DAIRY DEVELOPMENT IN INDIA

The dairy sector in India has shown remarkable development in the past decade and it has become one of the largest producers of milk and value added milk products in the world. India contributes to world milk production from 12-15% and it will increase upto 30-35% till year 2020. When dairy was first started at that time our country had no large capacity milk processing machinery but today our country has the milk processing plant or machinery which processes the milk upto 508 million litres per day. The major developments in milk production are shown in table below:

Production in India		
Year	Production (Million Tonnes)	Per Capita Availability (gms/day)
1991-92	55.7	178
1992-93	58.0	182
1993-94	60.6	187
1994-95	63.8	194
1995-96	66.2	197
1996-97	69.1	202
1997-98	72.1	207
1998-99	75.4	213
1999-2000	78.3	217
2000-01	80.6	220
2001-02	84.4	225
2002-03	86.2	230
2003-04	88.1	231
2004-05	92.5	233
2005-06	97.1	241
2006-07	100.9	246
2007-08	104.8	252
2008-09	108.5	258

Source: Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture, GOI.

The origin of dairy was done as Khaira District Co-operative Milk Producers Union in Khaira district also, known as AMUL. The first co-operative was the result of a farmers meeting in Samarkha (Khaira district, Gujarat) on 4th January 1946, called by Morarji Deasi under the advice from Sardar Vallabhbhai Patel, to fight rapacious (greedy) milk contractor. It was Sardar's vision to organise farmers, to have them gain control over production, procurement and marketing by entrusting the task of managing these to qualified professionals, thereby eliminating the middle men, the bane (pest) in farmer's prosperity. Finally, Khaira District Co-operative Milk Producers Union Ltd. (AMUL), Anand registered on 14th December 1946.

The founder Chairman of AMUL, Tribhuvandas Patel and the vision of the father of the white revolution, Dr. Varghese Kurien who worked as a Professional Manager of AMUL, the World Food Prize and Magsaysay Award winner, is the architect of India's white revolution, which helped India emerge as the largest milk producer in the world.Impressed with the development of dairy cooperative in Khaira district and its success, Shri Lal Bahadur Shastri, Prime Minister of India during visit to Anand in 1964, asked Dr. V. Kurien to replicate the Anand type dairy cooperative all over India. Thus, the National Dairy Development Board was formed (came into existence) and operation flood programme was launched for replication of the AMUL model all over India.

Operation Flood, the world's largest dairy development programme, is based on the experience gained from the "AMUL Model" dairy cooperatives. The facilities at all levels are entirely farmer owned. The cooperatives are able build markets, supply inputs and create value added processing. Thus, AMUL model cooperatives seem to be the most appropriate organizational force for promoting agricultural development using modern technologies and professional management and thereby generating employment for rural masses and eradicating poverty in these undeveloped areas. Some other programme like; assistance to dairy cooperatives for implementation of the rehabilitation schemes, Tribhuvannamalai Dairy and Milk Powder Plant, National Agricultural Development Programme (NADP), Support to Training and Employment Programme for women (STEP), Intensive Dairy Development Programme (IDDP), organization of Milk Producers Co-operative Societies (MPCS), improved the development of dairies as well as the economic condition of farmers.

A wide number of institutions have contributed including the National Dairy Research Institute, Karnal; Agricultural Universities, Veterinary colleges for development of dairies in India. National Dairy Development Board (NDDB) also provides all the facilities related with dairy development.

At the foundation of our dairy industry are the cows and buffaloes that produces most of our milk and now India have some excellent breeds for production of milk. As compare to worlds buffalo population from 147 millions about 142 millions are in Asia and Pacific.

Potential of our nondescript (ordinary) cattle and buffaloes is increasing by artificial insemination. (Insemination is done with the help of semen which is provided from semen stations or from bull mother farm. NDDB supports this type of 11 semen stations).

Foot and Mouth Disease (FMD) is a major cause of reduced milk yields and diminished draught power in India, to prevent animals from this disease, NDDB established a state of art facility, Indian Immunologicals which is largest FMD vaccine plant in Asia. Mastitis is another endemic (widespread) disease that undermines (weaken) the health and productivity of our cattle and buffaloes. NDDB has developed a simple diagnostic aid for its detection at a stage when the rapentic and control measures can reduce losses from decreased production.

First dairy farm set up at Allahabad in 1886 and in 1950 pasteurized and bottled milk sold for the first time to common man in India and nowadays / today from any place / everywhere we can buy a pasteurized and bottled milk easily not only milk but all the products which are made from milk.

Today we have all the machineries for milk processing from cleaning/ separation to packaging of milk and milk products.

COMPOSITION AND STRUCTURE OF MILK:

Milk is a very complex food with over 100,000 different molecular species found. There are many factors that can affect milk composition such as breed variations, cow to cow variations, herd to herd variations - including management and feed considerations, seasonal variations, and geographic variations. With all this in mind, only an approximate composition of milk can be given:

- 87.3% water (range of 85.5% - 88.7%)
- 3.9 % milkfat (range of 2.4% - 5.5%)
- 8.8% solids-not-fat (range of 7.9 - 10.0%):
    - protein 3.25% (3/4 casein)
    - lactose 4.6%
    - minerals 0.65% - Ca, P, citrate, Mg, K, Na, Zn, Cl, Fe, Cu, sulfate, bicarbonate, many others
    - acids 0.18% - citrate, formate, acetate, lactate, oxalate
    - enzymes - peroxidase, catalase, phosphatase, lipase
    - gases - oxygen, nitrogen
    - vitamins - A, C, D, thiamine, riboflavin, others

The following terms are used to describe milk fractions:

- Plasma = milk - fat (skim milk)
- Serum = plasma - casein micelles (whey)
- solids-not-fat (SNF) = proteins, lactose, minerals, acids, enzymes, vitamins
- Total Milk Solids = fat + SNF

Not only the composition important in determining the properties of milk, but the physical structure must also be examined. Due to its role in nature, milk is in a liquid form. This may seem curious if one takes into consideration the fact that milk has less water than most fruits and vegetables. Milk can be described as:

- an oil-in-water emulsion with the fat globules dispersed in the continuous serum phase
- a colloid suspension of casein micelles, globular proteins and lipoprotein partilcles
- a solution of lactose, soluble proteins, minerals, vitamins other components.

Milk Lipids - Chemical Properties

The fat content of milk is of economic importance because milk is sold on the basis of fat. The main milk lipids are a class called **triglycerides** which are comprised of a glycerol backbone binding up to three different fatty acids. The fatty acids are composed of a hydrocarbon chain and a carboxyl group. The major fatty acids found in milk are:

Long chain

- C14 - myristic 11% , C16 - palmitic 26% , C18 - stearic 10% , C18:1 - oleic 20%

Short chain (11%)

- C4 - butyric* , C6 - caproic ,C8 - caprylic , C10 – capric

* butyric fatty acid is specific for milk fat of ruminant animals and is responsible for the rancid flavour when it is cleaved from glycerol by lipase action.

Saturated fatty acids (no double bonds), such as myristic, palmitic, and stearic make up two thirds of milk fatty acids. Oleic acid is the most abundant **unsaturated fatty acid** in milk with one double bond. Triglycerides account for 98.3% of milkfat.

The small amounts of mono- , diglycerides, and free fatty acids in fresh milk may be a product of early lipolysis or simply incomplete synthesis. Other classes of lipids include **phospholipids** (0.8%) which are mainly associated with the fat globule membrane, and **cholesterol** (0.3%) which is mostly located in the fat globule core.

Milk Lipids - Physical Properties

The physical properties of milkfat can be summerized as follows:

- density at 20° C is 915 kg m(-3)*
- refractive index (589 nm) is 1.462 which decreases with increasing temperature

- solubility of water in fat is 0.14% (w/w) at 20° C and increases with increasing temperature
- thermal conductivity is about 0.17 J m(-1) s(-1) K(-1) at 20° C
- specific heat at 40° C is about 2.1kJ kg(-1) K(-1)
- electrical conductivity is <10(-12) ohm(-1) cm(-1)
- dielectric constant is about 3.1

At room temperature, the lipids are solid, therefore, are correctly referred to as "fat" as opposed to "oil" which is liquid at room temperature.

Milk Protein Fractionation

1. The nitrogen content of milk is distributed among caseins (76%), whey proteins (18%), and non-protein nitrogen (NPN) (6%).

The concentration of proteins in milk is as follows:

Proteins in milk	grams/ litre	% of total protein
Total Protein	33	100
Total Caseins	26	79.5
Total Whey Proteins	6.3	19.3

Vitamins

Milk includes fat soluble vitamins A , D, E, and K. Vitamin A is derived from retinol and ß -carotene. Because milk is an important source of dietary vitamin A, fat reduced products which have lost vitamin A with the fat, are required to supplement the product with vitamin A.

Milk is also an important source of dietary water soluble vitamins:B1 - thiamine , B2 – riboflavin, B6 - pyridoxine , B12 - cyanocobalamin , niacin , pantothenic acid. There is also a small amount of vitamin C (ascorbic acid) present in raw milk but it is an insignificant amount relative to human needs and is quite heat-labile: about 20% is destroyed by pasteurization.

Minerals

All 22 minerals considered to be essential to the human diet are present in milk. These include three families of salts:

1. **Sodium (Na), Potassium (K) and Chloride (Cl):**These *free* ions are negatively correlated to lactose to maintain osmotic equilibrium of milk with blood.
2. **Calcium (Ca), Magnesium (Mg), Inorganic Phosphorous (P(i)), and Citrate:** This group consists of 2/3 of the Ca, 1/3 of the Mg, 1/2 of the P(i), and less than 1/10 of the citrate in *colloidal* (nondiffusible) form and present in the casein micelle.
3. ***Diffusible* salts of Ca, Mg, citrate, and phosphate:** These salts are very pH dependent and contribute to the overall acid-base equilibrium of milk.

Physical Properties

Density

The density of milk and milk products is used for the following;

- to convert volume into mass and vice versa
- to estimate the solids content
- to calculate other physical properties (e.g. kinematic viscosity)

Density, the mass of a certain quantity of material divided by its volume, is dependant on the following:

- temperature at the time of measurement
- temperature history of the material
- composition of the material (especially the fat content)
- inclusion of air (a complication with more viscous products)

With all of this in mind, the density of milk varies within the range of 1027 to 1033 kg m(-3) at 20° C.

The following table gives the density of various fluid dairy products as a function of fat and solids-not-fat (SNF) composition:

Product	Product Composition Fat (%)	SNF (%)	Density (kg/L) at: 20°C
Producer milk	4.00	8.95	1.030
Homogenized milk	3.6	8.6	1.029
Skim milk, pkg	0.02	8.9	1.033
Light cream	20.00	7.2	1.012
Heavy cream	36.60	5.55	0.994

Viscosity

Viscosity of milk and milk products is important in determining the following:

- the rate of creaming

- rates of mass and heat transfer
- the flow conditions in dairy processes

Milk and skim milk, excepting cooled raw milk, exhibit Newtonian behavior, in which the viscosity is independent of the rate of shear. The viscosity of these products depends on the following:

- Temperature:
  - cooler temperatures increase viscosity due to the increased voluminosity of casein micelles
  - temperatures above 65° C increase viscosity due to the denaturation of whey proteins
- pH: an increase or decrease in pH of milk also causes an increase in casein micelle voluminosity

Cooled raw milk and cream exhibit non-Newtonian behavior in which the viscosity is dependant on the shear rate. Agitation may cause partial coalescence of the fat globules (partial churning) which increases viscocity. Fat globules that have under gone cold agglutination, may be dispersed due to agitation, causing a decrease in viscosity.

Influence of Heat Treatments on Lactose Properties

The normal pasteurization conditions used for fluid milk have no significant effect on lactose. The higher temperatures used for ultra high temperature (UHT) pasteurization of extended shelf life products and spray drying can cause browning and isomerization reactions, which may affect product quality and nutritional properties. The browning reaction, called the Maillard reaction, occurs between the lactose and protein in milk and produces undesirable flavors and color, and decreases the available content of the amino acid lysine in milk protein. The isomerization reaction is a molecular rearrangement of lactose to lactulose. Lactulose is produced for use by the pharmaceutical industry in pill production.

Influence of Heat Treatments on Milk Fat

Milk fat has a wide melting range, and is fully melted at 104°F (40°C). Typical high temperature short time (HTST) pasteurization conditions do not affect the functional and nutritional properties of milk fat. Higher heat treatments may stimulate oxidation reactions and cause fat deterioration and off-flavors. High heat treatments such as ultra high temperature (UHT) pasteurization can disrupt the milk fat globule membrane proteins and destabilize the globules, resulting in their coagulation.

Influence of Heat Treatment on Milk Proteins

The caseins are stable to heat treatment. Typical high temperature short time (HTST) pasteurization conditions will not affect the functional and nutritional properties of the casein proteins. High temperature treatments can cause interactions between casein and whey proteins that affect the functional but not the nutritional properties. For example, at high temperatures, ß-lactoglobulin can form a layer over the casein micelle that prevents curd formation in cheese.

The whey proteins are more sensitive to heat than the caseins. HTST pasteurization will not affect the nutritional and functional properties of the whey proteins. Higher heat treatments may cause denaturation of ß-lactoglobulin, which is an advantage in the production of some foods (yogurt) and ingredients because of the ability of the proteins to bind more water. Denaturation causes a change in the physical structure of proteins, but generally does not affect the amino acid composition and thus the nutritional properties. Severe heat treatments such as ultra high pasteurization may cause some damage to heat sensitive amino acids and slightly decrease the nutritional content of the milk. The whey protein α-lactalbumin, however, is very heat stable.

Effects of Heat Treatments & Light Exposure on the Vitamin & Mineral Content in Milk

The mild heat treatment used in the typical high temperature short time (HTST) pasteurization of fluid milk does not appreciably affect the vitamin content. However, the higher heat treatment used in ultra high temperature (UHT) pasteurization for extended shelf combined with the increased storage life of these products does cause losses of some water-soluble vitamins. Thiamin is reduced from 0.45 to 0.42 mg/L, vitamin B 12 is reduced from 3.0 to 2.7 µg/L, and vitamin C is reduced from 2.0 to 1.8 mg/L (Potter et al., 1984). Riboflavin is a heat stable vitamin and is not affected by severe heat treatments.

Calcium phosphate will migrate in and out of the casein micelle with changes in temperature. This process is reversible at moderate temperatures. This does not affect the nutritional properties of milk minerals. At very high temperatures the calcium phosphate may precipitate out of solution which causes irreversible changes in the casein micelle structure.

Exposure to light will decrease the riboflavin and vitamin A content in milk. Milk should be stored in containers that provide barriers to light (opaque plastic or paperboard) to maximize vitamin retention.

Heat Capacity of Milk:

The specific heat of milk and cream varies widely, depending upon the fat content and the temperature. The specific heat is greatest at a temperature 19 ^oC, and it decreases rapidly above and below this point. The greater percentage of cream, the more pronounced is this change. Higher percentage of fat results in lower specific heat, except in the immediate vicinity of the 19 ^oC temperature, where the apparent specific heat is greatest for the cream with the highest fat content.

Density of Milk

The specific gravity or density of milk also varies according to its composition. The usual range is from 1.028 to 1.035, which corresponds to a value of 1017 kg/m^3.
The specific gravity of concentrated milk products, such as plain condensed and sweetened condensed, is used as a rough approximation of the percentage of solids in the product.

Freezing point of milk products

The freezing point of milk is quite constant, however, it is always lower than water and varies with the composition of the milk. Fresh whole milk freezes at -0.5 ^oC. Added water raises the freezing point, added soluble substances, such as sugar and acid, lower the freezing point in a proportion to the amount added. Very accurate tables have been worked out by which it is possible to detect watering of the milk through variation in the freezing point.

Evaporated milk freezes at -14 ^oC, sweetened condensed milk, at -15 to -12 ^oC. Ice-cream mix freezes at a temperature depending upon its composition, usually, however, it starts freezing at -2 ^oC or there abouts.

When milk is frozen, changes occur in both its physical and chemical properties. Its volume is always increased. When it freezes in a container such as a can or bottle, a layer of ice is found around the sides and at the bottom first. Most of the sugar, casein, and other mineral matter collect in the center fluid portion, while the fat gathers at the top. When the milk is thawed out, small clots of albumen and fat will be found separated and floating on the top of the milk. If, however, the freezing takes place quickly, as when the milk is sprayed against a cold drum, this separation does not take place, and the thawed milk appears to be normal.

Slow freezing of cheese causes a crumbly body owing to the separation of the water rupture of cells. This same phenomenon is apparent in ice cream which is hardened slowly.

Boiling Point of Milk.

The boiling point of milk varies also with its composition and its pressure. The addition of solids, salts, sugars, or acids raises the boiling point. Normal milk boils at a temperature of approximately 100 ^{o}C at atmospheric pressure of 7 Kg absolute.

When the concentration is doubled, the boiling point rises 1.7 ^{o}C; if the concentration is 3 to 1, the boiling point will rise 17 ^{o}C. In practice, where milk is to be concentrated by boiling, it is done under vacuum in order to reduce the temperature of boiling and increase the rapidity of evaporation.

Boiling of milk at normal pressure produces a number of marked changes in the product as follows:

(1) it decreases the percentage of cream which will rise to the surface;
(2) it darkens the milk;
(3) it gives the milk a cooked taste;
(4) it coagulates the albumen and forms a scum on the surface;
(5) it decomposes the proteins;
(6) it precipitates calcium and magnesium salts;
(7) it breaks up fat globules;
(8) it destroys enzymes, and
(9) it decreases the curd tension.

The acidity of the milk greatly affects the heat stability. Milk of normal acidity of 0.12 and 0.17 per cent can be heated to 100 ^{o}C without trouble; however, if the acidity is 0.20 or above, the milk will usually coagulate before this temperature is reached, causing much trouble in milk-heating equipment. A very interesting phenomenon is noted when milk is heated too rapidly, i.e., when there is a wide temperature difference between the heating medium and the milk. This nearly always results in the formation of a deposit of milk stone on the heating surface. Most modern equipment uses a heating medium only a few degree warmer than the milk in order to prevent this difficult.

Viscosity of milk

Viscosity of dairy products is important from the standpoint of the effect upon agitation and rate of heat transfer in pasteurizers or heat exchangers. Materials of high viscosity require a large-surface, slow-moving type agitator to move them properly. High viscosity materials cause a slow-moving film on heating or cooling surfaces and thereby greatly reduce the rate of heat transfer of a given piece of equipment in comparison with low-viscosity substances. Viscous fluids also require high pump pressures for forcing them through pipe lines.

The viscosity of milk products varies greatly, according to composition, age, and treatment. Increase in concentration increases viscosity; aging at low temperatures increases viscosity; and homogenization does likewise.

EXAMPLE 1. Constituent balance of milk

Skim milk is prepared by the removal of some of the fat from whole milk. This skim milk is found to contain 90.5% water, 3.5% protein, 5.1% carbohydrate, 0.1% fat and 0.8% ash. If the original milk contained 4.5% fat, calculate its composition assuming that fat only was removed to make the skim milk and that there are no losses in processing.

Basis: 100 kg of skim milk. This contains, therefore, 0.1 kg of fat. Let the fat which was removed from it to make skim milk be *x* kg.

Total original fat = (x + 0.1) kg
Total original mass = (100 + *x*) kg

and as it is known that the original fat content was 4.5% so

$$\frac{x + 0.1}{100 + x} = 0.045$$

where, $x + 0.1 = 0.045(100 + x)$

$$x = 4.6 \text{ kg}$$

So the composition of the whole milk is then

$$\text{fat} = 4.5\% ,$$

$$\text{water} = \frac{90.5}{104.6} = 86.5\ \%$$

$$\text{protein} = \frac{3.5}{104.6} = 3.3\ \%$$

$$\text{carbohydrate} = \frac{5.1}{104.6} = 4.9\%$$

$$\text{and ash} = \frac{0.8}{104.6} = 0.8\%$$

EXAMPLE 2. Materials balance in continuous centrifuging of milk

If 35,000 kg of whole milk containing 4% fat is to be separated in a 6 h period into skim milk with 0.45% fat and cream with 45% fat, what are the flow rates of the two output streams from a continuous centrifuge which accomplishes this separation?

Solution: Basis 1 hour's flow of whole milk

Mass in

$$\text{Total mass} = \frac{35,000}{6} = 5833 \text{ kg.}$$

$$\text{Fat} = 5833 \times 0.04 = 233 \text{ kg.}$$

And so water plus solids-not-fat = 5600 kg.

Mass out

Let the mass of cream be x kg then its total fat content is $0.45x$. The mass of skim milk is $(5833 - x)$ and its total fat content is $0.0045(5833 - x)$.

Material balance on fat:

Fat in = Fat out

$5833 \times 0.04 = 0.0045(5833 - x) + 0.45x.$

and so $x = 465$ kg.

So that the flow of cream is 465 kg h^{-1} and skim milk (5833 - 465) = 5368 kg h^{-1}

Example :

Determine the protein content of the following mixture, clearly showing the accuracy:

	% Protein	Weight in mixture
Maize starch	0.3	100 kg
Wheat flour	12.0	22.5 kg
Skim milk powder	30.0	4.31 kg

(3.4%)

EXAMPLE 1.3. Velocity of flow of milk in a pipe.

Milk is flowing through a full pipe whose diameter is known to be 1.8 cm. The only measure available is a tank calibrated in cubic feet, and it is found that it takes 1 h to fill 12.4 ft^3. What is the velocity of flow of the liquid in the pipe'?

velocity is [L]/[t] and the units in the SI system for velocity are therefore m s^{-1}:

$v = L/t$ where v is the velocity.

Now $V = AL$ where V is the volume of a length of pipe L of cross-sectional area A

i.e. $L = V/A$.

Therefore $v = V/At$

Checking this dimensionally

$[L][t]^{-1} = [L]^3[L]^{-2}[t]^{-1} = [L][t]^{-1}$

which is correct.

Since the required velocity is in m s^{-1}, volume must be in m^3, time in s and area in m^2.

From the volume measurement

$V/t = 12.4 ft^3 h^{-1}$

As,

$1 ft^3 = 0.0283 m^3$

$1 = (0.0283 m^3 / 1 ft^3)$

1 h = 60 x 60 s

so (1 h/3600 s) = 1

Therefore V/t = 12.4 ft^3/h x (0.0283 m^3/1 ft^3) x (1 h/3600 s)
= 9.75 x 10^{-5} m^3 s^{-1}.

Also the area of the pipe $A = \pi D^2/4$
= $\pi(0.018)^2$ /4 m^2
= 2.54 x 10^{-4} m^2

$v = V/t \times 1/A$
= 9.75 x 10^{-5}/2.54 x 10^{-4}
= <u>0.38 m s^{-1}</u>

EXAMPLE 3. Flow of milk in a pipe

Milk is flowing at 0.12 m^3 min^{-1} in a 2.5-cm diameter pipe. If the temperature of the milk is 21°C, is the flow turbulent or streamline?

Viscosity of milk at 21°C = 2.1 cP = 2.10 x 10^{-3} N s m^{-2}
Density of milk at 21°C = 1029 kg m^{-3}.
Diameter of pipe = 0.025 m.
Cross-sectional area of pipe = $(\pi/4)D^2$
= π/4 x $(0.025)^2$
= 4.9 x 10^{-4} m^2
Rate of flow = 0.12 m^3 min^{-1} = (0.12/60)m^3 s^{-1} = 2 x 10^{-3} m^3 s^{-1}

So velocity of flow = (2 x 10^{-3})/(4.9 x 10^{-4})
= 4.1 m s^{-1},
and so (Re) = $(Dv\rho/\mu)$
= 0.025 x 4.1 x 1029/(2.1 x 10^{-3})
= 50,230
<u>and this is greater than 4000 so that the flow is turbulent</u>.

EXAMPLE 4 Pressure drop in a pipe
Calculate the pressure drop along 170 m of 5 cm diameter horizontal steel pipe through which olive oil at 20°C is flowing at the rate of 0.1 m^3 min^{-1}.

Diameter of pipe = 0.05 m,
Area of cross-section A
= $(\pi/4)D^2$
= π/4 x $(0.05)^2$
= 1.96 x 10^{-3} m^2

From Appendix 4,

Viscosity of olive oil at 20°C = 84 x 10^{-3} Ns m^{-2} and density = 910 kg m^{-3},
and velocity = (0.1 x 1/60)/(1.96 x 10^{-3}) = 0.85 m s^{-1},

Now (Re) = $(Dv\rho/\mu)$

= [(0.05 x 0.85 x 910)/(84 x 10^{-3})]
= 460

so that the flow is streamline, and from Fig. 3.8, for (Re) = 460

f = 0.03.

Alternatively for streamline flow from (3.18), f = 16/(Re) = 16/460 = 0.03 as before.

And so the pressure drop in 170 m, from eqn. (3.17)

$$\Delta P_f = (4f\rho v^2/2) \times (L/D)$$

$$= [4 \times 0.03 \times 910 \times (0.85)^2 \times 1/2] \times [170 \times 1/0.05]$$
$$= 1.34 \times 10^5 \text{ Pa}$$
$$= \underline{134 \text{ kPa}}.$$

2. Estimate the power required to pump milk at 20°C at 2.7 m s^{-1} through a 4 cm diameter steel tube that is 130 m long, including the kinetic energy and the friction energy.

[297.05 J s^{-1} = 0.4 HP]

4. It is desired to design a cooler in which the tubes are 4 cm diameter, to cool 10,000 kg of milk per hour from 20°C to 3°C. Calculate how many tubes would be needed in parallel to give a Reynolds number of 4000.

[11 tubes]

EXAMPLE 5. Cooling of milk in a pipe heat exchanger

Milk is flowing into a pipe cooler and passes through a tube of 2.5 cm internal diameter at a rate of 0.4 kg s^{-1}. Its initial temperature is 49°C and it is wished to cool it to 18°C using a stirred bath of constant 10°C water round the pipe. What length of pipe would be required? Assume an overall coefficient of heat transfer from the bath to the milk of 900 J m^{-2} s^{-1} $°C^{-1}$, and that the specific heat of milk is 3890 J kg^{-1} $°C^{-1}$.

Now

$$q = c_p G\,(T_1 - T_2)$$
$$= 3890 \times 0.4 \times (49 - 18)$$
$$= 48{,}240 \text{ J s}^{-1}$$

Also $q = UA\Delta T_m$

$$\Delta T_m = [(49 - 10) - (18 - 10)] / \ln[(49 - 10)1(18 - 10)]$$
$$= 19.6°C.$$

Therefore 48,240 = 900 x A x l9.6

$$A = 2.73 \text{ m}^2$$

but $A = \pi DL$

where L is the length of pipe of diameter D

Now D = 0.025 m.

$$L = 2.73/(\pi \times 0.025)$$
$$= \underline{34.8 \text{ m}}$$

This can be extended to the situation where there are two fluids flowing, one the cooled fluid and the other the heated fluid. Working from the mass flow rates (kg s^{-1}) and the specific heats of the two fluids, the terminal temperatures can normally be calculated and these can then be used to determine ΔT_m and so, from the heat-transfer coefficients, the necessary heat-transfer surface.

EXAMPLE 6. Pasteurisation of milk

A pasteurization heating process for milk was found, taking measurements and times, to consist essentially of three heating stages being 2 min at 64°C, 3 min at 65°C and 2 min at 66°C. Does this process meet the standard pasteurization requirements for the milk, as indicated in Fig. 6.7, and if not what adjustment needs to be made to the period of holding at 66°C?

Pasteurization times t_T can be read off the UK pasteurisation standard, and from and these and the given times, rates and fractional extents of pasteurization can be calculated:

At 64°C, t_{64} = 15.7 min
so 2 min is $\frac{2}{15.7}$ = 0.13
At 65°C, t_{65} = 9.2 min
so 3 min is $\frac{3}{9.2}$ = 0.33
At 66°C, t_{66} = 5.4 min
so 2 min is $\frac{2}{5.4}$ = 0.37

Total pasteurization extent = (0.13 + 0.33 + 0.37) = 0.83.

Pasteurization remaining to be accomplished = (1 - 0.83) = 0.17.
At 66°C this would be obtained from (0.17 x 5.4) min holding = 0.92 min.
So an additional 0.92 min (or approximately 1 min) at 66°C would be needed to meet the specification.

1. A stream of milk is being cooled by water in a counter flow heat exchanger. If the milk flowing at a rate of 2 kg s^{-1}, is to be cooled from 50°C to 10°C, estimate the rate of flow of the water if it is found to rise 22°C in temperature. Calculate the log mean temperature difference across the heat exchanger, if the water enters the exchanger at 5 °C.

[11.8 °C]

2. A flow of 9.2 kg s^{-1} of milk is to be heated from 65°C to 150°C in a heat exchanger, using 16.7 kg s^{-1} of water entering at 95°C. If the overall heat-transfer coefficient is 1300 J m^{-2} s^{-1} $°C^{-1}$, calculate the area of heat exchanger required if the flows are (a) parallel and (b) counter flow.

[(a) 53 m^2 ;(b) 34 m^2]

3. A counter flow regenerative heat exchanger is to be incorporated into a pasteurization plant for milk, with a heat-exchange area of 23 m^2 and an estimated overall heat-transfer coefficient of 950 J m^{-2} s^{-1} $°C^{-1}$. Regenerative flow implies that the milk passes from the heat exchanger through further heating and processing and then proceeds back through the same heat exchanger so that the outgoing hot stream transfers heat to the incoming cold stream. Calculate the temperature at which the incoming colder milk leaves the exchanger if it enters at 10°C and if the hot milk enters the exchanger at 72°C.

[Milk, originally colder, leaves the exchanger at 55.7 °C]

4. A plate evaporator is concentrating milk from 10% solids to 30% solids at a feed rate of 1500 kg h^{-1}. Heating is by steam at 200 kPa absolute and the evaporating temperature is 75°C. (a) Calculate the number of plates needed if the area of heating surface on each plate is 0.44 m^2 and the overall heat-transfer coefficient 650 J m^{-2} s^{-1} $°C^{-1}$. (b) If the plates, after several hours running become fouled by a film of thickness 0.1 mm, and of thermal conductivity 0.1 J m^{-1} s^{-1} $°C^{-1}$, by how much would you expect the capacity of the evaporator to be reduced?

[(a) 50 (b) 13% of its former value]

5. (a) Estimate the 12°C cooling water requirement for a jet condenser to condense the 70°C vapours from an evaporator which concentrates 4000 kg h^{-1} of milk from 9% solids to 30% solids in one effect. If the cooling water leaves at a maximumm of 25°C. (b) For the same evaporator estimate for a surface condenser, the quantity of 12°C cooling water needed and the necessary heat-transfer area if the cooling water leaves at a maximum of 25°C and the overall heat-transfer coefficient is 2200 J m^{-2} s^{-1} $°C^{-1}$ in the condenser.

[130 x 10^3 kgh^{-1} Note in practice this is higher ; (b) 130 x 103 kgh^{-1}, 17.3 m^2]

6. For a particular ultrafiltration plant concentrating skim milk, for a concentration ratio of 7:1 of protein relative to lactose, the plant capacity is 570 kg m^{-2} h^{-1} of skim milk. Assume that this is the flow rate through the membrane. Estimate (a) the plant capacity at a concentration ratio of 2:1 and (b) the percentage of the water in the skim milk removed by the ultrafiltration.

[(a) 1600 kgh^{-1} ; (b) 50%]

EXAMPLE 7. Centrifugal separation of milk and cream

If a cream separator has discharge radii of 5 cm and 7.5 cm and if the density of skim milk is 1032 kg m^{-3} and that of cream is 915 kg m^{-3}, calculate the radius of the neutral zone so that the feed inlet can be designed.

For skim milk, r_1 = 0.075m, ρ_A = 1032 kg m^{-3}, cream r_2 = 0.05 m, ρ_B= 915 kg m^{-3}

$$r_n^2 = [1032 \times (0.075)^2 - 915 \times (0.05)^2] / (1032 - 915)$$
$$= 0.03 \text{ m}^2$$
$$r_n = 0.17 \text{ m}$$
$$= 17 \text{ cm}$$

7.1 If it is desired to reduce the separation time for milk to at least one week (before cream will rise to the top), what maximum diameter of cream droplet would Stokes' Law predict to be necessary for the homogenization to achieve? Assume the depth is 10 cm.

[0.0567 microns]