane, basically lactose and minerals

Membrane technology

In the dairy industry, membrane technology is associated with;

1. *Reverse osmosis (RO)*; concentration of solids by removal of water. Used for dehydration of whey, UF permeate and condensate. *Particle size*; 0.0001 *Molecular weight (D)* 100, *particle characteristic*; ionic, *Milk components separated*; ions-salts, lactose/derivatives
2. *Nanofiltration (NF)*; concentration of organic components by removal of part of monovalent ions like sodium and chlorine (partial demineralisation). Used when partial desalination of whey, UF permeate or retentate is required.

Particle size; 0.0001-0.001 *Molecular weight (D)* 100-1000, *particle characteristic*; ionic and molecular, *milk components separated*; ions-salts, lactose/derivatives, vitamins

3. *Ultrafiltration (UF)*; concentration of large and macromolecules. Typically used for concentration of milk proteins in milk and whey and for protein standardisation of milk intended for cheese, yoghurt and some other products. *Particle size*; 0.001-0.1 *Molecular weight (D)* 1000- 100 000, *particle characteristic*; molecular/macromolecular, *milk components separated*; vitamins, whey proteins, casein micelles, fat globules, whey protein aggregates.

4. *Microfiltration (MF)*; removal of bacteria, separation of macromolecules. Basically used for reduction of bacteria in skim milk, whey and brine, but also for defatting whey intended for whey protein concentrate (WPC) and for protein fractionation. *Particle size*; 0.1 -10 *Molecular weight (D)* 100,000 – 500,000, *particle characteristic*; macromolecular, cellular and microparticulate, *milk components separated*; casein micelles, fat globules, whey protein aggregates, cheese fines, bacteria, yeasts, moulds.

Standardisation of fat content in milk and cream

Standardisation of fat content involves adjustment of the fat content of milk or a milk product, by addition of cream or skim milk as appropriate to obtain a given fat content. Various methods exist for calculating the quantities of products with different fat contents that must be mixed to obtain a given final fat content. These cover mixtures of whole milk with skim milk, cream with whole milk, cream with skim milk and skim milk with anhydrous milk fat (AMF).

The Pearson square can be used and is illustrated with the following example:

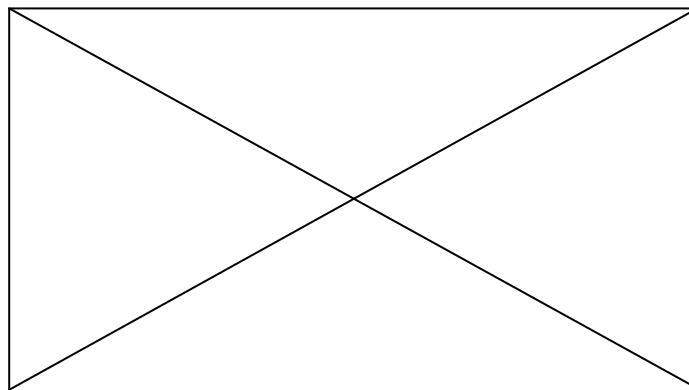
How many kg of cream of A% fat must be mixed with skim milk of B% fat to make a mixture containing C% fat?

The answer is obtained from the Pearson Square (Figure 5) where the given figures for fat content are placed.

Figure 5: Calculation of the fat content in product C

A 40%

C-B 3-0.05%



B 0.05

A-C 40-3%

A cream fat content 40%

B skim milk fat content 0.05%

C Fat content of end product 3%

Subtract the fat content values on the diagonals to give C-B = 2.95 and A-C = 37

The mixture is then 2.95 kg of 40% cream and 37 kg of 0.05% skim milk to obtain 39.95 kg of a standardised product containing 3% fat.

2.2 Emulsifying and Homogenisation

Study aims: After studying this unit, the student needs to be knowledgeable of the following:

1. Define what meant by emulsification.
2. Explain the basic principles involved in producing a stable emulsion.
3. Explain the mechanisms by which an emulsion works; list examples of natural and synthetic emulsifiers.
4. Explain how the pressure homogeniser is applied in the production of homogenised fluid milk, butter and ice cream.
5. Explain how the pressure homogeniser works to produce emulsions.

What is emulsification?

It is a process whereby two normally immiscible liquids are intimately mixed. One liquid (the discontinuous, internal or dispersed phase) becomes dispersed in the form of small droplets or globules in the other liquid (the continuous, dispersing or external phase). In dairy processing the two liquids are usually oil and water. In a crude emulsion droplets will coalesce into larger droplets and eventually the phases will separate

What is an emulsifier and how does it work?

An emulsifier is a third substance added to 2 normally immiscible liquids to reduce surface tension and to prevent coalescence of droplets. Most emulsifiers are substances with molecules containing both polar and nonpolar groups. As a rule the phase in which the emulsifier most readily dissolves will be the continuous phase.

Examples of natural emulsifiers: proteins, phospholipids and sterols. They may be affected by heat and pH during processing

Examples of synthetic emulsifiers: esters of glycerol, propylene glycol, sorbitan esters of fatty acids, cellulose ethers and carboxymethyl cellulose. They are more stable to changes in conditions during processing

Producing a stable emulsion

Work must be done on the system to overcome the resistance to the creation of new interphases. The protective film of emulsifying agent is adsorbed to the newly formed droplets and a stable emulsion is produced. The time needed to produce a stable emulsion must be determined as per formulation. Working an emulsion beyond the optimum time may cause it to break down as the protective film becomes damaged

Points to note when making an emulsion;

1. The right type of emulsifier must be used for the type of emulsion required
2. The type of emulsion depends on the phase-volume (P/V) ration (the percentage by volume of the internal phase). The phase present in the larger proportion tends to become the external phase
3. The temperature of emulsification is important. Interfacial tension and viscosity decrease with rise in temperature. The maximum temperature will depend on the heat sensitivity of the ingredients
4. As a general rule the two phases are generally prepared separately and the emulsifier is added to the external phase.

Applications

1. Homogenisation of milk using a pressure homogeniser

The pressure homogeniser consists of a high pressure pump and a homogenising valve. The valve forms an adjustable gap through which the milk is pumped at very high pressure. On entering the gap the milk serum (water phase) and the fat globules (oil phase) are greatly accelerated and the fat droplets shear against each other. They are deformed and this promotes the disruption of the unstable droplets

As the phases leave the gap there is a sudden drop in pressure and they collapse due to cavitation. This causes a reduction in droplet size. The individual fat droplet is stretched out (attenuated) to form a chain of even smaller droplets which still stick together. The lower pressure on this side of the valve causes the velocity of the phases to decrease sharply. The sudden decrease in pressure creates a whirling in the milk (explosion effect) whereby the long drawn out fat globules are broken up into small individual droplets. The average diameter of

the fat globules is decreased about 10 times and the number of globules increased about 1000 times. As a result the total surface area of globules increases 10 fold and there is not enough natural fat globule membrane to cover all small fat globules

New membranes are formed from casein and other surfactant material in the milk serum. Membrane formation takes time which leaves the globules unprotected and vulnerable to clustering. The tendency to cluster occurs in high fat products

Factors which affect the efficiency of homogenisation

1. Pressure
2. Temperature
3. Construction of the valve

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Study Unit 3

HEAT PRESERVATION AND PROCESSING

3.1 Pasteurisation

Study aims: After studying this unit, students need to be knowledgeable about the following aspects;

1. Define what is meant by the term pasteurisation
2. Explain the principles involved in the process of pasteurisation
3. List the circumstances that dictate the use of the pasteurisation process
4. Have an understanding of the terms conduction, convection, radiation, laminar flow and how some of these terms apply to the pasteurisation process
5. List the limitations of the pasteurisation process
6. The principles of a plate pasteuriser- use of a schematic diagram to explain (the importance of counter flow and regeneration

Heat transfer is important in ensuring that every particle is heated to the required temperature. It refers to the heat penetration into and throughout the container or the mass of product

Methods of heat transfer

i. Conduction

Heat moves from one particle to another through contact. The product does not move in the container and there is no circulation to mix the hot and cold product. Evaporated milk receives heat through the can by conduction

ii. Convection

It involves movement in the product being heated. The heated portion becomes lighter in density and rises. This sets up circulation within the container. This speeds up temperature rise. Liquid milk can be readily set into convection heating motion. Evaporated milk and sweetened condensed milk are viscous liquids. The rise in temperature will be by a combination of conduction and convection. Convection heating is more rapid than conduction heating and so other factors being equal, if liquid milk and sweetened condensed milk are subjected to the same heat source, uniform complete heating will be expected to be reached first in the liquid milk

iii. Radiation

It is the emission of heat from a body which has accumulated thermal energy. The thermal energy is converted into radiant energy, emitted from the body and absorbed by other bodies which it strikes. Almost all substances emit radiant energy.

How liquids flow in a pipe

1. *Laminar flow* is a type of flow in which particles maintain a continuous steady motion along parallel paths. This type of flow occurs in straight round pipes or between parallel walls at low velocities. To obtain laminar flow in a round pipe, the diameter must be small, the velocity low and the viscosity of the product high.
2. *In turbulent flow*, the particles have an erratic motion and intermix intensively with each other.
3. *Flow resistance*, every component in a pipe offers resistance to the flow when a liquid is forced through a pipe system. In straight lines the resistance is due to the friction between the liquids and the walls. In bends, additional friction occurs from the liquid having to change direction. In the same way friction, changes of direction and changes of section result in resistance in fittings, valves and process equipment. The magnitude of this resistance is relative to the velocity of the liquid in the system.

Heat transfer principles

All heat transfer in dairies takes place in the form of convection and conduction. Two principles are involved; direct and indirect heating.

1. Direct heating

This technique is used;

- a) heat water. Steam is injected directly into the water and transfers heat to the water by both convection and conduction.
- b) To produce products such as curd in the manufacture of certain types of cheeses (by mixing hot water with the curd) and to sterilise milk by the direct method (direct injection of steam or infusion of milk into steam).

The method is efficient for rapid heating. It however involves mixing the product with the heating medium and this necessitates separation. It also makes strict demands on the quality of the heating medium.

2. Indirect heating

This is the most commonly used method in dairies. A partition is placed between the product and the heating/cooling medium. The heat is then transferred from the medium through the partition to the product.

The heat exchanger is used to transfer heat by the indirect method.

Factors affecting the heat exchanger

1. Product flow rate

If the product flow rate is doubled (10 000l/h to 20 000l/h) the heat exchanger must be extended to twice the original size, provided the flow rates of the service media are also doubled, other factors being constant.

2. Physical properties of the liquids

The density is determined by the product. The specific heat tells us how much heat must be supplied to the product in order to increase the temperature by 1°C.

3. Temperature programme

The objective of heat transfer is to heat or cool a given quantity of product such as milk from a given inlet temperature to a given outlet temperature. This is done in the heat exchanger with the help of a service medium (which can be water). In the case of heating the temperature of the water drops correspondingly. Aspects of the temperature program which must be considered include the changes of temperature, the differential temperature between the liquids and the flow direction of the liquids.

4. Temperature change

The inlet and outlet temperatures of the product depend on the preceding and subsequent processing stages. The inlet temperature of the service medium is determined by processing conditions. The temperature of the outgoing service medium depends can be calculated by an energy balance calculation. For modern heat exchangers, heat losses to the environment are negligible. Thus the heat given off by the hot liquid is equal to the heat absorbed by the cold liquid. There is an energy balance.

5. Countercurrent flow

The temperature difference between the two liquids is best utilised if they flow in opposite directions through the heat exchanger. The cold product meets the cold heating medium at the inlet and a progressively warmer heating at the inlet. During the passage the product is gradually heated so that the temperature is always only a few degrees below that of the heating medium at the corresponding point. This type of arrangement is called countercurrent flow.

6. Logarithmic mean temperature difference (LMTD)

There must be a temperature difference between the two media for heat transfer to take place. The temperature differential is the driving force. The greater the difference in temperature the more is the heat transfer and the smaller the heat exchanger needed. For sensitive products however limits to how great a differential can be used.

7. Concurrent flow

Both liquids enter the heat exchanger from the same end and flow in the same direction. It is impossible to heat the product to a temperature higher than that which is obtained if the product and the heating medium were mixed.

8. *Viscosity*

The viscosities of the product and medium determine the dimensions of the heat exchanger. A product with high viscosity develops less turbulence as it flows through the exchanger compared to one with lower viscosity. This means that a larger heat exchanger is needed everything else being constant.

9. *Shape and thickness of the partition*

The partition is often corrugated to create a more turbulent flow which results in better heat transfer. The thickness is also important. The thinner the partition the better the heat transfer. This must be balanced against the need withstand the pressure of the liquids.

10. *Material of the partition*

The normal material is stainless steel in food processing.

11. *Presence of fouling matter*

Most dairy products are sensitive to heating, which must be done carefully to avoid changes in the products. Protein will coagulate and encrust the inside of heat exchangers if the heat transfer surface is too hot. The differential temperature between the heating medium and the product should be 2-3°C. If the surface is too hot in relation to the product, the protein in the milk will coagulate and be deposited in thin layers in the partition. Heat must also be transferred through this layer which will cause the value of the overall heat transfer coefficient to drop. The differential temperature between heating medium and product will no longer be sufficient to transfer the same amount of heat as before and the temperature at the product outlet will drop.

Thermisation

In large dairies it is not possible to pasteurise and process all the milk immediately after reception. Some of the milk must be stored in silos for hours or days. Under these conditions even deep chilling is not enough to prevent serious quality deterioration.

Many dairies preheat milk to a temperature below the pasteurisation to temporarily inhibit bacterial growth. This process is called thermisation. The milk is heated to 63-65°C for 15 seconds, a temperature which does not inactivate the enzyme phosphatase. The milk is rapidly chilled to 4°C to prevent aerobic spore-forming bacteria from multiplying. The milk must not be mixed with untreated milk.

Pasteurisation

It involves low order heat treatment of milk with temperatures less than the boiling point of water (100°C). The primary object of pasteurisation is to eliminate pathogenic microorganisms from milk. The process also lowers the total number of bacteria thereby reducing the chance of spoilage.

Pasteurisation methods

1. The holding/Batch/Long Time Low Temperature (LTLT) method; milk is heated in a large bulk tank at 62.9°C for 30 minutes. Constant stirring during pasteurisation ensures even heating. Because of the thicker consistency and higher fat content cream and ice cream mixes are pasteurised at 69.5°C to ensure successful pasteurisation.
2. *Flash/Plate/High Temperature Short Time (HTST) method.*

This is the more modern method of pasteurisation. Milk is warmed using the heat of previously pasteurised milk. The milk is heated to 71.6°C and held for a period of 15-17 seconds. The milk is then cooled rapidly in part by transferring its heat to incoming raw milk.. It is useful for high quality raw milk in which the bacterial count is consistently low.

Regeneration

The method of using the heat from a pasteurised product to preheat cold incoming milk is called regeneration. The cold milk also serves to cool the hot thus economising on water and heat. Regeneration efficiencies of up to 94-95% can be achieved in efficient modern pasteurisation plants. We can take the simplest operating profile- heat treatment of raw milk as an example.

Using the formula:

$$R = [(tr - ti) \times 100] / (tp - ti)$$

Where;

R= regenerative efficiency

Tr = milk temperature after regeneration (68°C)

Ti = temperature of raw incoming milk (4°C)

Tp = pasteurisation temperature (72°C)

We get;

$$\begin{aligned} R &= [(68 - 4) \times 100] / (72 - 4) \\ &= 94.1\% \end{aligned}$$

The more the milk is heated/cooled through regeneration, the more efficient is the pasteurizer.

Holding

Correct heat treatment requires that milk be held for a specified time at the pasteurisation temperature. This is done in an external holding cell. A holding cell usually consists of a pipe arranged in a spiral or zig-zag pattern and often covered by a metal shroud to prevent people from being burnt if they touch the holding cell. The length of the pipe and flow rate is calculated so that the time in the holding cell is equal to the required holding time.

3. Ultra pasteurisation method

This is used when a particular shelf life is required. Some manufacturers may aim for an extra 30-40 days on top of the 2-16 days normally associated with pasteurised products. The fundamental principle is to reduce the main causes of re-infection of the product during processing and packaging so as to extend the shelf-life of the product. This requires extremely high levels of hygiene and a distribution temperature of no more than 7°C. The lower the temperature, the longer the shelf-life. Heating milk to 125-138°C for 2-4 seconds and cooling to <7°C is the basis of extended shelf life. Extended Shelf Life (ESL) is the term used for heat treated products which have been given improved keeping qualities by one means or another. ESL products must be kept refrigerated during distribution and in retail stores.

4. Ultra High Temperature treatment

Involves exposing milk to intense heating normally to temperatures in the range of 135-140°C. This kills micro-organisms which would otherwise destroy the product. UHT treatment is a continuous process which takes place in a closed system to prevent the product from being contaminated by airborne micro-organisms. The product passes through heating and cooling stages in quick succession. Aseptic filling is an integral part of the process. Two alternative methods of UHT treatment are used;

1. Indirect heating and cooling in heat exchangers
2. Direct heating by steam injection or infusion of milk into steam and cooling by expansion under vacuum.

The shelf life of pasteurised milk

It depends on the quality of the raw milk. When produced from raw milk of sufficiently high quality and under good technical and hygienic conditions, ordinary pasteurised milk should have a shelf life of 8-10 days at 5-7°C. The shelf-life can be shortened if the milk is contaminated with micro-organisms such as species of *Pseudomonas* that form heat resistant enzymes (lipases and proteases) and/or with heat resistant bacilli such *B. cereus* and *B. subtilis* which survive pasteurisation in the spore state

The phosphatase test

Heating milk to 72-75°C with a hold of 15-20 seconds before it is cooled destroyed the enzyme phosphatase. The phosphatase test is therefore used to check if milk has been properly pasteurised. The test result must be negative. There must be no detectable phosphatase activity

Cream and cultured products

Phosphatase tests should not be used on products with fat contents above 8%. Some reactivation of the enzyme takes place a fairly short time after pasteurisation. The heat treatment must be stronger as fat is a poor conductor of heat.

Peroxidase is used for checking the pasteurisation results for cream. The product is heated to a temperature above 80°C with a holding time of about 5 seconds. This more intense heat treatment is sufficient to inactivate peroxidase. The test must be negative- there must be no detectable peroxidase in the product. As the phosphatase test cannot be used for acidified products either, heating control is based on the peroxidase enzyme. Milk intended for cultured milk production is normally subjected to intense heating to coagulate whey proteins and increase its water binding properties in order to prevent the formation of whey.

Self test questions

1. Define the terms pasteurisation, laminar flow, countercurrent flow, concurrent flow, conduction, convection, radiation, turbulent flow
2. Explain how a plate pasteuriser works and illustrate your answer using a simple diagram
3. Under what circumstances is pasteurisation used?
4. What is regeneration and what is it a measure of?
5. What are the limitations of the pasteurisation process?
6. What is the phosphatase test and what are its limitations?
7. Which test would you use to measure the effectiveness of pasteurisation of cream and fermented products? Why would you use this test?
8. You are employed as a dairy scientist in a factory that produces fresh pasteurised milk. Evaluate the three methods of pasteurisation available. Which method would you recommend? Give reasons for your recommendation

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3.2 Sterilisation

Study aims: After studying this unit, students should be knowledgeable about the following aspects;

1. Define what is meant by sterilisation
2. Have an understanding of the principles involved in the heat sterilisation process
3. Be able to explain the terms absolute sterility and commercial sterility
4. The importance of heat penetration or heat transfer in the design of a safe sterilisation process
5. The different types of spoilage of sterilised milk and how they can be prevented
6. Effects of sterilisation on the nutritional, sensory and nutritional attributes of sterilised milk
7. What is meant by the terms aseptic packaging and aseptic processing

What is sterilisation?

Absolute sterility is the complete destruction of micro-organisms (absolute sterility). This normally requires a temperature of at least 121°C of wet heat for 15 minutes or its equivalent. For food this is not sufficient because of the slow rate of heat transfer. The time required to achieve absolute sterility may be several hours. During this time changes occur in the product which reduce its quality.

Commercial sterility refers to the degree of sterilisation at which all pathogenic and toxin forming micro-organisms have been destroyed as well as other types of micro-organisms which if present would grow in the product and produce spoilage under normal handling and storage conditions. Commercially sterile products may contain small numbers of heat resistant bacterial spores but these will not normally multiply in the product. Sterilised products can have a shelf life of 2 years or more and even deterioration occurs, it is generally due to texture and flavour changes rather than microbial growth

Selecting heat treatments

The heat that is required to destroy micro-organisms and food enzymes also negatively affects other properties of food. The mildest heat treatments that guarantee freedom from pathogens and toxin and produce the desired storage life will be the treatments of choice. To select a safe heat preservation treatment the following must be known:

- a) Time-Temperature combination required to inactivate the most heat resistant pathogens and spoilage micro-organisms in a particular product. For products canned under anaerobic conditions this is usually *Clostridium botulinum*

Examples of time-temperature combinations for low acid products;

0.78 mins at 127°C

1.45 mins at 124°C

2.78 mins at 121°C

5.27 mins at 118°C

10 mins at 116°C

36 mins at 110°C

150 mins at 104°C

330 mins at 100°C

The high temperatures required for commercial sterility are obtained from steam under pressure

- b) Heat penetration characteristics of a particular food, including the can or container of choice if it is packaged. When heat is applied from outside the product nearest the container surface will reach sterilisation temperature sooner than that nearer the centre. The point in a can or product which is last to reach the final heating temperature is called the cold point. To ensure that commercial sterility is achieved, sufficient time must be allowed for the cold point of containers/cans to reach sterilisation temperature and remain there for the required time interval to destroy the most heat resistant bacterial spores.

Protective effects of food constituents

1. Sugar in high concentration protects bacterial spores. A sweetened dairy based beverage would require higher temperatures or longer heating than liquid milk.
2. Thickeners also have a protective effect on bacterial spores. Evaporated milk which has a higher viscosity would require higher temperatures or longer heating compared to liquid milk.
3. Fats and oils have a great protective effect on micro-organisms and their spores by interfering with the penetration of moist heat. Ice cream mixes and cream are pasteurised at higher temperatures compared to milk

Heating product in a container/can

- i. *The still retort* is the simplest method. The containers with evaporated milk remain still while they are being heated. With liquid products the time required to bring the cold point to sterilisation temperatures would be relatively long.
- ii. *Agitating retorts* reduce the processing time markedly by shaking the containers. When processing time is shortened, food quality is also improved. This is important with liquids and semi-liquid products

Heating product prior to packaging

- i. *Aseptic packaging* is used for milk sterilised outside the container, usually in a continuous process. The container/package can be sterilised by a combination of heat and chemicals

(e.g. hydrogen peroxide). Ultraviolet radiation can be combined with chemicals to make use of lower temperatures.

- ii. *Hot fill*; Milk is packaged while still hot, into clean but not necessarily sterile containers under clean but not necessarily aseptic conditions. The heat and some holding time before cooling the closed container may be enough to render the container commercially sterile.

Effects of sterilisation on the quality of milk

- a) When milk is kept at high temperatures for long, it acquires a cooked and a caramel flavour and there may be some sedimentation. This can be minimised by use of higher temperatures for a shorter time
- b) With the use of high temperatures for shorter periods of time it is not possible to distinguish between good ultra high temperature (UHT) processed milk.
- c) Sterilisation has no effect on fat, marginally changes the lactose, partially denatures whey proteins, partially precipitates mineral salts and there are marginal losses in vitamins.
- d) The physical and chemical limiting factors of shelf life are gelling, increase in viscosity, sedimentation and creamlining.

Self test questions

1. Explain briefly why heat treatments required to guarantee commercial sterility of the following dairy products differ; sterilised milk, evaporated milk, plain yoghurt, low fat yoghurt with fruit chunks, sweetened yoghurt with fruit chunks. Give the order of heat treatment required for each product
2. What do you understand by the term commercial sterility? Why do we not make use of absolute sterility in dairy processing?
3. What do you understand by the term aseptic processing?
4. Discuss the factors that you would consider if you were asked to develop a safe sterilisation process for sweetened yoghurt with fruit chunks. In your answer refer to the problems that you need to address.

References

1. **Desrosier N. W. and Desrosier J. N. (1977)**: The technology of food preservation. Chapter 6
2. **Potter N. N. and Hotchkiss J. H. (1995)**: Food Science. Chapter 8

Study Unit 4

COLD PRESERVATION AND PROCESSING

4.1 Refrigeration/Chill/Chilling storage

Study aims: After studying this unit, students need to be knowledgeable about the following;

1. What is meant by the term refrigeration
2. The principles of refrigeration
3. The importance of the following during refrigeration; controlled low temperature, air circulation and humidity
4. How product characteristics affect the conditions selected for refrigeration
5. Storage conditions that yield maximum shelf lives for various products.
6. Causes of quality loss in products stored at refrigeration temperatures
7. Insight into refrigeration of fresh milk, powdered milk, butter and cheese

Refrigeration usually refers to storage at temperatures above freezing., usually from 16°C down to -2°C. Commercial and household refrigerators normally operate between 4.5-7°C. Depending on product, refrigeration will preserve food for days or weeks. Refrigeration will slow down the rate of deterioration but will not prevent it. Food held under good refrigeration will still spoil as a result of the activity of microbes. Some food poisoning pathogens can also grow at refrigeration temperatures that are as low as 3.3°C and they are known as psychrotrophic pathogens. Ideally refrigeration of dairy products starts at the milking parlour and should be maintained throughout transportation, during processing, warehousing, merchandising and storage prior to ultimate use.

Requirements of refrigerated storage

- i. **Controlled low temperature;** Temperature should be maintained to within $\pm 1^\circ\text{C}$ of the selected refrigeration temperature. The amount of heat that needs to be extracted from a food in order to reduce its temperature is determined by the specific heat capacity of the product, insulation requirements, heat generating lights and electric motors, the number of people working in the cold room, number of doors and how often they are opened and closed. The amount of heat that needs to be removed from the product and storage area in order to go from the initial temperature to the final temperature is known as the refrigeration load.
- ii. **Air circulation and humidity;** Proper air circulation helps remove heat away from the vicinity of the product towards refrigerator cooling coils and plates. The air must not be too dry or moist. If the air is too dry it will cause the drying out of the product e.g. cracking of unwrapped cheese due to loss of moisture. Cheese can be packaged in sealed plastic bags or sprayed with moisture resistant coating. Most products require a relative humidity of air between 80-95%. Powdered milk is favoured by very dry conditions and

relative humidities above 50% can cause excessive lumping and caking if packaging is not moisture tight.

Changes in products during storage

1. Refrigerated storage permits exchange of flavours between many foods. Butter and milk will absorb odours from fish and fruit.
2. Loss of vitamins
3. Oxidation of fats in butter and other high fat products
4. Caking of powdered milk

Self test questions

1. Discuss the causes of quality loss in products stored at refrigeration temperatures
2. Identify the undesirable consequences of refrigerating fresh milk, butter, cheese and milk powder. Can these problems be overcome? How?

References

1. **Potter N. N. and Hotchkis J. H. (1995):** Food Science. Chapter 9- Cold preservation and processing. P 163-199
2. **Fennema O. R. (1975) (ed):** Principles of Food Science Part II. Physical Principles of food preservation (Chapter- Chilling storage of food. p133-172

4.2 Freezing

Study aims: After studying this unit, students need to be knowledgeable about the following;

1. What is meant by the term freezing
2. Distinguish between freezing and refrigeration
3. The advantages and disadvantages of freezing
4. The physical and chemical changes that occur during freezing
5. The freezing point of different products, freezing point depression, freezing curve
6. Factors to consider when making high quality ice cream and frozen yoghurt
7. Changes that occur during frozen storage
8. Freezing methods; their advantages and disadvantages

If properly done it preserves food without major changes in their size, shape, texture, colour and flavour. In aqueous solutions increasing their concentrations will lower their freezing point. Therefore the more salts, sugar, minerals or proteins in a solution the lower its freezing point and the longer it will take to freeze when put in a freezing chamber. If water and fruit juice are placed in a freezer the water component will freeze first. Unless the temperature is considerably lower than that of pure water the juice will never freeze completely but will remain icy and slushy. This is because the water component of the juice freezes first and leaves the dissolved solids in a more concentrated solution which requires a still lower temperature to freeze it. Different foods have different water contents, kinds and amounts of solids dissolved in them and so have different initial freezing points. Under a given condition, different foods require different times to reach a solidly frozen state.

Changes during freezing

Water expands when it freezes. This disrupts food texture, breaks emulsions, denatures proteins and causes chemical and physical changes.

i. Concentration effects

For quality to be maintained a product must be solidly or very nearly solidly frozen. An unfrozen core/partially frozen zone will deteriorate in quality. Possible growth of psychrotrophs and greater activity of enzymes when water remains unfrozen contributes to deterioration. In partially frozen foods, the high concentration of minerals and salts can cause denaturation of proteins and breakup of emulsions. Damage from the concentration effect can be of various kinds;

- i. Solutes can precipitate out of solution as do excessive levels of lactose in ice cream; a sandy gritty texture to the food occurs as a result
- ii. Solutes that do not precipitate but remain in concentrated solution can cause proteins to denature because of a salting out effect.
- iii. Acidic solutes, on concentration, can cause the pH to drop below the isoelectric point of milk (point of minimum solubility) causing proteins to coagulate.

- iv. Colloidal suspensions (milk protein) are in delicate balance with respect to the concentrations of anions and cations. Some of these ions essential to maintain colloids and precipitation of these ions can disturb this balance.

ii. *Ice crystal damage*

When water freezes rapidly it forms minute ice crystals. When it freezes slowly it forms large ice crystals and clusters of crystals. Large ice crystals disrupt emulsions such as butter, ice cream and gels such as puddings and pie fillings.

The rate of freezing

Fast freezing is preferred for high quality of product. The faster the freezing, the better the quality. Fast freezing produces minute crystals and reduces concentration effects.

Final temperature

Products should be frozen to an internal temperature of -18°C or lower and kept at that temperature throughout transport and storage. Temperatures below -30°C are not economically viable. Storage at -18°C prevents growth of pathogens (they do not grow below 3.3°C) and the growth of spoilage microorganisms (they do not grow below -9.5°C). It slows down but does not stop enzyme reactions. Reaction rates are, however, extremely slow. Non-enzymatic reactions are not entirely stopped but proceed very slowly.

Effects of intermittent thawing

Repeated freezing and thawing cycles are detrimental to stored products. Damage is the same as what happens during slow freezing. Slow thawing intensifies concentration effects. Refreezing creates large ice crystals.

Pre-freezing treatment

If properly done freezing does not cause significant changes in food quality. Pre-freezing treatments include addition of protective chemicals to some products (antioxidants), rigorous observance of sanitary practices and observance of recommended cooling temperatures.

Freezing methods

1. Air freezing

It is the oldest and least expensive method. Food is placed in an insulated room at a temperature of -23 to -30°C . Depending on the size, freezing time can be several hours to several days. Blast air freezers are operated with forced air. Freezer burn (drying out at the surface of the food) can occur if food is not packaged properly.

2. Indirect contact freezing

Food or its package is in direct contact with the cold wall which in turn is in direct contact with the refrigerant. This allows the use of refrigerants which might otherwise adversely affect the food or its package. Freezing time is 1-2 hours. Efficiency depends on the extent of contact between the plate and the food. Solid compact products freeze more rapidly compared to products into which air has been incorporated or have air pockets.

3. Immersion freezing

There is direct contact between food /package and refrigerant. Refrigerants must be non-toxic, pure, clean and free from colours, odours, bleaching agents and foreign tastes. Examples include solutions of sugar, glycerol and sodium chloride. This method is used to freeze canned products. When nitrogen is used as a refrigerant, temperatures lower than -30°C can be achieved in minutes. This is known as cryogenic freezing. Nitrogen has the advantage that it is inert and does not react with the ingredients in a food product.

The manufacture of ice cream

Ice cream composition

It contains milk components, emulsified fat, protein in colloidal solution and a solution of lactose and salts. Sugars, emulsifiers/stabilisers and flavourings are added during processing. Water can be found as sugar and salt solution or as ice crystals. Air is incorporated into the product as finely distributed air cells protected by a layer of fat globule agglomerates.

Ingredients

1. Fat

The minimum fat content is 10%. Cream, butter or butter oil can be used as sources of fat. Fat type and melting point and composition are of great importance in determining organoleptic properties and storage stability.

2. Milk Solids Non Fat (MSNF)

It consists of proteins, lactose and minerals. The most commonly used sources are skimmed milk, whey protein concentrate (WPC) and skimmed milk powder. The proteins affect the whipping characteristics of the ice cream. They interact with some stabilisers to create a stable fat emulsion after homogenisation. They bind water. Lactose restricts the MSNF amounts that can be included to 10-11% because it crystallises. When it crystallises it causes a sandy texture which gives an unpleasant mouthfeel.

3. Sweeteners

They include the lactose which is added as MSNF. They make up the major portion of the solids contained in the ice cream. Sweeteners affect the freezing point and hence control the amount of frozen water in ice cream. This in turn affects the softness of the final product.

4. Emulsifiers

They make it possible to form an emulsion by reducing the surface tension. The two main emulsions in ice cream are;

- a) An oil in water emulsion
- b) An air in partially frozen ice cream mix

Glycerol esters of fatty acids are the emulsifiers most commonly used in ice creams.

Pasteurisation (refer to section on pasteurisation)

Homogenisation (refer to homogenisation section)

Freezing (refer to section on freezing)

Self test questions

1. What factors need to be considered when manufacturing ice cream?
2. Describe briefly the changes that occur in ice cream during the freezing process
3. Discuss the methods that are used to freeze dairy products. Refer specifically in your answer to the advantages and disadvantages of the different techniques as well as where these methods can be applied successfully
4. You are employed by a factory that supplies frozen dairy desserts to local outlets. The company is considering changing from conventional plate freezing to cryogenic freezing. Compare and contrast the advantages of the two methods. Which method would you recommend? Why?

References

1. **Potter N. N. and Hotchkiss J.H. (1995)** Food Science. Chapter 9. Cold Processing and Preservation. P163-199
2. **Fennema O. R. (1975)** (ed). Freezing. In: Principles of Food Science. Part II. Physical principles of food preservation. New York: Marcel and Dekker

Study Unit 5

CONCENTRATION, DEHYDRATION AND FREEZE DRYING

5.1 Concentration

Study aims: After studying this unit, students need to be knowledgeable about;

1. The principles of the manufacture of evaporated milk
2. The objectives and advantages of concentration
3. The different methods used to concentrate milk, their advantages and disadvantages

Why is food concentrated?

1. It reduces weight and volume
2. Foods to be dried are concentrated before drying because;
 - i. Evaporators are more economical in the early stages of water removal
 - ii. Increased viscosity from concentration often is needed to prevent liquids from running off drying surfaces and to facilitate foaming or puffing
 - iii. Some concentrated foods are desirable components of the diet in their own right

The aim of concentration is to minimise alteration of food components.

Preservative effects

Levels of water are more than enough to permit microbial spoilage unless additionally processed. Sugar can be added to alter the osmotic concentration of the product and thereby slow down microbial growth.

Methods of concentration

1. Solar concentration

It is the simplest method of evaporating water. It is very slow. Open kettles are heated by steam. It is used mainly to make jellies, jams and certain types of soups. Its use in dairy products is limited by high temperatures and long concentration times which damage products. Thickening and burn-on of product to the kettle wall gradually lower the efficiency of heat transfer.

2. Flash evaporators

Food is subdivided and brought into contact with the heating medium. Clean steam superheated to 150°C is injected into the food which is pumped into an evaporating tube where boiling occurs. The mixture enters the separator vessel in which the concentrated food is drawn off at the bottom. Steam plus water vapour from the food is evacuated in a separate

outlet. There is loss of volatile flavour constituents. These can be recovered on the basis of different boiling points.

3. *Thin film evaporators*

Food is pumped into a vertical cylinder which has a rotating element that spreads the food into a thin layer on the cylinder wall. The cylinder wall is heated by steam. Water evaporates from the thin layer of food. The concentrated food is wiped from the cylinder wall.

4. *Vacuum evaporators*

They are used for heating sensitive foods. Thin film evaporators are used under vacuum. Vacuum vessels are arranged in series so that the product moves from one chamber to the next becoming more concentrated in stages.

5. *Freeze concentration*

Water in the food product is the first to freeze into ice crystals. Before the entire mixture freezes, initially frozen ice is separated by centrifugation through a fine mesh screen. The concentrated unfrozen food passes a screen while the frozen ice crystals are retained.

Changes that occur during concentration

Temperatures above 100°C and prolonged periods of exposure alter organoleptic and nutritional properties. Cooked flavours and darkening of colour are two of the common results. Lactose is soluble to the extent of 2 parts sugar in 1 part water. If water is removed beyond this concentration sugar crystallises out due to overconcentration. High concentrations of minerals and salts cause precipitation of proteins. When milk is overconcentrated milk protein denatures and slowly forms a gel. Concentration above 100°C kills vegetative cells but not bacterial spores.

1. *Sweetened condensed milk*

Whole milk alone cannot be concentrated sufficiently to effect preservation by reducing water activity. This is because;

- i. lactose tends to crystallise out of solution.
- ii. Viscosity and gelation with storage lead to product quality defects

To achieve a stable product, sucrose is added in sufficient quantities to prevent microbial spoilage and food poisoning. Sweetened condensed milk may be subject to spoilage by xerophilic and osmophilic yeasts which tolerate a water activity of 0.61. Sucrose is added to give a sucrose in water ratio of 62.5%. When the level approaches 64.5% crystallisation becomes a problem. Cans into which the milk is packed are flame sterilised. Sweetened condensed milk is used for the manufacture of confectionary (toffee, caramel and fudge).

2. *Evaporated milk*

Milk is standardised to achieve the desired fat: non fat solids ratio by blending with skimmed milk. The milk is preheated at 85-90°C for 10-20 minutes. Protein interactions which occur during heating make the final product heat stable. Evaporated milk is subject to coagulation and stabilisers are added to prevent this defect. Commonly used stabilisers are hydrogen

orthophosphate, sodium dihydrogen orthophosphate and trisodium citrate. Stabilisers ensure that the product thickens during heating to the point before coagulation when it turns into a creamy consistence. Evaporated milk is filled into cans with a lacquered surface to prevent chemical reactions between salts in the milk and the metal of the can. Evaporated milk is in-can sterilised to achieve commercial sterility and a high probability of the destruction of *Clostridium botulinum*. Product defects include coagulation and precipitation of protein. Microbial problems have been reported as swelling of cans due to *Bacillus spp* and *Clostridium spp*.

Self test questions

1. Why is milk concentrated?
2. Why are vacuum conditions often created when concentrating foods using heat?
3. What are the advantages and disadvantages of any 3 methods used to concentrate foods
4. How is (i) evaporated and (ii) sweetened condensed milk manufactured?
5. What is the role of stabilisers in the manufacture of evaporated milk?
6. What are the uses of (i) evaporated (ii) sweetened condensed milk?
7. What are the causes of quality loss in (i) Evaporated (ii) sweetened condensed milk?

References

1. **Potter N. N. and Hotchkiss J.H. (1995)** Food Science. Chapter 10. Food dehydration and concentration

5.2 Drying, Dehydration and Freeze Drying

Study aims: After studying this unit, students need to be knowledgeable about the following aspects;

1. The terms drying and dehydration and what they mean
2. The principles of drying or dehydration
3. Objectives of drying and dehydration, advantages and disadvantages
4. The relationship between moisture content of a product (water activity) and spoilage of products
5. The meaning of the following terms; Relative Humidity (RH), Equilibrium Relative Humidity (ERH) and water activity (a_w)
6. The relationship between temperature and relative humidity; the implications thereof during the drying process
7. The 3 forms of water in foods
8. Factors that affect the rate of drying
9. Explain the different methods used to dry foods, their advantages and disadvantages
10. The principles of freeze drying

5.2.1 Water activity

Water is an essential constituent of many foods. A relationship exists between the water content of a food and its perishability. Foods most likely to show rapid deterioration (biological and chemical) are those of high water content. However, food products with similar water contents differ significantly in perishability. This means that water content is not a reliable indicator of perishability.

What is water activity?

The state of water in a food product is described by the relationship between the moisture content of the food product and the relative humidity of the air surrounding it. The ratio of these two figures is called the water activity:

$$a_w = P/P_o$$

Where;

a_w = water activity

P = the partial pressure of water above the sample

P_o = vapour pressure of pure water at the same temperature (must be specified)

There is a relationship between the water activity and environmental relative humidity;

$$a_w = ERH/100$$

Where; ERH is the equilibrium relative humidity (%) surrounding the product

Most of the water in foods has a high water activity

Water activity is an intrinsic property of food and ERH is a property of the atmosphere surrounding the food product. Water activity refers to the available or free water for biological and chemical reactions.

Table 1: Typical water contents of some selected foods

Product	Water (%)
Tomato	95
Milk	87
Potato	78
Meat	65
White bread	35
Rice	12
Milk Powder	4

Water activity and food stability

The control of the moisture content is an ancient method of food preservation (sun drying, salting, curing and addition of sugar). The principle is to control the water content by

removing it or binding it in such a way that the food becomes stable to microbial, biochemical and chemical deterioration. Foods can be divided into 3 categories;

1. High moisture foods ($a_w = 1-0.9$)
2. Intermediate moisture foods ($a_w = 0.9-0.6$)
3. Low moisture foods ($a_w = 0.6-0$)

Water activity and microbial spoilage

Most of the water in foods has a high water activity ($a_w = 0.98$) which can only be reduced by drying the food products to less than 50% water or by adding solutes. Dried foods have water contents of 5-15%. Most bacterial growth important for food deterioration ceases at a water activity of below 0.9. Most yeasts cease to grow at a_w below 0.85 and mould growth is inhibited by an a_w below 0.7. Food with an a_w of 0.6 or less is stable towards microbial growth and is classified as dehydrated food.

Sorption isotherms

The sorption isotherm of a food is the plot of the amount of water adsorbed as a function of the Relative Humidity or activity of the vapour space surrounding the product. Sorption isotherms are useful in concentration and dehydration processes because the ease or difficulty of removing water is related to water activity. They are also useful for assessing the stability of the food. 80-90% of the total water vapour present in a food product exerts a vapour pressure nearly equal to that of pure water ($a_w = 1$). 10-20% of the remaining water is of concern to the stability of the food products and the drying time.

Types of water in foods

1. The water that is most strongly absorbed and the most immobile in food. It does not serve as a solvent
2. Intermediate between 1 and 3
3. Least strongly bound and most mobile

Figure 7: The relationship between moisture content and water activity in a food

Table 2: Examples of water a_w ranges, types of micro-organisms and foods

Range a_w	Micro-organisms generally inhibited by lowest a_w in this range	Foods generally in this range
1-0.9	<i>Escherichia, Bacillus</i> , some yeasts	Fresh foods, canned fruits, vegetables, milk
0.95-0.91	Salmonella, Clostridium botulinum	Cured meat (ham), cheeses (cheddar), fruit concentrates
0.91-0.87	Many yeasts, <i>Micrococcus</i>	Cakes, dry cheeses, margarine
0.87-0.8	Most moulds, <i>Staphylococcus aureus</i>	Fruit juice concentrates, sweetened condensed milk, chocolate syrup, flour, rice
0.8-0.75	Mycotoxigenic moulds such as <i>Aspergillus</i> and halophilic bacteria	Jam, marmalade
0.75-0.65	Xerophilic moulds	Molasses, raw cane sugar, some dried fruits, honey
0.65-0.6	Osmophilic yeasts	Dried fruits, honey, caramel and toffee
0.5	No proliferation	Pasta, spices
0.4	No proliferation	Whole egg powder
0.3	No proliferation	Cookies, bread crusts
0.2	No proliferation	Dried vegetables, corn flakes

Water activity, biochemical and chemical deterioration of foods

Enzymatic reactions are not inactivated and occur in low moisture foods. A certain minimal amount of water is necessary for enzymatic activity. Most enzymes are inactivated when the water activity falls below 0.85. Non-enzymatic browning (Maillard reaction) is a problem in dried and concentrated foods. Maximum browning occurs at a_w 0.3-0.7 depending on type of food. Oxidation is influenced by water content. Minimising oxygen in packaging and dehydrating the food will prevent oxidation, loss of ascorbic acid and Maillard reactions.

5.2.2 Food drying and dehydration

1. Sun drying

It is used in many parts of the world and depends on the elements. It is slow and will not lower moisture content below 15% which is too high for storage stability. The food is subject to contamination and losses from dust, insects, rodents and bird droppings.

2. Food dehydration

It refers to artificial drying under controlled conditions. It involves the near complete removal of water from food under controlled conditions that cause minimum or no other changes in the food properties. Final moisture is within the range 1-5%. Examples include milk powder. Foods are not sterile after drying. Many bacterial spores survive. Food enzymes may also survive drying conditions.

Important

When reconstituted by the addition of water dehydrated foods must be very close to or virtually indistinguishable from the original food material used

Why dehydrate foods?

1. For preservation
2. To decrease weight and bulk which lowers shipping and container costs
3. To retain the shape and size of the original food
4. Production of convenient items

Principles of food dehydration

It involves getting heat into a product and getting moisture out. Maximum drying rates are achieved when the following factors are optimised:

1. Surface area

Food to be dried is subdivided into small particles or thin layers to speed heat and mass transfer. A large surface area provides more surface in contact with the heating medium and more surface from which moisture can escape. Large surface areas reduce the distance heat must travel to the centre of the food and reduces the distance through which moisture must travel to reach the surface and escape.

2. Temperature

The greater the temperature difference between the heating medium and the food, the greater will be the rate of heat transfer into the food. This provides the driving force for moisture removal. When air is used for drying and as water is driven from the food as water vapour, it must be carried away or it will create a saturated atmosphere at the food surface which will slow down the rate of subsequent removal. It is important to note that;

- i. The hotter the air, the more moisture it will hold before becoming saturated
- ii. A greater volume of air can take up more moisture than a lesser volume.

3. Air velocity

Heated air takes up more moisture than cool air. Air in motion will sweep away moisture from the drying food surface and prevents the creation of a saturated atmosphere.

4. Humidity

The drier the air the faster is the rate of moisture removal. Moist air is closer to saturation and so can absorb and hold less additional moisture than when it is dry. Dryness of air also determines to how low a moisture content the food product can be dried. Dehydrated foods are hygroscopic. Each food has its own equilibrium relative humidity at which it will neither lose moisture to the atmosphere nor pick it up from the atmosphere.

Changes in food during drying

a. Physical changes

1. Shrinkage
2. Case hardening; formation of a dry skin, common with foods which contain dissolved sugars
3. Thermoplasticity; softening on heating, high sugar foods exhibit this tendency
4. Porosity; a porous structure is encouraged to aid reconstitution
5. Bulk density; is the weight of a unit volume of powder. It is expressed as g/ ml, g/ 100g or g/ l. For shipping over long distances, powders must have high bulk density to reduce the volume. A high bulk density also saves packaging costs. Bulk density is influenced by powder material density which in turn is given by powder material density and the content of the occluded air inside the particles and the content of interstitial air i.e. air between the particles.

b. Chemical changes

1. Browning changes due to enzymatic oxidations of polyphenols, caramelisation of sugars and scorching of other materials.
2. Maillard browning products from the reaction of aldehydes and amino groups of sugars and proteins respectively
3. Loss of ease in rehydration due to denaturation of proteins and changes in starches and gums. These changes make them less hydrophilic.
4. Loss of flavour
5. Altered texture

Types of driers

1. Air convection driers

These are insulated enclosures into which heated air is introduced. Heat is generated by gas or electricity. The movement of air is controlled by fans and blowers.

2. Kiln drier

A furnace or burner on the lower floor generates heat. Warm air rises to an upper storey through a slotted floor. Foods such as apple slices are spread on slotted floor and dried.

3. Tunnel and Continuous belt driers

Tunnel driers are elongated cabinets through which trays on carts pass. The time taken to dry to desired moisture must be known. The drying air moves in the opposite direction to that in which the trays are moving.

4. *Spray drier*

This procedure is limited to foods that can be atomised e.g. purees, low viscosity pastes and purees. Minute droplets are dried by air at temperatures of 200°C. Evaporative cooling does not permit particles to get warmer than 80°C. Dried particles must be quickly removed from heated zones. Uniform droplet size is important for even drying.

5. *Drum or Roller driers*

Purees, pastes and mashes are applied in a thin layer onto the surface of a revolving, heated drum.

6. *Vacuum driers*

They produce high quality dried products but costs are high. The temperature of the food and rate of water removal are controlled by regulating the degree of vacuum and intensity of heat input. Heat transfer to food is through conduction and radiation.

7. *Freeze drying*

This method is used to dehydrate high value, sensitive liquid foods such as coffee and fruit juices. It is also used for foods which have delicate textural and appearance attributes that cannot be well preserved by other methods e.g. strawberries. Food is dried from a solidly frozen state so that in addition to low temperature the food has little chance to shrink or distort while giving up its moisture.

5.2.3 Milk powder

Uses of milk powder

1. recombination of milk
2. Mixing into dough in the bakery industry to increase loaf volume and to improve dough water binding capacity
3. Mixing into pastry dough to it crisper
4. As a substitute for eggs in bread and pastries
5. Producing milk chocolate
6. Producing sausages
7. In infant formula
8. Production of ice cream
9. Livestock feed

i. Skim milk powder

It is the most common type of milk powder. If the powder is to be mixed with water for recombined/reconstituted milk, it must be easily soluble and have the correct taste and nutritive value. Some degree of caramelisation of the lactose is desirable in chocolate manufacture. Two types of powder are distinguishable; Roller dried powder and spray dried powder. Heat treatment denatures whey proteins and the percentage denatured increases with increasing heat intensity. The degree of denaturation is normally expressed by the Whey Protein Nitrogen Index (WPNI) as milligrams of undenatured whey protein (u.w-p) per gram of powder.

ii. Whole milk powder

Spray dried whole milk powder is normally produced from fat standardised milk. The milk need not be homogenised provided that it is thoroughly agitated without air inclusion before evaporation, and again between evaporation and spray drying. Fat standardised milk for production of roller dried powder is normally homogenised. Milk is normally pasteurised at 80-85°C to inactivate lipolytic enzymes that would otherwise degrade the milk fat during storage.

iii. Instant milk powder

Special methods for the production of skim milk and whole milk powder are available. The powder has a larger grain size, influenced by agglomeration, than normal spray milk powder and dissolves instantly even in cold water.

Self test questions

1. Discuss the factors that need to be considered when drying milk
2. Sketch and explain the normal drying curve of a food product
3. Discuss how a freeze drier, roller drier, spray drier and vacuum drier work. Which method would you use to dry a milk based infant porridge which contains maize. Give reasons for your answer
4. Use a figure to explain the relationship between ERH, water activity and temperature
5. What do you understand by the term ERH and what is its importance in drying?

References

1. **Potter N. N. and Hotchkiss J. H. (1995)** Food Science. 5th edition. Chapter 10. Food dehydration and concentration. p200-244
2. **Karel M. (1975)** Water activity and food preservation. p237-261. *In*: Fennema O. R. (ed) Principles of food science. Part II. Physical Principles of Food Preservation

Study Unit 6

FERMENTATION TECHNOLOGY

6.1 Yoghurt

Study aims: After studying this unit, students need to be knowledgeable about;

1. The different types of yoghurt
2. Examples of fermented products that are similar to yoghurt and the part of the world in which they are
3. Ingredients for the manufacture of yoghurt and the role of each of them
4. Different types of starter cultures, end products of fermentation and factors affecting the rate of fermentation
5. The process of making yoghurt and process optimisation (using a flow chart)

What is yoghurt?

Yoghurt is a coagulated milk product obtained by lactic acid fermentation of milk, with or without additives (whole milk powder, skim milk powder or whey powder) through the action of *Lactobacillus delbrueckii* spp *bulgaricus* and *Streptococcus salivarius* spp *thermophilus*. In the modern large and small scale manufacture of yoghurt the process involves a number of distinct steps (Figure 6).

Types of yoghurt

1. *Set type*; incubated and cooled in the package
2. *Stirred type*; incubated in tanks and cooled before packaging
3. *Drinking type*; similar to stirred type but the coagulum is broken down to a liquid before being packed
4. *Frozen type*; incubated in tanks and frozen like ice cream
5. *Concentrated*; incubated in tanks, concentrated and cooled before being packed. Sometimes called strained yoghurt, labner, labaneh

The manufacture of yoghurt

Increasing the total solids content of milk increases the firmness and viscosity of yoghurt. It is often considered that unless the solids contents of milk is increased to 16-18% the yoghurt gel will be weak and prone to syneresis. The solids content of the milk can be increased by the addition of skim milk powder, whey protein concentrate or sodium caseinate.

Yoghurts can have fat contents ranging from 0.5-10%. Fat gives the perception of creaminess and improves the mouthfeel of the yoghurt products. Homogenisation of the milk for yoghurt manufacture prevents fat separation, increases whiteness and reduces whey separation.

Heat treatment of milk is considered to be one of the most important parameters affecting the texture of acid-milk gels. Optimum conditions for heating milk are a temperature of 80-85°C with a holding time of 30 minutes. The objectives of heating are;

1. To eliminate micro-organisms that might compete with the starter culture to be added later or lead to the spoilage of the product.
2. To induce chemical changes in the milk such as expulsion of oxygen and the release of free amino acids that encourage the rapid development of starter micro-organisms.
3. To modify milk proteins in such a way that the physico-chemical properties of the yoghurt are altered. Milk is cooled to 42-43°C prior to inoculation.

Sugars, sweeteners and stabilisers may be used as additives in yoghurt production.

Sucrose or glucose can be added alone or in conjunction with fruit addition. For dieters such as those with diabetes, sweeteners may be used. A sweetener has no nutritional value. It cannot be used as a preservative. Fruit usually contains 50% sugar so the required sweetness can be achieved by adding 12-18% fruit puree. Adding more than 10% sugar adversely affects fermentation because it changes the osmotic pressure of the milk.

Correctly produced natural yoghurt requires no stabilisers. Stabilisers are hydrophilic colloids which bind water. They increase the viscosity and help prevent whey separation in yoghurt. The type and rate at which it is applied is important. The product may acquire a rubbery hard consistency if the wrong stabiliser is used. Commonly used stabilisers for yoghurt are gelatin, pectin, agar-agar and starch.

During the process of fermentation, live bacteria are involved and both the cells and enzymes remain active in the final product. The characteristics of the coagulum formed are largely determined by the behaviour of the proteins present in the milk. The incubation temperatures of yoghurt are usually in the range 40-45°C. The final pH of most yoghurts varies from 4.0 to 4.6. After the pH of the yoghurt has dropped to the desired level the gel is cooled to less than 10°C.

The two cultures commonly used in the manufacture of yoghurt are *Lactobacillus delbrueckii* spp *bulgaricus* and *Streptococcus salivarius* spp *thermophilus*. They are both essential for proper development of flavour. Lactic streptococci are nutritionally fastidious and require an exogenous supply of pre-formed leucine, valine, methionine, arginine, histidine, glutamic acid and in some cases phenylalanin, proline and cystine. Free amino acid concentrations are too low to support the starter growth required in the manufacture of fermented milk products. The amino acids essential for *Streptococcus salivarius* spp *thermophilus* are liberated by the *Lactobacillus* during fermentation. Formic acid produced by *Streptococcus thermophilus* during fermentation is believed to stimulate acid production by *Lactobacillus delbrueckii* spp *bulgaricus*.

Biochemical changes that occur during yoghurt fermentation

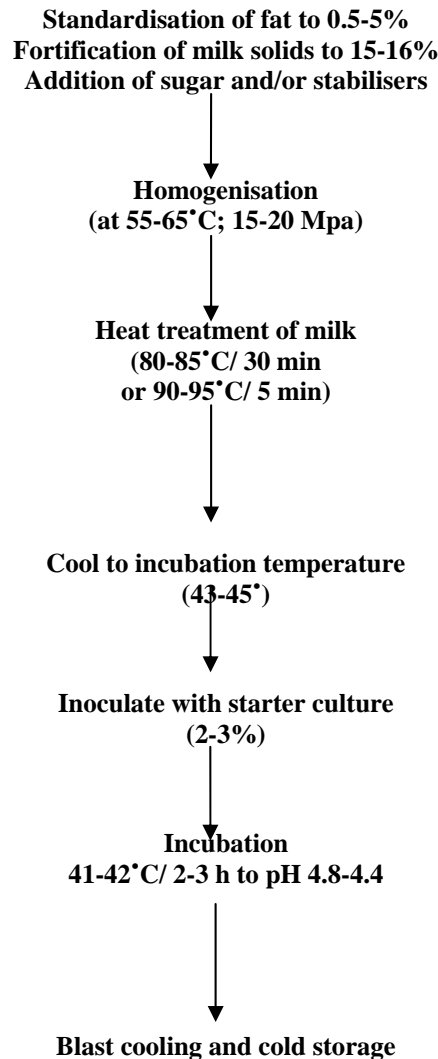
The proteins of milk can be divided into caseins and serum proteins. Caseins are defined as phosphoproteins which precipitate at pH 4.7 while serum proteins are soluble under these conditions. Cows' milk contains 30-35 g protein per litre of which 80% is present as casein micelles.

The caseins form aggregates, known as micelles, of up to 680 nm in diameter with a wide size distribution. In cows' milk casein micelles occur in colloidal suspension. They are highly hydrated, sponge-like and can bind 3.7g water/ g protein.

The caseins consist of four principal proteins which are α_1 -, α_2 -, β - and κ -caseins. All caseins are phosphorylated to varying extents.

During the fermentation of milk, the colloidal calcium phosphate in the casein micelles progressively solubilises and aggregation of the casein occurs at the isoelectric point (4.6). At a molecular level an acid set gel is held together by hydrophobic forces between casein molecules along with some specific interactions provided by hydrogen bonds and ionic interactions.

Figure 6: Flow diagram for the manufacture of set-style plain yoghurt (Adapted from Deeth and Tamime, 1981)



Self test questions

1. Using a flow diagram, describe how yoghurt manufactured
2. List the ingredients that are essential for the manufacture of yoghurt. What role does each of them play in the quality of the yoghurt?
3. Which starter cultures are commonly used to manufacture yoghurt? What are their optimal conditions and what are the end products of fermentation?

Homework

How are cheeses classified? Choose one cheese and use a flow chart to explain how it is manufactured.

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Study Unit 7
QUALITY OF DAIRY PRODUCTS

Study unit theme: Quality control, hygienic quality, local and international standards

Study aims: After studying this unit, students should be able to;

1. List the major sources of contamination in a dairy plant
2. Define HACCP
3. Explain what critical control points are and be able to identify them in a processing operation
4. Define the cold chain
5. Explain why it is important to maintain the cold chain in the manufacture of dairy products
6. The development of quality control schemes from early product inspection to total quality management
7. The objectives of each quality control scheme, its advantages and disadvantages
8. The ISO series
9. How the ISO can be incorporated into a quality control scheme
10. The main components of an ISO based quality control program
11. The roles of the Quality Premium Scheme, Legislation and the Standards Association of Zimbabwe in the manufacture of high quality dairy products

Approaches to quality managements

1. Quality inspection

The focus is on identifying product defects. The emphasis is on the negative aspects of quality followed by rejection of substandard work. The inspector becomes someone the other staff dread.

2. Quality control

This approach recognises that quality should be designed into a detailed specification and that quality checks should be made throughout the production process. More sophisticated inspection methods are developed at appropriate points in the production process. This approach will find more errors and fix them earlier. However the focus is still a find and fix mentality. Quality control will not improve the product but will only highlight when it is not present. A non conforming product must be produced before action will be taken to correct it. This can lead to inefficiency and waste. The focus is still on mistakes.

3. *Quality assurance*

This approach recognises the inherent inefficiency of waiting for mistakes to happen and makes attempts to design quality into the process so that things cannot go wrong. It recognises that lasting and continuous improvement in quality can best be achieved through planning and preventing problems from arising at source. Quality assurance tools and techniques such as statistical quality control (SPC), cause and effect diagrams and quality costing help to move emphasis from detection to prevention.

4. *Total quality management (TQM)*

The key differences between quality assurance and total quality management are in the scale and nature of involvement within and outside the organisation. The driving force of any TQM approach is the focus on the satisfaction of customer needs. The whole system of operation should be directed at customer satisfaction and anything that could get in the way of delivering this satisfaction must be removed. This therefore involves the whole organisation including suppliers in looking for ways of continually improving the quality of the product. The TQM approach places emphasis on the people in the organisation and their role through a broadening of their outlook and skills, through encouragement of creativity, through training and empowerment.

The ISO 9000 series

This is an example of an internationally recognised total quality management system. It outlines the key elements of a quality system and lays down a structured approach on which the system can be based. The guidelines are based on practices that have proved successful in other businesses and they should be applicable irrespective of the size of the factory. The standards sets out how to establish, document and maintain an effective quality system that will prove to customers that the organisation is committed to quality and has the necessary systems and procedures in place to achieve it. Some of the main elements covered by the system include: management responsibility, quality system, product identification and traceability, purchasing, contract review, inspection and testing, control of non conforming products, handling, storage, packaging and delivery and control of quality records.

Codex Alimentarius

It is a collection of internationally adopted food standards presented in a uniform manner. These food standards aim at protecting consumers health and economic interests at a global scale and ensuring fair practices in the food trade through reduction of non-tariff trade barriers on account of food labelling, food additives, pesticide residues, veterinary drug residues in foods, food composition requirements and other safety provisions such as contaminants. It includes standards of foods whether processed, semi-processed or raw for the distribution of the consumer. Materials for further processing into food are included to the extent necessary to achieve the purposes of Codex Alimentarius. The Codex Alimentarius includes provisions with respect of hygiene and nutritional quality of food, including microbiological norms when considered necessary or feasible, provisions for food additives, pesticide residues, contaminants, labelling and presentation. It is a subsidiary body of FAO and WHO established in 1962.

Risk assessment analysis

A part of the process of setting priorities is assessing the food control problem areas in terms of their risks to the consumer. Joint FAO/WHO expert committees make periodic recommendations at an international level when new areas of risk are identified. Risk assessment is a dynamic area and new information needs to be continuously disclosed. This information is necessary for food control managers to use for developing compliance policies and to implement programmes dealing with significant food hazards. Health risks associated with food consumption can range from the acute immediate effects to chronic long term effects. Examples of risks with immediate effects would be those associated with microbiological food pathogens or toxins, toxic chemicals, and heavy metal contamination. Carcinogenic effects of chemicals in food in low but continuous doses over a long period of time would be the example of long term effects. The following risks should be addressed in every food control programme regardless of country; pathogenic microbial contamination, pesticide residues in foods, food additive safety, aflatoxin and other biotoxin contamination, toxic chemical contamination, radionuclide contamination and food adulteration

Hazard Analysis

Using frozen foods as an example, Hazard Analysis is based on three general hazard characteristics;

1. A processed product contains a sensitive ingredient or ingredients assumed to be a potential source of contamination under normal circumstances
2. The manufacturing process does not contain a controlled step that effectively destroys harmful bacteria
3. There is a substantial potential for the abuse of processed products in handling or distribution by consumers that could render the product harmful when eaten due to the result of microbial growth. The combination of these factors is used to classify processed foods as to the consumer's risk. If all three hazard characteristics are present in the product it would have a hazard classification of +++. If a hazard is absent a 0 would designate this such that 0++ = no sensitive ingredient, +0+ = product pasteurised and 000 = no hazard involved.

The hazard categories in order of decreasing risk are;

1. Category I; A special category on non-sterile products designed to be consumed by the aged, infirm and infants e. g. milk
2. Category II; Food products subject to all 3 general hazard characteristics (+++). E.g. milk solids (salmonella)
3. Category III; Food products subject to 2 general hazard characteristics (+0+, ++0, 0++) e. g. butter
4. Category IV; Food subject to one general hazard characteristic (+00, 0+0, 00+)
5. Category V; Foods subject to none of the general hazard characteristics (000)

Hazard Analysis Critical Control Point (HACCP)

The aim of HACCP is to ensure food safety and it is a requirement in the USA to incorporate elements of HACCP in the processing of meat, eggs and poultry. It involves;

1. Identifying the potential hazards of a food operation and deciding which areas are critical to the safety of the consumer.
2. Identifying critical control points (CCPs) and monitoring

Deviations from safety limits are corrected. It can be applied to small and large operations. Each product requires a separate HACCP system. It requires team effort and a typical team would include the food technologist, engineer, production manager and hygiene manager.

Advantages of HACCP

1. Control efforts are concentrated on critical steps in the operation
2. Control is achieved by easily monitored parameters such as time and /or temperature
3. Results are available as faults occur.
4. Potential hazards are taken into account
5. The system is flexible and can be applied to changes in the process or introduction of new processes.
6. It involves all levels of staff

The Standards Association of Zimbabwe

The Standards Association of Zimbabwe is the national standards body of Zimbabwe. (SAZ). SAZ depends on the work of technical committees whose members develop generally acceptable national standards. Their basic principles are to carry out their task in the national interest, take into account all significant views and secure appropriate representation at all technical committee levels and as an authoritative body of opinion behind every SAZ standard. International standards are adopted only if they are found applicable to the Zimbabwe situation. SAZ standards are developed on the basis of a project approach consisting of the following stages; proposal stage, preparatory stage, committee stage, draft for public comment stage and publication stage.

Self test questions

1. Discuss how quality management approaches have evolved from quality inspection to total quality management.
2. What is the ISO 9000 series? What elements can be included in this tool?
3. What do you understand by the term HACCP? What are its advantages?
4. What is the role of Codex Alimentarius in food quality control?
5. What role can Risk Assessment analysis play in ensuring food safety in Zimbabwe?

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