# 20 TPD MILK POWDER PRODUCTION

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**Chapter # 1**

# Introduction of Milk

Milk is a natural source of energy and a natural source of 15 essential nutrients. Besides these nutrients, milk also contains compounds that have been found to be anti-carcinogen; such as conjugated linoleic acid (CLA) and butyric acid.

It is essential therefore to understand the makeup of this extraordinary, wholesome and safe source of goodness that provides us with so many health-giving factors.

**Milk** is the nutrient fluid produced by the mammary glands of female mammals (including monotremes). The female ability to produce milk is one of the defining characteristics of mammals. It provides the primary source of nutrition for newborns before they are able to digest more diverse foods. Humans, like other mammals, consume mother's milk during their infancy, but many human societies consume the milk of domesticated ruminants as well, especially milk from cows, but also that from sheep, goats, yaks, water buffalo, horses and camels. Milk can be processed into dairy products such as cream, butter, yogurt, ice cream, cheese, casein, whey protein, lactose, condensed milk, powdered milk, and many other food-additive and industrial products. Milk contains significant amounts of saturated fat, protein and calcium, although these amounts are not large in comparison to other foods rich in them, including coconuts, fish, and kale respectively.

The term *milk* is also used for the processed meat and juice of the coconut, nonanimal substitutes such as soy milk, rice milk, and almond milk, and even the regurgitated substance pigeons feed their young, called crop milk, which bears little resemblance to mammalian milk.

Human milk is fed to infants through breastfeeding, either directly or by expressing the milk to be stored and consumed later. The early lactation milk is known as colostrum, and carries the mother's antibodies to the baby. It can reduce the risk of many diseases in both the mother and baby.

In the Western world today, cow's milk is extracted on an industrial scale for human consumption and industrial uses. It is the most commonly consumed form of milk. Commercial-scale dairy farming using automated milking equipment produces the vast majority of milk in many countries. Types of cattle such as the Holstein have been specially bred for increased milk production. According to McGee, 90% of the dairy cows in the United States are Holsteins, and 85% in Great Britain. Other milk cows in the United States include Ayrshire, Brown Swiss, Guernsey, Jersey, and Milking Shorthorn. The largest producers of dairy products and milk today are India followed by USA and New Zealand.

**Other milk animals**

- Sheep
- Goats
- Horses
- Donkeys
- Camels (including the South American camelids)
- Yaks
- Water buffalo
- Reindeer

### 1.2 Physical and chemical structure

Milk is an emulsion of butterfat globules within a water-based fluid. Each fat globule is surrounded by a membrane consisting of phospholipids and proteins; these emulsifiers keep the individual globules from joining together into noticeable grains of butterfat and also protect the globules from the fat-digesting activity of enzymes found in the fluid portion of the milk. In unhomogenized cow's milk, the fat globules average about four micrometers across. The fat-soluble vitamins A, D, E, and K are found within the milkfat portion of the milk.

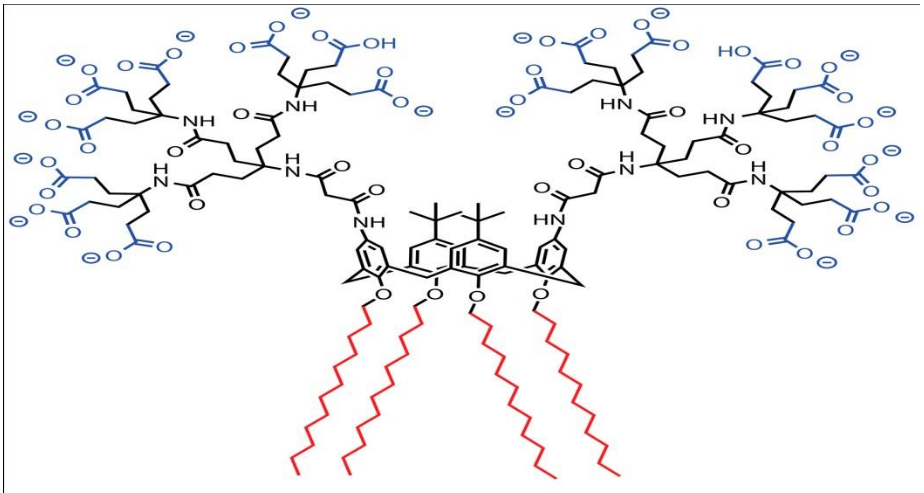

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Fig 1. Micelle Molecule (google)

The largest structures in the fluid portion of the milk are casein protein micelles: aggregates of several thousand protein molecules, bonded with the help of nanometer-scale particles of calcium phosphate. Each micelle is roughtly spherical and about a tenth of a micrometer across. There are four different types of casein proteins, and collectively they make up around 80 percent of the protein in milk, by weight. Most of the casein proteins are bound into the micelles. There are several competing theories regarding

the precise structure of the micelles, but they share one important feature: the outermost layer consists of strands of one type of protein, kappa-casein, reaching out from the body of the micelle into the surrounding fluid. These Kappa-casein molecules all have a negative electrical charge and therefore repel each other, keeping the micelles separated under normal conditions and in a stable colloidal suspension in the water-based surrounding fluid

Both the fat globules and the smaller casein micelles, which are just large enough to deflect light, contribute to the opaque white color of milk. The fat globules contain some yellow-orange carotene, enough in some breeds —Guernsey and Jersey cows, for instance — to impart a golden or "creamy" hue to a glass of milk. The riboflavin in the whey portion of milk has a greenish color, which can sometimes be discerned in skim milk or whey products. Fat-free skim milk has only the casein micelles to scatter light, and they tend to scatter shorter- wavelength blue light more than they do red, giving skim milk a bluish tint.

Milk contains dozens of other types of proteins besides the caseins. They are more water-soluble than the caseins and do not form larger structures. Because these proteins remain suspended in the whey left behind when the caseins coagulate into curds, they are collectively known as *whey proteins.* Whey proteins make up around twenty percent of the protein in milk, by weight. Lactoglobulin is the most common whey protein by a large margin.

The carbohydrate lactose gives milk its sweet taste and contributes about 40% of whole cow milk's calories. Lactose is a composite of two simple sugars, glucose and galactose. In nature, lactose is found only in milk and a small number of plants. Other components found in raw cow milk are living white blood cells, marnmary-gland cells, various bacteria, and a large number of active enzymes.

## Additives

Milk, sold commercially in countries where the cattle (and often the people) live indoors, commonly has vitamin D added to it to make up for lack of exposure to UVB radiation. Milk often has flavoring added to it for better taste or as a means of improving sales. Chocolate flavored milk has been sold for many years and has been followed recently by such other flavors as strawberry and banana.

## Nutrition and health

The composition of milk differs widely between species. Factors such as the type of protein; the proportion of protein, fat, and sugar; the levels of various vitamins and minerals; and the size of the butterfat globules and the strength of the curd are among those than can vary.Introduction to Dairy Science and Technology, webpage of University of Guelph For example:

- Human milk contains, on average, 1.1% protein, 4.2% fat, 7.0% lactose (a sugar), and supplies 72 kcal of energy per 100 grams.
- Cow's milk contains, on average, 3.4% protein, 3.6% fat, and 4.6% lactose, and supplies 66 kcal of energy per 100 arams. See also Nutritional benefits further on.

Milk began containing differing amounts of fat during the 1950's. A serving (1 cup or 250 ml) of 2%-fat milk contains 285 mg of calcium, which represents 22% to 29% of the daily recommended intake (DRI) of calcium for an adult. Depending on the age, 8 grams of protein, and a number of other nutrients (either naturally or through fortification):

- Vitamins D and K are essential for bone health.
- Iodine is a mineral essential for thyroid function.

- Vitamin B12 and riboflavin are necessary for cardiovascular health and
- Energy production.
    - Biotin and pantothenic acid are B vitamins important for energy production.
- Vitamin A is critical for immune function.
- Potassium and magnesium are for cardiovascular health.
- Selenium is a cancer-preventive trace mineral.
- Thiamine is a B-vitamin important for cognitive function, especially memory.
- Conjugated linoleic acid is a beneficial fatty acid that inhibits several types of cancer in mice, it has been shown to kill human skin cancer, colorectal cancer and breast cancer cells in vitro studies, and may help lower cholesterol and prevent atherosclerosis; only available in milk from grass- fed cows.

Studies show possible links between low-fat milk consumption and reduced risk of arterial hypertension, coronary heart disease, and obesity. Overweight individuals who drink milk may benefit from decreased risk of insulin resistance and type 2 diabetes.

## 1.3 Different Food Ingredients

Foodstuffs are very often available as an aqueous solution, a slurry or a paste, having a limited shelf life due to bacterial activity destroying the nutritive value of the product, unless it is kept at low temperatures or preservatives are added, sugar or salt for example, to reduce the bacterial activity.'

Removal of water from the product will likewise reduce the bacterial activity in the final product and thus ensure an almost infinite shelf life, if the product is dry enough and kept in a dry, cold place.

Animal or vegetable food products, or combinations hereof, are characterized by their content of:

- Proteins
- Carbohydrates
- Fat
- Starch
- Other ingredients

### Proteins

Generally speaking, the more protein, the easier becomes the drying. With increased protein content, the viscosity of the concentrate will increase and, 1o maintain good atomization, it is necessary to reduce the solids content. Drying economy is thus

reduced, as a pure protein product (egg white, Na- or K- casein ate) is dried from a feed of 20-24% solids, and the final product consists of single particles.
Proteins are difficult to agglomerate (no binding material) in conventional dryers. The Multi-Stage Dryer is therefore selected, if agglomerated powders are aimed at.

Hydrolyzed proteins are generally more difficult to dry, as the short-chain molecules become thermoplastic and hygroscopic, which makes the product stick to the drying chamber walls.

**Carbohydrates**

Carbohydrates of different origins and forms are found in most food products. Generally speaking, the more carbohydrate, the more difficult becomes the drying process, as carbohydrates, if dried from a non-crystallized feed, are thermoplastic and hygroscopic. **Carbohydrates will reduce the viscosity of the concentrate.**

One large group of carbohydrates is lactose, which is found only in milk and by-products from milk processing, for example in whey from cheese production. The advantage of lactose from a drying point of view is that it can be pre crystallized if found in a supersaturated solution (high solids, low temperature). The sticking point temperature is increased by pre crystallization, and drying becomes easier.

Sucrose is used in food products as a sweetener, and also to add calories in e.g. baby foods and other powdered beverages. If the final sucrose content in a product must be larger than what is possible to incorporate in liquid form in the concentrate to be dried, it is possible to add it in dry form into the spray dryer during the drying of the liquid feed and thus obtain a blended, agglomerated, homogeneous final product.

Fructose as found in all fruits is very thermoplastic and hygroscopic. Products like fruits therefore cannot be spray dried unless a filler is used as carrier, skim milk solids or maltodextrine, for example.

Maltodextrine is another carbohydrate, which is frequently used as a filler, carrier, or sweetener. With a DE of 10-40 it can be used in many food products, as it is easy to dry.

Carbohydrates are excellent as binding material, and agglomerated products can easily be produced, if the spray drying plant is designed for this purpose

**Fat**

If fat is not found in the original food product, it may be added to reach a certain composition. The more fat in a product, the lower the viscosity and the more difficult becomes the spray drying (powder deposits). If the fat is found in free form (unprotected by proteins) in the final product, the drying operation becomes even more difficult. Homogenization of the concentrate prior to spray drying is therefore recommended. Homogenization will increase the viscosity of a concentrate slightly.

**Starch**

If the starch is precooled, it increases the viscosity. It is therefore necessary to lower the solids content in the concentrate to be dried.

**Other Ingredients**

There is a wide variety of other ingredients that are typically added in small quantities, such as:

- Vitamins
- Flavorings
- Emulsifiers
- Stabilizers
- Colors

In general, these do not cause too many problems during spray drying.

- Salts and other chemicals

The higher salt and chemical content the more difficult becomes the drying due to increased hygroscopicity.

## 1.4 POWDERED MILK

Powdered **Milk** is a powder made from dried milk solids. Powdered milk has a far longer shelf life than liquid milk and does not need to be refrigerated due to its low moisture content.

**HISTORY**

Powdered milk was first made in the 20th century and is used extensively today.
It is found abundantly in many developing countries because of reduced transport and storage costs (as it does not require refrigeration). Like other dry foods it is considered nonperishable and is favored by survivalists, hikers and other people in need of nonperishable easy to prepare foodstuffs.

## 1.5 Types of Powder milk

1. Skim Milk Powder
2. Whole Milk Powder

## SKIM MILK POWDER / NONFAT POWDER MILK

**DISCRIPTION**
Instant Nonfat Milk Powder is manufactured by spray drying fresh organic pasteurized skim milk. Nonfat Dry Milk has a creamy white to light yellow color and is uniform throughout.

**SUGGESTED USES**
Instant Nonfat Milk Powder has a wide range of applications including but not limited to product solids fortification and dry blends. Organic Nonfat Dry Milk Powder has consistent and uniform composition.

**INGREDIENTS**
Organic Pasteurized skim milk

**TYPICAL COMPOSITION**

| | |
|---|---|
| Milk fat | 0.85% |
| Lactose | 51.0% |
| Protein | 36.0% |
| Moisture | 4.0 % |
| Ash8.0% | |
| Bulk Density | 0.55-0.60 g/cm |

**Approximate Composition and Food Value of Nonfat Dry Milk**

| | |
|---|---|
| Protein (N x 6.38) % | 36.0 |
| Lactose (Milk Sugar) % | 51.0 |
| Fat % | 0.7 |
| Moisture % | 3.0 |
| Minerals (Ash) % | 8.2 |
| Calcium % | 1.31 |
| Phosphorus % | 1.02 |
| Vitamin A (I.U./lb) | 165.0 |
| Riboflavin (mg/lb) | 9.2 |
| Thiamin (mg/lb) | 1.6 |
| Niacin (mg/lb) | 4.2 |

| | |
|---|---|
| Niacin Equivalents * (mg/lb) | 42.2 |
| Pantothenic Acid (mg/lb) | 15.0 |
| Pyridoxine (mg/lb) | 2.0 |
| Biotin (mg/lb) | .02 |
| Choline (mg/lb) | 400.0 |
| Energy (Calories/lb) | 2260.0 |

## POWDERED WHOLE MILK

**DESCRIPTION**

Our Organic Whole Milk Powder is manufactured by spray drying fresh pasteurized organic whole milk. The Whole Milk Powder has been subjected to a low heat treatment. This process accounts for the pleasing flavor when reconstituted.

**SUGGESTED USES**

Our Organic Whole Milk Powder has a wide range of applications including but not limited to confectionery products, bakery products, reconstitution, nutrient supplements and dry blends. Our Whole Milk Powder has consistent and uniform composition.

**INGREDIENTS**

Pasteurized organic w*hole milk.*

***TYPICAL COMPOSITION***

| | |
|---|---|
| Milkfat | 26.0% - 30.0% |
| Lactose | 38.0% |
| Protein | 26.0% |
| Moisture | 2.5% |
| Ash | 6.0% |
| Bulk Density | .52 g/cm |

**Approximate Composition and Food Value of Dry Whole Milks**

| | |
|---|---|
| Protein (N x 6.38) % | 26.0 |
| Lactose (Milk Sugar) % | 38.0 |
| Fat % | 26.0-30.0 |
| Moisture % | 2.25 |
| Minerals (Ash) % | 6.0 |
| Calcium % | 0.97 |
| Phosphorus % | 0.75 |
| Vitamin A (I.U./lb) | 4950.0 |
| Riboflavin (mg/lb) | 6.7 |
| Thiamin (mg/lb) | 1.2 |
| Niacin (mg/lb) | 3.1 |
| Niacin Equivalents * (mg/lb) | 30.6 |
| Pantothenic Acid (mg/lb) | 13.0 |
| Pyridoxine (mg/lb) | 1.5 |
| Biotin (mg/lb) | .2 |
| Choline (mg/lb) | 400.0 |
| Energy (Calories/lb) | 2260.0 |

## 1.6 Uses and applications of powder milk

Powdered milk is often used in baking, in recipes where adding liquid milk would render the product too thin to be used. It is also a common sight in UN food aid supplies, fallout shelter, warehouses and wherever fresh milk is not a viable option. Powdered milk is also used in Western blots as a blocking agent to prevent nonspecific protein interactions.

The most important use of the dried milk is as food for children. The extensive use of dry whole milk, dry buttermilk and dry skim milk is in bakeries, confectioneries, hospitals and ice cream manufacturers.

1. Milk powder is used as a food.
2. Milk powder is used as an alternative of ordinary milk.
3. Cheese, Yogurt, Ice cream, Lassi, Tea, etc., can be prepared with skimmed milk powder.
4. Skimmed milk powder is used almost in every home.

## ANSWERING QUESTIONS AND EXPLORING SITUATIONS CONCERNING THE STEPS TAKEN IN THE PROCESS OF MAKING MILK SAFE TO DRINK.

**WHAT IS PASTEURISATION?**

Pasteurisation involves heating milk to high temperatures to kill harmful bacteria that can cause illness. Milk is heated to a high temperature and then rapidly cooled. Pasteurisation does not involve the use of any additives.

Apart from making milk safe to drink, pasteurisation increases the length of time it can be kept before it spoils. The nutrient losses due to pasteurisation are so small, they are considered insignificant.

**IS IT SAFE TO DRINK RAW MILK?**

No. Milk that has not been pasteurised is raw milk. Bacteria found in raw milk can be harmful.

**WHAT IS HOMOGENISATION?**

Homogenization is a mechanical process that changes the size of the fat globules in milk. It keeps the fat from separating from the rest of the milk and gives milk a smooth creamy texture.

Homogenisation does not change the nutrient value of the milk.

**WHY IS MILK OPAQUE AND IS IT WHITE OR DOES IT HAVE A YELLOWISH TINT?**

It is opaque because it contains very small particles of casein (rtwlk protein). The fat globules in milk give it a yellowish tint. Cows, which are fed a carotene rich diet such as grass or hay, pass the orange-coloured vitamin A into the milk fat that makes milk slightly yellowish.

**WHAT IS UHT MILK?**

Milk that has been pasteurised by a special method involving ULTRA HIGH TEMPERATURES is called UHT milk. This process extends the shelf life of the milk without changing the nutrient value. UHT milk does not need refrigeration until after it is opened.

Packaging protects products from spoilage and important information on size, ingredients and nutritional value can be given. The packaging in no way affects the quality or make-up of the contents.

**WHAT IS STERILIZED MILK?**

Sterilized milk is homogenised milk heated to 150 degrees C (300 degrees F) for several seconds. Sterilization destroys all germs. Date stamped plastic bottles and cartons have a shelf life of several months and can be kept at room temperature. After opening it should be stored in the refrigerator. It has a flavour like caramel.

**IS THERE ANTIBIOTICS IN MILK?**

No. If a cow becomes sick and is given antibiotics, she is milked separately from the rest of the herd and the milk is discarded. This continues until she has recovered from her illness and no antibiotics are detected in her milk.

**HOW IS THE SAFETY OF OUR MILK GUARANTEED?**

Tests are done both at the farm and at the processing plant to ensure the milk is of good quality and free of antibiotics. Any milk that does not meet strict standards is discarded. The highest level of hygiene is observed at all times.

## 1.7 Basic Test for Determining Fat in the Milk

### Babcock test

The **Babcock test** is the first inexpensive and practical test factories could use to determine the fat content of milk.

### MOTIVATION

Until the 1890's dishonest farmers could water down their milk or remove some cream before selling it to the factories. Milk was paid for by volume. Honest farmers as well as those that produced naturally rich milk were not being compensated fairly.

### Babcock Test process

Babcock researched the problem at the University of Wisconsin and developed the following process:

1. Measure milk into graduated test tube. You usually take 18 grams of milk or 17.6 milliliters.
2. Add 17.6 milliliters of 90-92% sulphuric acid.
3. Centrifuge at 50°C.
4. Measure fat which will be floating on top of liquid in the test tube.

### Principle of Babcock test

Key to this process is that everything in milk except the fat dissolves in sulphuric acid. The fat floats to the top. The centrifuge ensures complete separation with no bubbles in the fat, and the fat content can be measured using the graduations on the test tube and knowing the initial amount of milk used.

## 1.8 Analyses for Milk Powder

### Moisture

All milk powder has to meet a requirement for residual moisture. For skim miik it is usually 4% and for whole milk usually 2.5%. There may naturally be deviations from country to country.

The moisture content will have an influence on the keeping quality of the powder. High moisture content (high water activity Aw) will thus decrease the keeping quality, as the proteins will denature and the lactose, which is found in an amorphous stage, will crystallize causing the free fat to increase in whole milk powders, and oxidation of the fat will be the result.

Residual moisture is determined by a simple drying oven method. The powder is dried at 102-105°C for three hours. The difference in weight (i.e. weight loss) is determined and the moisture calculated in per cent of the powder weight.

Various quick methods for determination of moisture have also been developed. They usually work with a powerful heating lamp, the voltage of which can be adjusted. This type of equipment will never be so accurate as the drying oven method, but is a great help during operation of a plant, as the operator can have quick response from the laboratory enabling him to find suitable drying parameters.

Automatic control of the moisture content is measured with infrared light. The reflection from the sample is direct proportional to the moisture content, and the output is used to control the outlet temperature by regulation of either tjie feed pump or the heat applied to the heating section of the Vibro-Fluidizer.

**Bulk Density**

The bulk density is an economically, commercially, and functionally important property. When shipping powders over long distances the producers are of course interested in a high bulk density in order to reduce the shipping volume. A high bulk density also saves packing material and storage capacity.

For some powders the aim is a low bulk density, obtained by agglomeration, for optical reasons, or because of requirements to instant powder production.

Bulk density is defined as the weight of a given volume of powder and is expressed in g/rnl, g/100 ml, or g/l. The reciprocal value is the bulk volume which is expressed in ml/100 g or ml/g. The bulk volume is usually used when a graduated cylinder glass is used for the determination. The volume of 100 g of powder is then measured in the cylinder. As to the other method giving the bulk density, the weight of the powder in a 100 ml cylinder is measured. Both results can naturally be converted to the other expression. See Fig. 104. The value may either be expressed as tapped 0 times (loose), tapped 10 times (poured), 100 times, or 1250 times. Various types of equipment can be used for the tapping. Also manual tapping is used. The intensity of the tapping is naturally influencing the value.

The bulk density of rnilk powders is a very complex property, as it is a result of several other properties. However, the primary factors determining the bulk density are:

- Particle density, given by:
  - the solids density, a function of product composition
  - the content of occluded air in the particles
- Amount of interstitial air, i.e. air between particles (agglomeration)
- Flow ability

**Particle Density/Occluded Air**

The particle density is given by the density of the powder solids and the occluded air in the particles. The powder solids density expresses the density of solids without any air and is given by the composition of the powder. When the composition and the density of the single components are known the density of the solids (D solids) can be calculated using the following formula:

$$D_{solids} = \frac{100}{\frac{\%A}{D_A} + \frac{\%B}{D_B} + \frac{\%C}{D_C} + etc + \%W}$$

where %A, %B, %C are equivalent to the composition and $D_A$, $D_B$, and $D_c$ the corresponding solids density. %W is the percentage of moisture. The solids densities of various typical components in milk powders are as follows:

| **Solids, air and moisture free:** | **Density, g/ml at 20°C** |
|---|---|
| Milk fat | 0.94 |
| Non-fat milk solids | 1.52 |
| Calcium caseinate phosphate complex 1.39 Amorphous lactose | 1.52 |
| Beta-lactose | 1.59 |
| Alpha-lactose monohydrate | 1.545 |

Powder solids density cannot be changed without changing the composition and is thus for a given product constant.
The particle density may be measured in an air pycnometer. However, as this equipment is not available in all laboratories, the petroleum ether method will be discussed. A given amount of powder is mixed with a given volume of petroleum ether in a graduated measuring cylinder:

Particle = W / $V_r$ V2 (19)

Where:
D particle: particle density in g/ccm
W particle: weight of powder in g
N/S particle: volume of powder + petroleumether in ml
$V_2$ particle: volume of petroleumether in ml

The occluded air content is calculated as follows:

$V_{oa}$ = 100 / D particle -100 / D solids (20) where:

$V_{oa}$ = Volume of occluded air in ccm/100 g powder D particle = Particle density, see formula (19)
D solids = Density of solids, see formula (18)

The particle density for the reciprocal value of the occluded air content is influenced by many factors previously discussed. They are summarized here:

- Pasteurization temperature of the milk prior to evaporation
- Amount of air in the concentrate
- Foaming ability of the concentrate
- Type of wheel used or size of nozzle
- Solids content in the concentrate
- Drying conditions (one-stage or two-stage)

**Flow ability**

The flow ability of a powder is not fully understood. Two free-flowing powders mixed together will not necessarily be free-flowing. A good flow ability is obtained from large particles or agglomerates without small particles - this will, however, tend to decrease the bulk density. Also the particle surface plays an important role and especially the content of free fat. Nozzles are generally believed to produce particles with better flow-properties than the wheel, especially in whole milk powder. A powder with a good flow ability will increase especially the poured and loose bulk density.
A method developed by NIRO is however suitable for any kind of powder. In this method the time is measured by a given volume of powder to flow through well de-fined slits in a drum rotating with a given revolution/min.

**Solubility**

That milk powder has to be soluble in water is obvious. However, not all of the components in the powders are soluble when reconstituted in water. In powders produced in modern dryers, this amount is very small and approaching 100% solubility. Nevertheless, powders with a bad solubility are still produced and any dryer can in fact be manipulated resulting in a powder with bad solubility.

The method for measuring the solubility is very simple, well defined, and easy to perform:

10 g of skim milk powder, 13 g of whole milk powder or 6 g of whey powder (or equivalent amount of concentrate depending on solids content) is mixed with 100 ml of water at approx. 24°C in a mixer at high speed for 90 sec. The milk is then left for 15 min. after which it is stirred with a spatula. 50 ml is filled into a graduated 50 ml centrifuge glass with conically graduated bottom. The glass is spun in a centrifuge for 5 min., the sediment-free liquid is sucked off, the glass is filled up again with water (to make the reading easier), and the content is stirred up. Then the glass is put into the centrifuge and spun for 5 min. after which the sediment is read.

The sediment is expressed in ml and is termed Insolubility Index. It is usually below 0.2 ml in powder from good quality milk dried in modern well-designed evaporators and dryers.

The reasons for high Insolubility Index (i.e. bad solubility) in a powder may be many. It is usually denatured caseins or very complex combinations of casein- whey protein and lactose, the chemistry of which is not fully understood. The main contributing factors are:

- Bad quality milk with a high development of lactic acid, i.e. bacterial activity will result in high Insolubility Index, as any extensive heat- treatment will cause an irreversible protein denaturation, especially of fhe caseins.
- High temperatures of the concentrate during the evaporation will cause a pronounced age-thickening resulting in viscosity increase and bad atomization, i.e. high temperatures during the drying.
- Generally it may be said that the higher temperatures and viscosities during the processing, the higher Insolubility Index may be expected. Powders with a high lactose content such as baby food will practically never get a high Insolubility Index, as lactose protects the proteins from denaturation.
- Powders dried according to the one-stage drying principle will more easily get a high Insolubility Index than from the two-stage drying principle.

It is not only the dryer, which is to blame for high Insolubility Index. Also the evaporator may harm the concentrate. It is, however, measured very rarely. But if a factory has untraceable problems, it is recommended to investigate the concentrate. This is done by using the same method as described above, but with an amount of concentrate depending on the solids content and corresponding to the specified amount of powder. If milk powders with high Insolubility Index are used in "compounded" products like baby food, a correspondingly higher Insolubility Index should be expected.

**Scorched Particles**

Scorched particles are generally accepted to be a measure for any deposits in the drying chamber having been exposed to high temperatures thus getting scorched, discolored and at the same time insoluble.

However, it is not only the dryer that contributes to the scorched particles, as even the raw milk may contain some dirt or sediment, and if not clarified in a separator these will be found in the powder.

Also from the evaporator brown, insoluble, jelly lumps may contribute to the scorched particles, if deposits have been formed in the tubes due to insufficient coverage of the tubes, (remedies for this have been discussed earlier) or insufficient cleaning.

If it has been concluded that the scorched particles originate from the dryer, the reason is very often deposits in the wheel or around the nozzles or in the air disperser. How to solve the problem may differ from case to case, but adjustment of the air disperser will usually help in most cases.

The test for determining scorched particles is simple and rapid:

25 g skim milk powder, 32.5 g whole milk powder or 15 g whey powder (or equivalent amount of concentrate depending on total solids), is mixed with 250 ml of water of 18-28°C in 60 sec. in the same kind of mixer as used for insolubility index. The milk solution is filtered and the filter pad is compared with a standard for classification. The scorched particles are expressed as A, B, C, or D depending on the intensity and color

If scorched particles cannot be traced to the evaporator, see page 189 or the spray dryer, they may originate from milk powder used in "compounded" products like baby food.

**Total Fat**

The total fat in the whole milk powder is a question of standardizing the raw milk prior to the processing and has got nothing to do with the drying process.
The standardizing is carried out either by adding skim milk or cream to the milk, or removing cream from the milk, depending on the content of fat in the raw milk and the fat content aimed at in the final powder. Standardizing tanks equipped with agitators are in most cases used, but other methods are also recommendable.

As the fat content in the raw milk in practically all cases is too high when producing whole milk powder, skim milk powder is sometimes used for standardizing. The equipment needed is an in-line powder/liquid blender known from recombining plants. As the solids content will increase by adding skim milk powder, the evaporator should be designed accordingly.

For an accurate determination of the fat in whole milk powder the Rose-Gottlieb method is used and for a quick determination the Gerber method is used.

**Surface Free Fat**

In whole milk powder the fat is present as fine globules covered with a membrane substance and distributed evenly in the particles. However, not all the fat is protected by a membrane, especially on the surface of the particle, but it is also found inside the particles. This type of fat is termed Free Fat, and it will have a direct influence on the shelf-life of the powder and is directly responsible for the non-wet able surface when the powder is mixed with cold water.

Free fat in the whole milk powder cannot be avoided but reduced considerably. This is done by:

- Avoiding excessive pumping and agitation of the raw uncondensed milk. Recirculation in the evaporator should be avoided by all means.
- The pasteurization of the milk prior to the evaporator plays a role. Direct pas-teunzation, especially at low temperature, results in low viscosity of the concentrate and a fine atomization with a big surface to mass ratio leading to increased free fat content.
- The free fat is most efficiently reduced by homogenization of the concentrate, preferably in a two-stage homogenizer. In the first stage a pressure drop of 70-100 kg/cm2 is applied. The fat globules will disintegrate into small globules which might - due to static electricity - agglomerate again, i.e. they will consist of many small fat globules. In the second stage a pressure drop of 25-50 kg/cm2 is applied breaking up above mentioned agglomerates.

- It is a general rule that nozzles produce a powder with a lower free fat content than with the wheel, mainly due to the homogenization effect of the nozzle.
- Any strong mechanical handling of the powder should be avoided, and then it is not astonishing that the two-stage drying gives a powder with a lower free fat content than the one-stage drying.
- In plants with integrated fluid beds the free fat will increase, if the bed temperature is too low signifying too high moisture content in the powder which results in lactose crystallization, where production of whole milk powder with high free fat used in the chocolate industry is discussed.

To determine the free fat in the powder 50 ml of petroleum ether and 10 g of powder are mixed slowly for exactly 15 min. The mixture is filtrated and 25 ml of the filtrate is evaporated, the residue weighed and the free fat percentage is calculated either based on total fat or more commonly based on the powder.

In another method for determination of the free fat toluene is used, and the extraction time is sometimes as long as 24 hours. The result will naturally be different from that obtained by the above method.

It is generally accepted that the first method gives results representing the surface free fat, whereas the other methods represent the total free fat, i.e. aiso what is inside the pores and capillary network.

**Wet ability**

The wet ability is a measure for the ability of a powder to be wetted with water at a given temperature. **This analytical method is only used when producing instant powders.** It is obvious that the wet ability depends on the surfaces of the agglomerates or single particles - are they water repellent or will they absorb water too quickly thus forming a film through which the water cannot penetrate.

Generally speaking, **wetting is a process in which the gaseous phase at the surface of the solid phase is replaced by a liquid phase,** all three phases coexisting for some time, so that a certain amount of intermixtures and solutions (mainly of the solid and the liquid phase) is not only possible but usually unavoidable.

Besides this, milk powder must be considered as a composite surface with the separately enclosed surfaces connected by more or less stable 'bridges' to form a complex capillary network. For simplification, let us first discuss the mechanism of wetting a single surface.

The factor deciding if there will be any wetting at all is the interfacial **tension** between the particle surface and the water**.** Skim milk powder particles will usually be wetted easily (provided there is less than 0.03% fat on the surface), as the powder material is mainly lactose being in an amorphous phase and protein, both absorbing water readily. However, whole milk powder particles are always covered by a layer of fat, making them water repellent. The amount of this surface free fat varies between 0.5 and 3% of the powder.

This water repellence of the particles caused by their fat coating may be overcome, and an interfacial tension facilitating the wetting may be achieved by adding a surface active agent to the surface free fat. It has been known for years that phospholipids such as lecithin are well suited for this purpose. Lecithin has the advantage of being a natural product and even a natural component of milk, and being both lipophilic and hydrophilic it is able to absorb water.

When the particles have been wetted, the individual components of the milk powder start dissolving and dispersing, thus forming a concentrated solution of milk around the particles. At the same time the particles start sinking to the bottom, but it should be mentioned that, in order to make the particles sink, the density of the particles has to be greater than that of the water.

The density of a particle depends on its composition and amount of occluded air. During the first stages of reconstitution the density of the particles decreases, mainly because the lactose and the minerals, which are the heaviest milk components, start dissolving faster than the other components. At the same time, the density of the solution being formed is increased because of the dissolving lactose, so that the difference between the densities of the particles and of the surrounding liquid is reduced. The particle density may even become the same or lower than that of the liquid, so that, after the initial sinking, the particles start to rise again. Thus to prevent this, the particle density should be high, i.e. the content of occluded air should be low.

The reconstitution of a mass of powder is more complicated. As already mentioned, powder is a composite surface with a greatly ramified system of capillaries of various dimensions and a complicated geometrical pattern thus having different capillary attraction effects.

Under these conditions there will be wetting not only on the surface of the water, but also of particles lying above the surface, as the water is drawn toward them by capillary attraction. This replacement of interstitial air by water through capillary penetration is very often incomplete, as the amount of penetrating water is insufficient, thus leaving air bubbles between the wetted particles. In this way we have all three phases going on simultaneously, resulting in the coexistence of their products of varying concentrations. This coexistence is very dangerous, because after a short time the space between the particles will be filled with miik of different, including high, concentrations. This results in a sticky jelly with islands of unwetted powder and residual air. Furthermore, lumps, that are wet and swollen outside and dry inside, are created. As these are impervious to water, their complete reconstitution is extremely difficult even with strong agitation.

To obtain a fully reconstituted milk in a reasonably short time and with minimum effort, capillary penetration of water into the powder must therefore be avoided. The capillary effect depends on the structure of the powder, i.e. the size of the agglomerates, the size and the amount of non-agglomerated particles, the amount of interstitial air and the specific surface area of the powder. Penetration of water into the powder is easily avoided/delayed - to allow dispersion before dissolution - when the powder consists of large agglomerates.

**The analytical method is simple and easy to perform:**

10 g skim milk powder or 13 g whole milk is poured into 100 ml water at a given temperature, usually 20°C ± 2°C. The time required for all the powder to be wetted is measured by means of a stop watch. IDF prescribes the use of 10 g skim milk or whole milk powder in 250 ml water at a temperature of 25°C.

Skim milk powder should be wetted within 15 sec. to be termed instant. For whole milk powder there is no requirement, but many producers of instant whole milk powder manufacture the powder to the same standard as valid for the skim milk powder. However, for the subsequent dispersing process, especially for whole milk powder, it is advantageous that the wettability is about 30-60 sec., as it eases the subsequent dispersion of the powder into the water

**Dispersibility**

**Another important property of instant powders is the ability to disperse in water by gentle stirring.** This means that the powder should disintegrate into agglomerates which again should disintegrate into the single primary particles.

To obtain a good dispersibility of a powder it is necessary that the powder is wettable and that the agglomeration is optimal, i.e. no fine particles should be present.
The analytical method is very difficult to define and perform and the reproducibility is very poor. There are numerous methods, and the results cannot be compared.
Being aware of that, IDF has developed a new dispersibility test. This test is based on determining the capability of a powder (25 g of skim or 34 g of whole milk powder) being poured on a surface of water (250 g, 25°C) to disintegrate into particles capable of passing through a 150-micron sieve when applying the prescribed manual stirring for 20 sec. The amount of powder passing the sieve and being dissolved or dispersed is found by the determination of total solids of the filtrate and expressed in percentage as dispersibility.
The powder is considered instant by IDF, if the dispersibility is at least 85% (whole milk) or 90% (skim milk). However, plants with new drying technology easily produce powders with a dispersibility of 95%.

There is no doubt that this test presents a more reliable basis for assessment of instant milk powders than the wettability test. On the other hand, it is a test requiring relatively high expenditure of work, so it can hardly be used as a routine test. Besides, even when using skilled workers the reproducibility is rather poor.

A more simple method is to pour 10 g of skim milk powder or 13 g of whole milk powder into 100 ml of water at room temperature and then manually stir with a teaspoon until the powder is dispersed leaving no lumps on the bottom of the glass. The time used is measured by means of a stop watch.

After some training the reproducibility is fairly good, and the method is quick. Furthermore, it has the supreme advantage that it is just what the housewife does when she wants to prepare a glass of milk.

### Sludge

Similar to the IDF dispersibility (used only for instant cold-water soluble whole milk), but only 12.5 g powder in 100 ml water at 25°C and 85°C is used. The sieve used is 600-micron. The residue on the sieve after filtration is weighed and recorded

### Slowly Dispersible Particles (SDP)

The same procedure as for Sludge is used. After filtration through the 600-micron sieve the milk is poured into a test tube which is emptied again immediately. The remaining film with undissolved particles/agglomerates is compared with a photograph 5-grade scale. The SDP is determined in both 25°C and 85°C warm water. The remedy to tmprove the SDP value is agglomeration

### Hot Water Test

Similar to the Sludge test using 85°C. The reconstituted filtered milk is poured into two graduated conical centrifuge glasses, similar to what is used for the Insolubility Index, and spun in a centrifuge for 5 min. The result is expressed in ml sediment from the two glasses added together. The result should preferably be <0.2 ml.

### Coffee Test

Similar to Hot Water Test, but using coffee at 85°C. Like SDP, and the Hot Water Test, the result is determined by the degree of agglomeration, but for the coffee test also the pasteurization of the milk prior to the evaporation (80-85°C in 15 sec. with WPNI * 3 mg/g), the content of Ca++ and total protein content is important.

With high content of proteins in the milk (Jersey cows or milk from low season) it is difficult to produce powders with a good coffee test, which should be <0.4 ml. Standardizing the milk with lactose or permeate to adjust the protein content is used in the industry. Concentrate preheating to 80°C and/or addition of phosphates and/or citrates to precipitate the ionic Ca can be used as well.

### Rate of Hydration

When the powder particles are dispersed evenly in the water they start to dissolve. Usually, the dissolution starts already at the very first contact with water, and the wetting, dispersing and dissolving or hydration take place simultaneously. **The ability of a powder to dissolve completely is expressed in the Insolubility Index** (see page 203). However, this method requires a rather strong mechanical agitation followed by up to 15 min. standing, while the idea of instant powders is to present to the consumers the possibility of preparing reconstituted milk in a short time by means of gentle, manual stirring. The reconstitution procedure used by the consumer is supposed to correspond to the one used at the above dispersibility test. At this stage, however, the powder may be dissolved only partly.

To fill this gap between the two methods a modified solubility test for the determination of the rate of hydration, especially for instant whole milk powder, can be applied. In this method 0.5 g of powder is poured into 50 ml of water in an ordinary solubility index glass. The glass is turned upside down 8 times after which it is spun in a centrifuge for 5 min. The resulting sediment is used in the calculation of the rate of hydra-tion:

**Rate of hydration** = (ml sediment x 12) - Insolubility Index (22)

## Chapter # 2

# Process for the Production of Powder Milk

## 2.1 MILK POWDER

Milk powder manufacture is a simple process now carried out on a large scale. It involves the gentle removal of water at the lowest possible cost under stringent hygiene conditions while retaining all the desirable natural properties of the milk - color, flavor, solubility, nutritional value. Whole (full cream) milk contains, typically, about 87% water and skim milk contains about 91% water. Dung milk powder manufacture, this water is removedby boiling the milk under reduced pressure at low temperature in a process known as evaporation. The resulting concentrated milk is then sprayed in a fine mist into hot air to remove further moisture and so give a powder. Approximately 13 kg of whole milk powder (WMP) or 9 kg of skim milk powder (SMP) can be made from 100 L of whole milk. New Zealand manufactures a wide range of spray dried milk powders (> 100) to meet the diverse and special needs of customers. Milk powders may vary in their gross composition (milkfat, protein, lactose), the heat treatment they receive during manufacture, powder particle size and packaging. Special "high heat" or "heat-stable" milk powders are required for the manufacture of certain products such as recombined evaporated milk. Milk powders of various types are used in a wide range of products such as baked goods, snacks and soups, chocolates and confectionary *(e.g.*milk chocolate), ice cream, infant formulae, nutritional products for invalids, athletes, hospital use *etc.,* recombined milks and other liquid beverages.

### INTRODUCTION

Marco Polo in the 13th century reported that soldiers of Kublai Khan carried sun- dried milk on their expeditions. In more recent times, milk has been dried in thin films on heated rollers.

The earliest patents for this process date from the turn of the century. Such roller drying was the main means of producing milk powders until the 1960s when spray drying took over. Milk powder manufacture is now very big business. New Zealand produced and exported over 450 000 tons of milk powder during the 1993/94 dairying season, earning in excess of NZ$1 billion.

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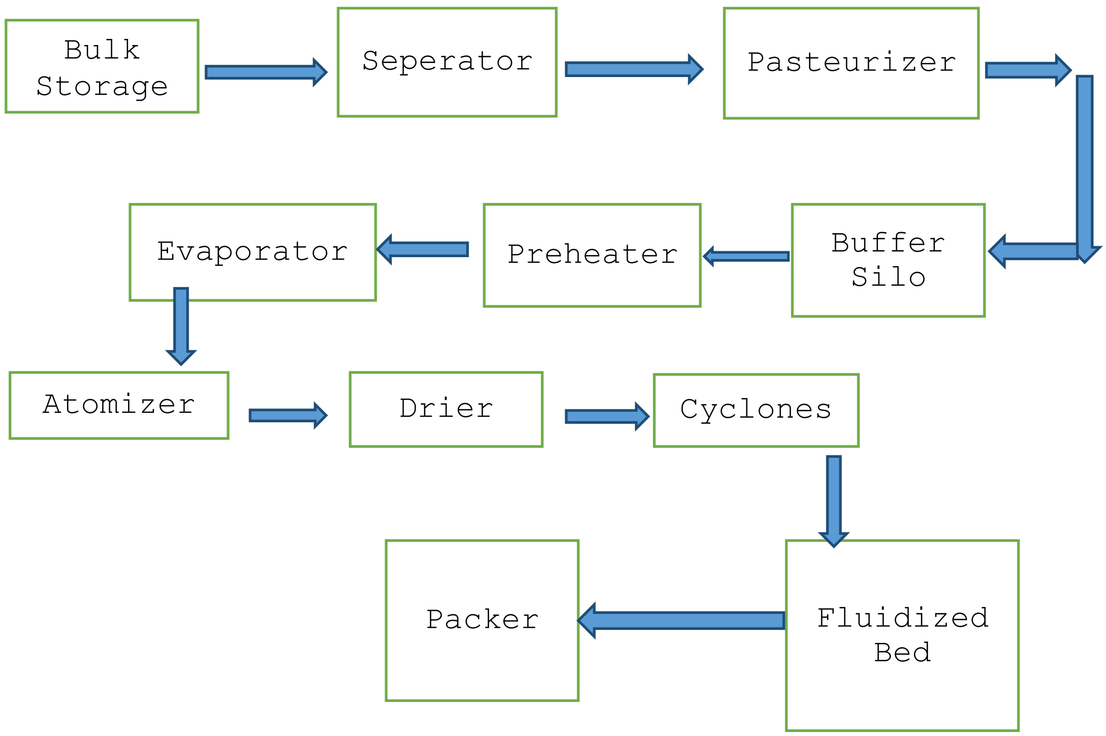
## 2.2 Process Flow Sheet




## 2.2 SEPARATION / STANDARDIZATION

The conventional process for the production of milk powders starts with taking the raw milk received at the dairy factory and pasteurising and separating it into skim milk and cream using a centrifugal cream separator. If WMP is to be manufactured, a portion of the cream is added back to the skim milk to produce a milk with a standardised fat content (typically 26- 30% fat in the powder). Surplus cream is used to make butter or anhydrous milkfat.

Cream Separation have following steps

**Centrifugation**
Centrifugal separation is a process used quite often in the dairy industry. Some uses include:

- clarification (removal of solid impurities from milk prior to pasteurization)
- skimming (separation of cream from skim milk)
- standardizing
- whey separation (separation of whey cream (fat) from whey)
- bactofuge treatment (separation of bacteria from milk)
- quark separation (separation of quarg curd from whey)
- butter oil purification (separation of serum phase from anhydrous milk fat)

**Principles of Centrifugation**

Centrifugation is based on *Stoke's Law.* The particle sedimentation velocity increases with:

- increasing diameter
- increasing difference in density between the two phases
- decreasing viscosity of the continuous phase

If raw milk were allowed to stand, the fat globules would begin to rise to the surface in phenomena called **creaming.** Raw milk in a rotating container also has centrifugal forces acting on it. This allows rapid separation of milk fat from the skim milk portion and removal of solid impurities from the milk.

**Separation**
Centrifuges can be used to separate the cream from the skim milk. The*- centrifuge consists of up to 120 discs stacked together at a 45 to 60 degree angle and separated by a 0.4 to 2.0 mm gap or separation channel. Milk is introduced at the outer edge of the disc stack. The stack of discs has vertically aligned distribution holes into which the milk is introduced.

Under the influence of centrifugal force the fat globules (cream), which are less dense than the skim milk, move inwards through the separation channels toward the axis of rotation. The skim milk will move outwards and leaves through a separate outlet.
Pasteurization kills many harmful microorganisms by heating the milk for a short time and then cooling it for storage and transportation. Pasteurized milk is still perishable and must be stored cold by both suppliers and consumers. Dairies print expiration dates on each container, after which stores will remove any unsold milk from their shelves. In many countries it is illegal to sell milk that is not pasteurized.

Milk may also be further heated to extend its shelf life through ultra-high temperature treatment (UHT), which allows it to be stored unrefrigerated, or even longer lasting sterilization. Those preferring raw milk argue that the pasteurization process also kills beneficial microorganisms and important nutritional constituents. The resulting pasteurized product is said to contribute to its own indigestibility, be less nutritious, and turn rancid (as opposed to sour) with age. However, unpasteurized milk can harbor harmful disease-causing bacteria such as tuberculosis, salmonella, diphtheria, polio, and Escherichia coli.

## 2.5 PREHEATING

The next step in the process is "preheating" during which the standardized milk is heated to temperatures between 75 and 120 C and held for a specified time from a few seconds up to several minutes (cf. pasteurization: 72_C for 15 s). Preheating causes a controlled de naturation of the whey proteins in the milk and it destroys bacteria, inactivates enzymes, generates natural antioxidants and imparts heat stability. The exact heating/holding regime depends on the type of product and its intended end-use. High preheats in WMP are associated with improved keeping quality but reduced solubility. Preheating may be either indirect (via heat exchangers), or direct (via steam injection or infusion into the product), or a mixture of the two. Indirect heaters generally use waste heat from other parts of the process as an energy saving measure.

## 2.6 EVAPORATION

In the evaporator the preheated milk is concentrated in stages or "effects" from around 9.0% total solids content for skim milk and 13% for whole milk, up to 45-52% total solids. This is achieved by boiling the milk under a vacuum at temperatures below 72_C in a falling film on the inside of vertical tubes, and removing the water as vapor. This vapor, which may be mechanically or thermally compressed, is then used to heat the milk in the next effect of the evaporator which may be operated at a lower pressure and temperature than the preceding effect. Modern plants may have up to seven effects for maximum energy efficiency. More than 85% of the water in the milk may be removed in the evaporator. Evaporators are extremely noisy because of the large quantity of water vapor travelling at very high speeds inside the tubes.

## 2.7 SPRAY DRYING

Spray drying involves atomizing the milk concentrate from the evaporator into fine droplets. This is done inside a large drying chamber in a flow of hot air (up to 200_C) using either a spinning disk atomizer or a series of high pressure nozzles. The milk droplets are cooled by evaporation and they never reach the temperature of the air. The concentrate may be heated prior to atomization to reduce its viscosity and to increase the energy available for drying.

Much of the remaining water is evaporated in the drying chamber, leaving a fine powder of around 6% moisture content with a mean particle size typically of < 0.1 mm diameter. Final or "secondary" drying takes place in a fluid bed, or in a series of such beds, in which hot air is blown through a layer of fluidized powder removing water to give product with a moisture content of 2-4%. Precautions must be taken to prevent fires and to vent dust explosions should they occur in the drying chamber or elsewhere. Such explosions can be extremely dangerous to life, property and markets.

## 2.8 LEVEL MEASUREMENT IN THE MILK POWDER SILO

Milk powder is the basic material of food production and is stored in high stainless steel silos. The consistency, fat and moisture content of the powder depends on the drying process and the milk composition. VEGAFLEX 62 is particularly suitable for this application because the guided microwave is independent of the product composition. Dust generation and build-up on the mounting socket have no affect on the measurement. To determine the maximum filling level, a vibrating level switch is installed in the vessel. The principle of the single rod prevents build-up, which can cause problems for traditional tuning fork switches. The device provides reliable level detection no matter how low the bulk density or what the product.

## 2.9 FLUID1ZED BED

A powder layer is vibrated on an air distributor plate. The effect of this vibration combined with the upward and forward directed flow of air through the plate creates ideal processing conditions and powder transport.

The unit operates with a shallow powder layer of less than 200 mm. This gives a much more lenient powder treatment, since powder residence times are shorter than in non-vibrating fluid beds which operate at much deeper powder layers. The VIBRO-FLUIDIZER® is successfully used on all types of powders, agglomerates, and granulates, especially those which fluidize poorly due to a broad particle size distribution or highly irregular particle shape, or require relatively low fluidization velocities to prevent attrition.

The VIBRO-FLUIDIZER® can be operated as a separate drying or cooling unit. It is often associated with a spray drying system to produce agglomerated instant powder or act as a powder conditioning plant for special coating operations.

### DESIGN FEATURES

**Air Distributor Plates**

Even and stable distribution of the fluidizing air is a prerequisite of sustained operation. Niro has developed its own patented distributor plates to obtain optimum fluidization and powder movement during operation and to prevent powder penetration through the plate on plant shutdown.

**Bubble plate**

The BUBBLE PLATE™ is the latest development by Niro in food grade fluid bed technology. It is non-sifting, i.e. does not allow heat sensitive products to fall through the plate perforations.The plate controls powder movement by means of the airflow. It has no surface imperfections and has been accepted by USDA.

**T-Profile Welding**

The stiffening T-profiles, used internally where the plates are welded on to the VIBRO-FLUIDIZER® wall housing and externally around the housing, comply with the radiirequirements of the 3A standards.

**Plate Stiffening**

The fully welded air distributor plate of 2 mm is supported underneath with stiffening profiles of special design according to sanitary requirements.

## 2.10 PACKAGING AND STORAGE

Milk powders are immensely more stable than fresh milk but protection from moisture, oxygen, light and heat is needed in order to maintain their quality and shelf life. Milk powders readily take up moisture from the air, leading to a rapid loss of quality and caking or lumping. The fat in WMPs can react with oxygen in the air to give off-flavours, especially at higher storage temperatures (> 30_C) typical of the tropics. Milk powder is packed into either plastic-lined multiwall bags (25 kg) or bulk bins (_ 600 kg). WMPs are often packed under nitrogen gas to protect the product from oxidation and to maintain their flavour and extend their keeping quality. Packaging is chosen to provide a barrier to moisture, oxygen and light. Bags generally consist of several layers to provide strength and the necessary barrier properties. Shipments of milk powder should never suffer prolonged exposure to direct sunshine especially in tropical countries. A few hours at elevated temperatures (> 40_C) during transshipment can negate many weeks of careful storage.

**AGGLOMERATED POWDERS**

Standard powders, because of their fine dusty nature, do not reconstitute well in water. "Agglomerated" and "instant" powders were specifically developed to counter this. The manufacture of an agglomerated powder initially follows the standard process of evaporation and drying, described above. However, during spray drying small particles of powder leaving the drier (the "fines") are recovered in cyclones and returned to the drying chamber in the close proximity of the atomizer. The wet concentrate droplets collide with the fines and stick together, forming larger (0.1-0.3 mm), irregular shaped "agglomerates". Agglomerated powders disperse in water more rapidly and are less dusty and easier to handle than standard powders.

## 2. 11 ENERGY AND ENVIRONMENTAL CONSIDERATIONS

Large amounts of energy are expended in the process of removing water and so plants developed over the years have become increasingly more energy efficient. Evaporators are much more energy efficient than driers, using only a fraction of a kilogram of steam (or the energy equivalent) per kilogram of water removed. Driers on the other hand use several kilograms of steam (or steam equivalent) per kilogram of water evaporated. Spray drying provides a means of rapidly and gently removing the bulk of the remaining water but, ideally, spray driers have short residence times. Hence fluid beds are used for the final stages of drying. The powder remains for several minutes in fluid beds allowing time for the last of the water to be removed.

Milk powder manufacturing plants tend to be very large, few in number and located in rural areas. If modern and well managed, they have only relatively small effects on the environment. They are moderately energy intensive, burning coal or gas and consuming substantial electricity. There are strong economic pressures to reduce energy consumption but there is little scope for further major improvement. Milk storage silos, cream separators and the evaporators and associated plant must be cleaned daily, and driers less often. Sodium hydroxide and nitric acid are used as cleaning agents. The spent cleaning fluids must be disposed of by suitable means. There can be emission of milk powder dust into the local environment during plant malfunctions but this is rare. Noise is a problem mainly within the plant buildings but fans can affect close neighbors. Unbleached paper and plastic laminate packaging must be disposed of in overseas markets.

**APPLICATIONS**

New Zealand manufactures a wide range of spray dried milk powders (> 100) to meet the diverse and special needs of customers. Milk powders may vary in their gross composition (milkfat, protein, lactose), the heat treatment they receive during manufacture, powder particle size and packaging. Special "high heat" or "heat stable" milk powders are required for the manufacture of certain products such as recombined evaporated milk. Some powders are agglomerated and they may be instantised for easy use in the home. Instant powders must wet, sink and disperse quickly, with minimal stirring, when added to water. The resulting liquid should closely resemble fresh milk and be free from undissolved particles. Some powders are fortified with vitamins and minerals. It is yery important to use a powder suited to the intended application. Milk powders of various types are used in a wide range of products including the following.

- Baked goods, snacks and soups
- Cheese milk extension (powder is added to local fresh milk to increase the yield of cheese)
- Chocolates and confectionery (e.g. milk chocolate)
- Dairy desserts
- Direct consumer use (home reconstitution)
- Ice cream
- Infant formulae
- Nutritional products for invalids, athletes, hospital use *etc.* Recombined "fresh", UHT, evaporated and sweetened condensed milks
- Recombined cheeses, mainly "soft" or "fresh"
- Recombined coffee and whipping creams
- Recombined yoghurts and other fermented products

**ATOMIZER**

**A device for producing fine droplets of liquid. Usually either a high pressuie nozzle or a perforated spinning disk through which the liquid is pumped.** Concentrate Milk concentrated by evaporation, typically containing around 48% total solids.

**Cyclone**
A device for separating air and powder particles.
**Effect**
A single unit in an evaporator operating at a particular pressure and temperature. Evaporators commonly have three to seven effects to allow heat to be reused several

times.

**Fluid bed**
A piece of equipment used for drying or cooling milk powder. Air is blown through the powder from below, causing the powder particles to separate and behave rather like a fluid. Alternatively, a layer of fluid-like powder in which the particles are kept apart by an air flow.

**Recombined**
Liquid milk or other "fresh" product made by mixing skim milk powder, milkfat, water and possibly other components. **Reconstituted** Liquid milk or other "fresh" product made by mixing milk powder and water.

# Chapter # 3

# Material & Energy Balance

**Task - given data**

A daily output of a milk powder is 20 t/d. Both dryer and evaporator work in a day cycle 20 h operation and 4 h chemical cleaning (CIP = cleaning in place). A milk heater is designed as a double heater. It means that one part operates as a heater / cooler and the second part is cleaned. In this way it is able to work 20 h like the evaporator.

Dry matter of incoming milk is 12 %, incl. fat content 4 %. In a separator is the fat separated, so that to the evaporator flows milk with the fat content c. 0 % (dry matter of skimmed milk is c. 8 %). In the fourth effect evaporator is the skimmed milk concentrated to 45 % DM and in the spray drier is dried to 97 % DM. Dry matter of cream from the separator is 40 %.

Milk specific heat is $C_{PM}$ = 3.9 kJ/kgK and from reasons of simplification it is not taken into account its dependence on temperature and milk concentration. We will calculate with a heat recuperation during milk heating and cooling (pasteurized hot milk will heat incoming cold milk in a regeneration section). Thus energy for milk heating and cooling is saved. Incoming milk temperature is 10 °C, pasteurization temperature is 80 °C, and outlet milk temperature is 10 °C. The separator is between regeneration and pasteurization sections (lower amount of milk).

According evaporator technical specifications (TS) is a specific steam consumption d= 0.28 kg steam/kg E.W. (related to a total amount of evaporated water). Boiling temperature in a 1st effect is 70 °C, heating (condensing) steam temperature in the 1st effect is 80 °C. Heat in superheated milk (+) and heat losses (-) are neglected.

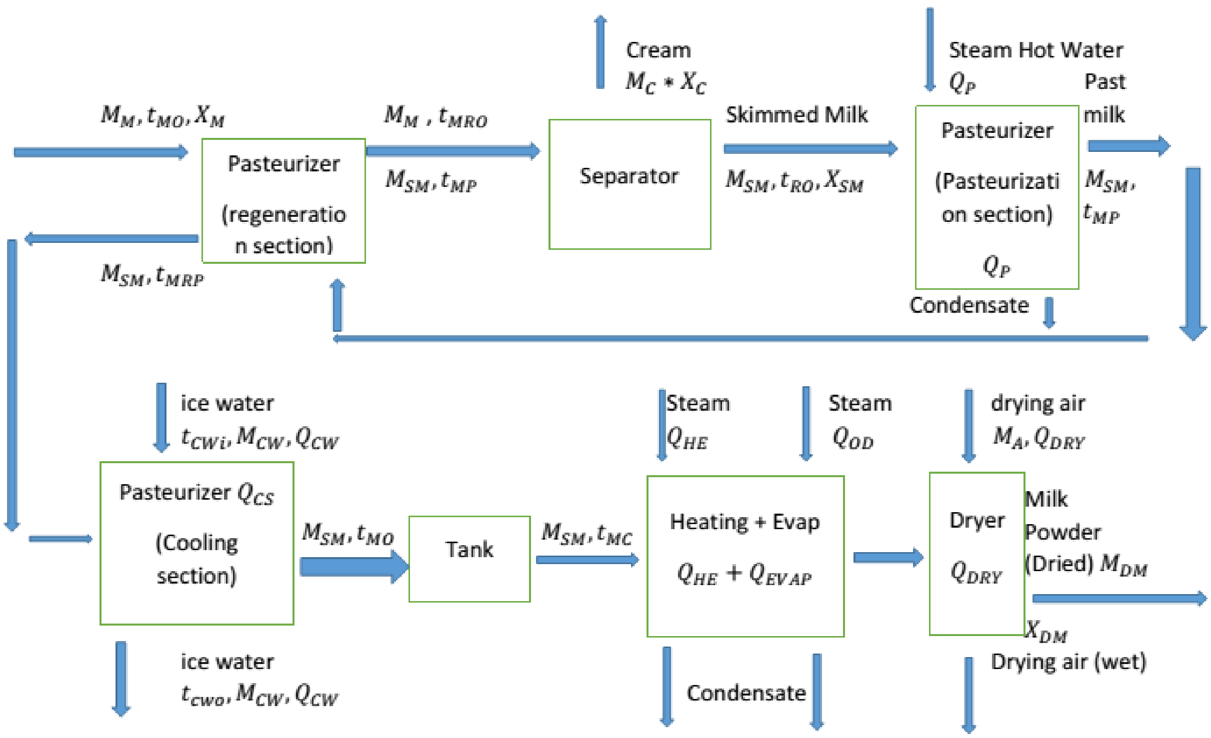
According dryer technical specifications is heat consumption in such drier c. twice as a theoretical one (calculated from a balance of dried water in h - x diagram). Aims = To calculate, design and set:

1. A technological scheme of the line (flow sheet) with single flow identifications
2. Daily amount of milk incoming to the line and amount of cream leaving separator. Specification of a line mass balance.
3. Consumption of energy of the line (thermal energy for heating or cooling, electric energy for pumps and fans.

### 3.2 Flow sheet Line for Dried Milk Production

Note: - A regeneration section is usually divided into 2 sections. Between them are installed a separator (centrifuge) and a hornogeniser (in a case of long-life drink milk production).

- Sections of regeneration, pasteurization and cooling are in one apparatus (in1 stand).
- By reason of simplification is the milk heating before the evaporator drawn in 1 block with the evaporator (in reality there are several steps of the milk heating; step by step with vapors from the evaporator.



## 3.3 Mass line balance

Given data:

| | |
|---|---|
| | $M_{QM}$= 20 t/d - |
| Dry matter of iniet milk | 20 t/20 h = 1.0 t/h |
| Amount of milk powder | |
| Dry matter of conc. milk Dry matter of milk powder | $x_M$ 12 % DM |
| | $X_{CM}$ = 45 % DM |
| | $X_{DM}$ = 97 % DM |
| | (moisture 3 %) |
| Dry matter of cream | $x_c$ = 40 % DM |
| | (incl. fat) - mostly fat |
| Dry matter of skimmed milk | $X_{sm}$ = 8 % DM |

For our solution the conservation of mass law is used. It is that the amount of inlet mass has to be equal to the amount of outlet mass (in a line or apparatus or process). This is concerned of single components too (dry matter, water, fat etc.).

*DM. of inlet milk = fat + milk sugar (lactose) + proteins*

*(Casein) + Mineral matters*

We suppose that all fat is separated (separation "sharpness" is c. 0,01 %) and that the amount of dry matter and water in the cream does not affect the skim milk dry matter too much. The simplification is done by reason of shortening of the long example.
We have to do the mass and dry matter balance of the line to calculate the amount of inlet milk. For the calculation we can use following figures.

DM = proteins + lactose + ...?.

**fresh inlet milk**
(*xmd* = dry matter without fat)
($X_M = X_{MS} + X_{FM}$)

**skim milk** - after cream separation >
(fat is separated - cream = Me)
cream = fat + proteins + lactose + water + ...
. DM'< DM

**concentrated milk** - after evaporation (part of water is evaporated - WEVAP)

**dried milk (milk** powder)~after drying (part of water is dried off - WDRY)

It follows from the figures that the amount of DM in milk is constant during processes of evaporating and drying. This makes possible to do the mass line balance. It is valid that:

$$M_{SM} * X_{SM} = Mew * X_{CM} = M_{DM} * X_{DM}$$
amount of DM in SM, CM, DM = const.

Amount of skim milk after the separator (= before the evaporator and in pasteurisation and cooling sections too).

$$Msm = M_{dm} * xdm / x_{SM} = 1.0 *97/8 =12.125 \text{ t/h}$$

**Amount of concentrated milk**

$$M_{CM} = M_{DM} * x_{DM} / x_{CM} = 1.0 * 97 / 45 = 2.156 \text{ t/h}$$

**Amount of evaporated water in the evaporator**

$$Wb/ap = M_{sm} - Mcm = 12.125 - 2.156 = 9.969 \text{ t/h}$$

**Amount of water dried off in the dryer**

$$Wqry = Mcm - M_{D}m = 2.156 - 1.000 = 1.156 \text{ t/h}$$

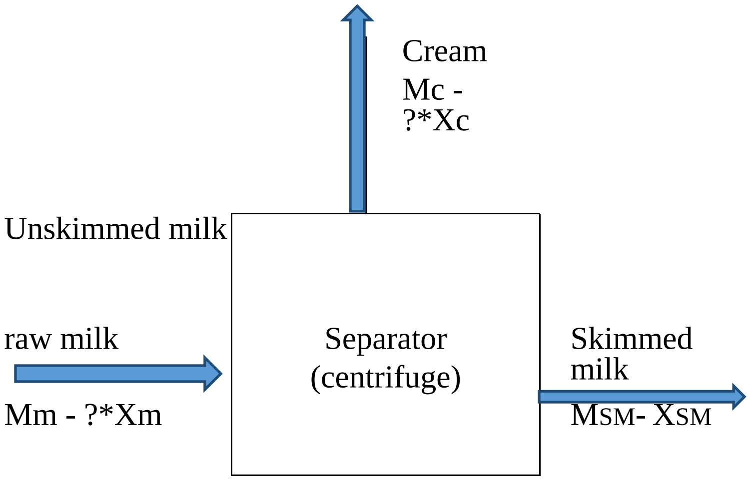
## 3.4 Fat and milk balance in separator

Note: Fat is concerned as DM

$x_M$ = 12 % DM raw milk
Xsm = 8 % DM skim
milk xc = 40 % DM
cream *Msm* = 12.125 t/h

$$M_M = M_{SM} + M_c$$
mass balance

$$M_M * X_M = M_{SM} * x_{SM} + M_C * x_C$$
DM balance




By substitution of given and calculated data in the 2 equations we specify amount of By substitution of given and calculated data in the 2 equations we specify amount of cream and amount of unskimmed raw milk incoming to the line.

$$M_M = M_c + 12.125$$

$M_M$ M2 $= M_c * 40 + 12.125 * 8 = M_c *40 + 97.0$

$(M_c+12.125) *12 = M_c *40 + 97.0$
$M_c = (12.125 * 12 - 97.0) / (40 - 12) = 1.732$ t/h amount of cream leaving the line

$M_M = M_{SM} + Me = 12.125 + 1.732 = 13.857$ t/h amount of unskimmed milk entering the line = fresh milk

Daily milk consumption is then (20 h operation + 4 h chem. cleaning)

**Mmd = 13.357 * 20 = 277.1 t/d**

Dry mass balance checking

13.857*0.12 = 1.663 t/h DM inlet to separator
1.732*0.40+ 12.125*0.08 = 1.663 t/h DM outlet from separator

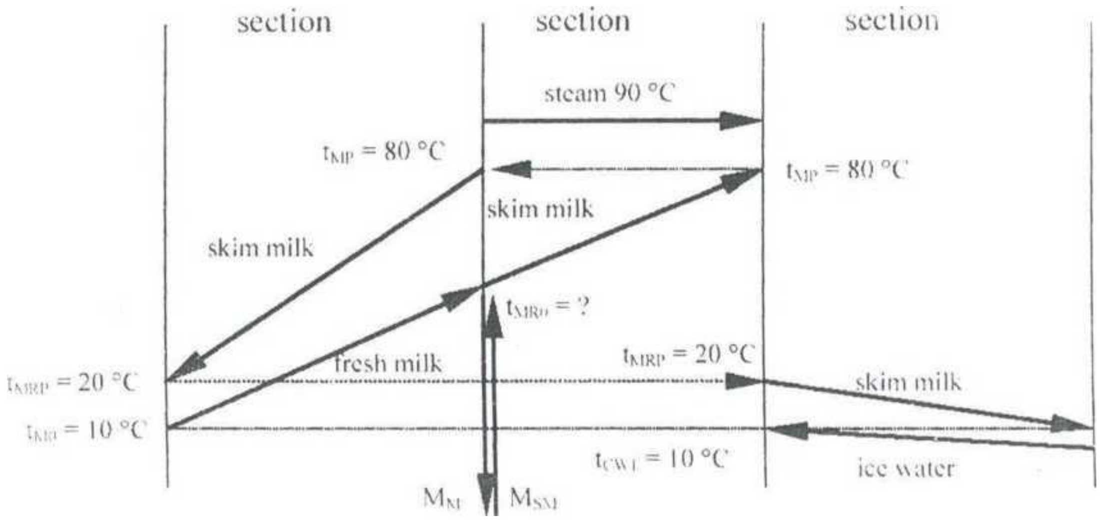
## 3.5 Energy consumption of line

For determination of an energy consumption of the line we have to do an energy balance of all parts of the line. We will use a principle of conservation of energy

**Thermal balance of pasteuriser**

We suppose that the temperature difference between outlet temperature of cooled skimmilk and inlet temperature of inlet fresh milk is 10 °C (it depends on HE quality). A temperature
course in regeneration, pasteurisation and cooling sections is in the next figure.

Note: In following balances units frequently used in praxis are used (i.e. kg/h, t/h etc. instead of SI units).

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## 3.6 <u>Thermal balance of regeneration section</u>

Firstly we have to specify a milk temperature after this section. Specifics heat ofwhole and skimmilk is c. 3,9 kJ/kgK (simplification - sec above - for 15 °C and whole milk is 3,94 kJ/kgK, for skim milk is 3,96 kJ/kgK, for both milks with higher temperature slightly falls). Heat losses are neglected too. Than is:

$$t_{MC} = 10 M_{SM}$$
$$t_{CW} = 5. M_{CW}$$

$Q_{REG\ HEAT} = Q_{REG\ COOL}$

$M_M * C_M$ ^ (tMRo - tMo) $^=M_{SM} * C_M$ * (tMP - tMRp)

13.857 * 3.9 * ($t_M$Ro - 10) = 12 125 * 3.9 * (80 - 20)

$t_{MRO}$ = (12.125 * 60 + 13.857 * 10) / 13.857 = 62.5 °C

Milk temperature after regen. Preheating Checking

*QREGheat* = 13857 * 3.9 * (62,5 - 10) / 3600 = 788.1 kW *Qregcooi* = 12125 * 3.9 * (80 - 20) / 3600 = 788.1 kW

For next calculation we specify a mean logarithmic temperature difference.

**$t_{LREQ}$= ((80 - 62.5) - (20 - 10)) / In ((80 - 62.5) / (20 - 10))= 13.4 °C**

It is a simplification for our example. In practice there are installed 2 regeneration sections.

1° heats milk to a temperature proper for fat separation alternatively for homogenization, 2° heats milk to max. Possible temperature before pasteurization section (energy economy).

### 3.7 Heat needed for milk heating in pasteurisation section

Milk inlets to the section with the temperature of 62.5 °C (we neglect a temperature drop during the fat separation) and has to be heated to pasteurization temperature 80 °C. With the temperature it flows to a holder (unheated tube or interpolate channels), where it flows for a given time. Then it flows back to the regeneration section and heats fresh milk. Similar like in the previous we made the thermal balance.

$Q_p = Q_{past} = M_{SM} * C_M * (t_{MP} - t_{MRO})$
$Q_P = 12125 * 3.9 * (80.0 - 62.5) / 3600 = 229.9$ kW
$= 229.9*3600*20/106 = 16.55$ GJ/d

The past, section can be heated with condensing steam or recirculating hot water that is heated with steam injecting into water. If we neglect heat losses is the steam consumption for both cases the same. We suppose steam with pressure 100 kPa - abs. ($r_P = 2258$ kJ/kg).
Then it is for milk pasteurization necessary amount of steam:

$M_{SP} = Q_P / r_P = 229.9 * 3600 / 2258 = 367$ kg/h

### 3.8 Heat taken awav in cooling section from milk

$Q_{cs} = M_{SM} * C_M * (t_{MRP} - t_{MC})$
$Q_{cs} = 12125 * 3.9 * (20 - 10) / 3600 = 131.4$ kW
$= 131.4*3600*20/106 = 9.46$ GJ/d

**Determination of heat regeneration ratio in pasteurizer - HRR**

The ratio says us how many % of heat fed in the pasteurizer is reused for heating in the regeneration section. Formerly the ratio was above 85 %, nowadays it is more than 95 %. The higher ratio the lower energy consumption (heat and cold) but we need a greater heat transfer area (economical comparison of energy and material costs). For the same milk amount, specific heat and negligible heat losses it is possible to simplify the ratio to the following relation.lt contains only known temperatures and it is possible to use it for approximate determination of HRR.

HRR - Qreused / Qfed $=(t_{MP} - t_{MRP}) \, I \, (t_{MP} - t_{MO})$
HRR $=(80.0 - 20.0) \, I \, (80.0 - 10.0) * 100 = 85.7$ %

Note:
Above the simplified relation is valid only for $M_M * c_M = M_{SM} * c_{sm}$

**Milk heating up before evaporator**

According the given data milk is heated up from 10 °C to a boiling temperature in the 1st evaporator effect, it is to 70 °C. Milk heating is done step by step with vapours leaving individual evaporator’s effects. In the last step heating steam is used.

**QHE** =Msm *** CM *** $(t_{EVAP1} - t_{SM})$
Qhe = 12^25 * 3.9 * (70 - 10) *I* 3600 = 788.1 kW
= 788.1*3600*20/106 = 56.75 GJ/d

**Heat fed as heating steam into the 1st evaporator’s effect**

Owing to the example simplification we do not calculate the evaporator exactly -various latent heats, heat losses, expansion of vapour from superheated milk or condensate etc. We take, for example, data from technical specifications, where the specific heating steam consumption **d** is given (see given data - **d** is related, for example, to steam at 0°C - $r_{re}$i = 2500 kJ/kg – this gives lower steam consumption, sometimes is d related to steam at 100 °C

$r_{re}$i= 2258 kJ/kg

This gives higher values, or to actual heating steam parameters always it is necessary to check for what heating steam parameters is the specific heating steam consumption d given).

$Q_{EVAP}$ = d * $W_{EVAP}$ * $r_{rel}$
*Qevap* = 0.28 * 9969 * 2500 / 3600 = 1938.4 kW
= 1938.4*3600*20/106

= 139.56 GJ/d

Amount of heating steam (pressure 100 kPa)

$M_{HSEVAP}$ =*Qevap* /$r_{rel}$ = 1938.4 * 3600 / 2258 = 3090.5 kg/h

## 3.9 Drying of concentrated milk in spray drier

For a dryer calculation we have to specify amount of drying air. Drying course is displayed in the Moliere’sh - **s** diagram of wet air.
Parameters of drying air are usually given by requirements to a product quality and a dryer economy. The higher air temperature $t_A$i the higher dryer economy, the smaller dryer dimensions and the smaller amount of drying air (smaller fan and its electric energy consumption).On the other side high air temperature can deteriorate a product quality (digestibility, taste, colour, solubility etc.). Temperature of outlet air 1a2 has to be so high so that in following equipment (piping, cyclone, filter, fan etc.) air temperature does not fall below temperature of wet thermometer (condensation of moisture from air). Therefore we set air temperature and relative humidity for 3 states (1, 2, 3) of drying air (for the parameters we specify from the Mollier’s diagram specific humidity **x** and enthalpy **h):**

Entering air before heating (sucked from a room where the dryer is installed - warm air -> energy saving)

$t_{A0}$ = 30 °C . AO = 40 % $h_{A}o$ = 55 kJ/kg d.air
$X_{AO}$ = 0.011 kg hum./kg d.air.

Air after heater = inlet to dryer
$t_{A1}$ = 180°C $h_{A}1$ = 211 kJ/kg d.air $x_{A}1$ = 0.011 kg hum./kg d.air.

Air leaving dryer (twT = 44 °C)
$t_{A}2$ = 85 °C . A2 = 13% $h_{A}2$ -211 kJ/kg d.air
$x_{A}2$ = 0.047 kg hum./kg d.air.

Amount of drying air is calculated on this premise. 1 kg of drying air with given temperatures is able to take away ($x_{A}2$ - $x_{A}1$) of moisture from a dried material (milk). In the dryer it is necessary to take away $W_{D}ry$ =1156 kg/h of water. Than the theoretical amount of drying air is:

Theoretical amount of heat needed for taking away the amount of water $W_{DR}$/ is (temperature of dried material is practically twi = 44 °C, for the temperature is the latent heat of Evaporation r = 2397 kJ/kg)

*Qdryt* = $W_{DRY}$ * r = 1156 * 2397 / 3600 = 769.7 kW

Theoretical amount of heat needed for heating up of heating air in the dryer is given as a product of the multiplication of the amount of heating air and a difference of its enthalpies (after and before heating).

$Q_{AT}$ = $M_{A}$ * ($h_{A}i$ - $h_{A}o$) = 32111 * (211 - 55) / 3600 = 1391.5 kW
For heat losses in dryer and all system c. 20 % is an real heat consumption in the dryer:

*Qdry*= 1-2* *Qat* = 1.2 * 1391.5= 1669.8 kW
= 1669.8*3600*20/106 = 120.23 GJ/d

**Note:**

A higher drying air amount or higher drying air temperature $t_{A}i$ (for example from 180 °C to 210 °C) or combinations compensate heat losses. Checking of the dryer effectiveness (dryer heat consumption =2 x theoretical consumption)

*Qdry* / *Qdryt* = 1669.8 / 769.7 = 2.17 set temperatures are OK

## 3.10 Power requirements of drying air fans

Such big dryer needs 2 fans, the first one (compressive) before the dryer, the second one (sucking) on the outlet after the dryer. A small under pressure has to be in the dryer (owing to a dusting to a dryer surroundings), so the sucking fan has to have a little higher discharge (performance) than the compressive one. We will consider both fans the same for our example. Total pressure losses in a dryer system (inlet air filter, heater, fan, piping, dryer, cyclones, outlet air filter, fan) are estimated to $\Delta ppL1 =$ 5000 Pa (on the basis of a similar system measuring or a calculations.

Than 1 fan (average) has to "give" pressure c. $\Delta ppL1$ =5000/2 = 2500 Pa. The 1 fan power requirement is then :

$$P_{F1} = V_A * \Delta_p PL1/nTF$$

VA = MA / pA = 32111 / (1.2 * 3600) = 7.43 m3/s amount of drying air(volumetric flow)
A fan efficiency is specified from a fan characteristic. The characteristic is available for every fan in a technical standard (see next fig.). The characteristic shows a dependence of total pressure on airflow (for various fan type, wheel diameter and speed). The efficiency is, for radial fans, c. from 75 to 86 %. For specified airflow and needed pressure we set $n_{TF}$ =82 %. Than is the power requirement of 1 fan (we consider 20 % of reserve — heat losses and from it resultant higher drying airflow)

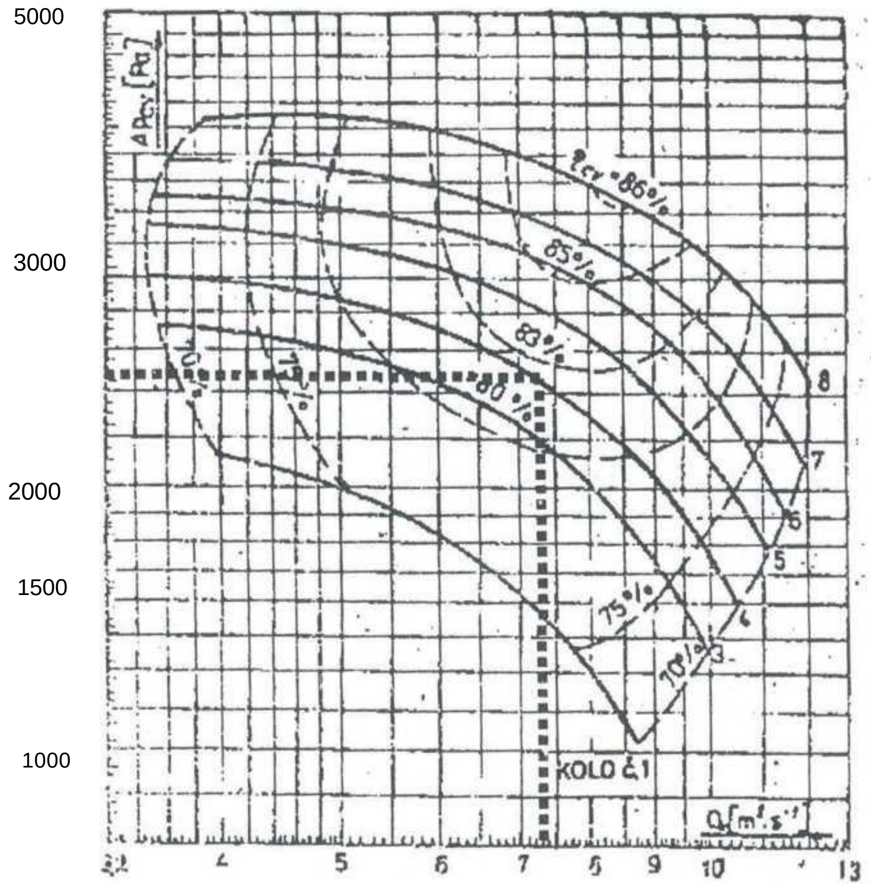
$P_{MF}$ = 1.2 * $P_F$ = 1 -2 * 7.43 * 2500 / 0.82 = 27183 W = 27.2 kW (average value)

Fan type is RVK 1250; n = 980 rpm, wheel No.4, motor 30 kW sucking and 25 kW compressing.

**Note:** Relations needed for a fan or pump power requirement calculation

$P_{TEOR}$= M * Ap / p* n W; kg/s, Pa, kg/m$^3$
$P_{TEOR}$= V * Ap $I$ p W, m$^3$/s,Pa, -ve
$P_{TEOR}$= *M*AH*g/n* W; kg/s, m, m/s, -ve
$\Delta P_{PL}$ = $H_{PL}$* p *g Pa = kg/ms$^2$; m, kg/m, m/s$^2$

(W = kgm$^2$/s$^3$)



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### 3.11 Milk pump (centrifugal) power requirement – beforePasteurizer

For this specification we have to know pressure losses in the pasteurizer, piping,valves and fittings and a hydrostatic head. For it we have to keep at our disposal technical specifications of the pasteuriser and a topology of its installation (location of tank, pump, pasteuriser, piping length and topology, number and types of valves and fittings etc.). Usually it is necessary to calculate pressure loses in piping and fittings (valves or butterfly valves characteristics = dependence of pressure loss on % of opening and flow rate). For our example we consider following values:

Pressure loss in system $\Delta P_{PL} = 60\ kPa$ (N/m$^2$ = kg/ms$^2$)

Hydrostatic head
$\Delta pH = 100$ kPa(c.10 m)
Milk flow rate $M_m$ = 13657 kg/h

Milk density $p\ m$ = 1030 kg/m$^3$

**Specific energy given to milk in pump We use a working characteristic of the pump and system for needed calculations.**

**Y** = specific energy given to pumped liquid by a pump in dependence on flow rate (a pump characteristic)

**e** = characteristic of the system = specific energy needed for a maintenance of the liquid flow rate (it is specified from the system pressure loss e = $Ap_{PL}$/ p)

**Note:** Needed flow rate in a system is set by a change of the system characteristic = for ex. by regulation valve. (Image copied from another software )

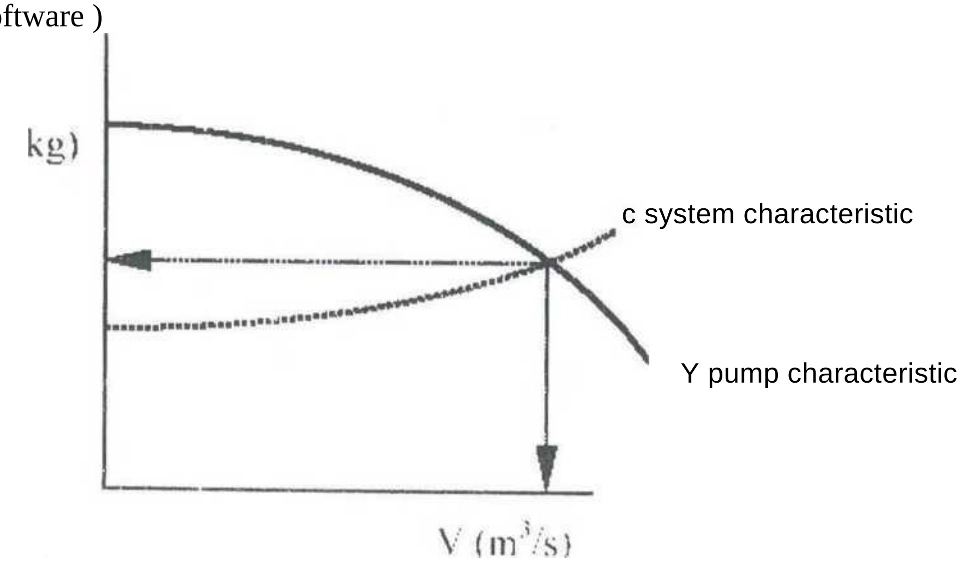


Fig 5. Relation of Mass and Flow rate

**Y** = e .......***pump working point for a given system***

e= $\Delta \boldsymbol{P}_{\boldsymbol{PLT}} / \boldsymbol{\rho}_{\boldsymbol{M}}$

(for p = 1000 kg/m$^3$, e = Y ~ Ap$_{PL}$, Y (J/kg) =10*H (m))

Considering of 20 % reserve is the pump power requirement

P$_{MPP}$$^{=}$ 1 -2 * (p $_M$ * V$_M$ * Y) /' r] p = 1.2 * M$_M$ * Y / f] p
[kg/m$^3$*m$^3$/s*J/kg=J/s=W]

Specific energy given to milk in the pump is:

e $^{=}\Delta \boldsymbol{P}_{\boldsymbol{PLT}}$ / $p\ m$= ($\Delta \boldsymbol{P}_{\boldsymbol{PL}}$ + $\Delta\rho_M$) / $\rho_M$= (60 + 100) * 103 / 1030
= 155.3 J/kg

Where,
$\Delta P_{PLT}$= total pressure loss
$\Delta P_{PLT}$ = pressure loss in system
$\Delta\rho_H$ = hydrostatic head

A pump efficiency varies, depending on pump types and pumping liquid, from 35 to 80 % (it is possible to set it from a pump characteristic for a selected pump). For our example is *n p* = 60%. Then is the milk pump power requirement:

$P_{MPP}$= (1.2 * 13857 " 155.3) / (3600 * 0.60) = 1196 W = 1.2 kW

Specification of the pump motor nominal input

$$P_{MPPN} = R * P_{MPP}$$

Coefficient of reserve R is specified in dependence on the motor input in the next table:

| $P_{MPP}$(KW) | 0.5-1.1 | 1.1-2.7 | 2.7-5.4 | 5.4-11 | 11-22 | >22 |
|---|---|---|---|---|---|---|
| R(-) | 2.0 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 |

Then is

$P_{MPPN}$ = 1.5 * 1.2 - 1.8 kW

On the basis of pump’s catalogues we can specify a pump with a next higher motor input. In an actual plant for such flow rates and equipment pumps with 2.5 to 3 kW motor are installed (reserve for higher flow rate during chemical cleaning etc.).

**Milk pump (centrifugal) power requirement - before evaporator**

The pump is considered the same like before the pasteurizer. The pump pumps milk from a baiance tank through 4 heaters to the 1st effect of evaporator (vacuum).

**Concentrated milk pump power requirement - before dryer**

Similar like in the previous we set:

| | |
|---|---|
| Pressure lost in system | $\Delta\boldsymbol{P_{PL}}$= 20 kPa ($N/m^2 = kg/m*s^2$) |
| Hydrostatic head | $\Delta_{\boldsymbol{PH}}$= 100 kPa (c. 10 m) |
| Concentrated milk flow rate | $\boldsymbol{M_{CM}}$= 2156 kg/h = 0.599 kg/s |
| Cone, milk density | $\boldsymbol{\rho_M}$= 1100 $kg/m^3$ |
| Pump efficiency (< flow rate, >$\boldsymbol{\mu}$) | n*p = 0.55 |

$\boldsymbol{P_{MPD}}$ =1.2* $\boldsymbol{M_{CM}}$ * $\Delta\boldsymbol{P_{total}}$ / p M * H P

$\boldsymbol{P_{MPD}}$= 1 2 * 0.599 *(20 + 100)/(1100 *0.55) = 143 W

$\boldsymbol{P_{MPDN}}$ = R * PMPD = 2.0 * 143 = 286 W

In an actual plant for such flow rates and equipment pumps with 0.5 to 1 kW motor are installed.

Power requirement of spray disc motor

The calculation goes from these ideas. Concentrated milk has to be accelerated to a disc circumferential velocity and then has to get through holes in the disc. For simplification we take into account only a power input needed for the mi!k acceleration (bigger part).

$\boldsymbol{P_{SD}}$ = $\boldsymbol{M_{CM}}$ * $v_t^2$ / 2 * n SD [kg/s *$m^2/s^2$=$kgm^2/s^3$ =W]

where

H sd = 0.6 az 0.7 is an effectiveness of spray disc

$v_T$ = 6 * $\boldsymbol{D_{SD}}$ * n = 100 to 300 m/s is a circumferential disc velocity

$v_T$ = 160 m/s (Niro uses c. 150 to 180 m/s)

$\boldsymbol{P_{SD}}$ = 0.599 * $160^2$ / 2 * 0.65 = 11794 W

Theoretic motor input (gearbox efficiency 90 %, motor efficiency 95 % + reserve 20 %)

$\boldsymbol{P_{SDM}}$= 1.2 * 11794/ 0.90 * 0.95 = 16553 W « 16.6 kW

**Nominal motor input**

$\boldsymbol{P_{SDMN}}$= R *$\boldsymbol{P_{SDM}}$= 1.2 * 16.6 = 19.9 kW - 20 kW

Note: We did not consider a motor efficiency for pumps, as the inputs were too low and designed motors had sufficient reserves. But for the spray disc there are too high inputs and there is a gearbox (for example from c. 2800 to 15000 rpm) between the motor and disc.

$Q_P$ = 229.9 kW = 16.55 GJ/d

## 3.12 Total energy balance of line

- Milk heating in pasteuriser (steam)

- Heat taken away from milk in cooling sec

Qcs =131.4 kW = 9.46 GJ/d
30 to 50% of it is electric energy for compressors in cooling system

$Q_{HE}$ = 788.1 kW
= 56.75 GJ/d

Milk heating before evaporator (steam, vapours)

Self-cleaning separator (electric energy) (set from TS of separator)
$Q_{SEP}$= 17 kW = 1.22 GJ/d

- Heat fed in heating steam into evaporator — $Q_{EVAP}$- 1938.4 kW = 139.56 GJ/d

- Heat for heating air (steam) — *Qdry* = 1670 kW = 120.23 GJ/d

$P_{MFC} = 25.1\ kW$
= 1,81 GJ/d

- Input of sucking fan (electricity) — Pmfs = 30 kW = 2.16 GJ/d

- Input of pump before pasteuriser (electricity) — Pmpp =1.2 kW = 0.09 GJ/d

- Input of pump before evaporator (electricity) — Pmpe = 1 2 kW = 0.09 GJ/d

* Input of pump before dryer (electricity) — Pmpd = 0.5 kW = 0.04 GJ/d

- Input of spray Disc motor (electricity)

$$P_{MSD} = 20\ kW$$

Total daily energy consumption of the line is
$Q_{LCD}$= 349.4 GJ/d

Note:
From the table it is possible to see, what parts of the line are energetically demanding. We have to take into account different costs of electricity and steam too.

# Chapter # 4

## Equipment Design

## EQUIPMENT DESIGN

**Following data are required for the equipment design.**

Material Balance

Energy Balance

Physical & Chemical Properties of Chemicals

Capacity of Plant

Temperature & Pressure Conditions

## 4.1 STORAGE OF MILK

The storage of milk for “3” days
Mass flow rate of Milk = 13.857 ton/hr
= 13857 Kg/hr
For “20” days = 277140 Kg/day
For “3” days = 831420 Kg
Vol. of Tank = 831420/1030 = 807.20 $m^3$
At 10% Clearance Vol. = 807.20 * 1.1 = 887.92 $m^3$
Density of milk Dm =1030Kg/m3

**Assumption:**

***L/D = 1.5*** (by peter Timmerhaus book)

For cylindrical tank V =3.14 *D$^A$3 / 4

Di= 10.093 m

L= 1.5 * 10.093 =15.139 m

Head of milk, Hm = 4 V / D$^A$2*3.14

= (4 * 887.92) /((10.093)$^A$2 *3.14)

=11.10 m

**Material of construction is Stainless steel**

Joint efficiency, J = 0.9

Friction Factor, f = 165 N / mm (from Coulson & Richardsons Vol.# 6 Page #809)

Thickness of tank, t =(Dm * FLm * g *Di)/ (2 f * j)

= (1030 * 11.10 * 9.8 * 10.093)/*(2 * 165 * 0.9 * 10 $^A$3)

=3.8 mm

## 41 DESIGN OF PUMP

**Pressure drop for pump to preheater**

Press.of tank = 101.3 kPa

Press at pasteurization = 161.3 kPa

Length of Pipe = 100 ft

No. of Globe Valves = 2

No. of 90 deg. Elbows = 3

Head of milk in tank, Z1 = 36 ft

Head of milk in pasteurization, Z2 = 70 ft Mass.

Flow rate of milk = 8.468 lb/s

Density of milk = 64.21 lb/ ft3

Vol. flow rate = 8.468/64.21

= 0.131 ft3/sec

Area =3.14* (0.167)$^A$2 / 4 = 0 .02189 ft3

Velocity = 0.131 / 0.02189 - 6 ft/s

Nre = (64.21 * 0.167 * 6)/ (2.1 * 0.000672)

= 45584

**By peter Timmerhaus book**

Friction factor, f = 0.005439

Equivalent length = no * factor * dia (for globe valve & bent)

Le = (2 *7*2.067/12) + (3 * 32 * 2.067 )

= 19 ft

Fl = 2 f v2 (L +Le)/gc.D

=2 * 0.00544 *6$^A$2 (100 +19 )/ 32.2 (2/12) = 8.86 ft Ibf /lbm

**Friction due to contraction & expansion**

Contraction, Fc = (Ke * v^2)/(2* a gc) =0.26 ft lbf /lbm
Where a is alpha.
Expansion Fe = (V1-V2)^2 / (2 a gc ) = 0.559 ft lbf/lbm
F2 = Fc + Fe = 0.26 + 0.599 = 1.11 ft lbf/lbm
Summation of, F =F1 + F2 = 8.86 + 1.11 = 9.97 ft lbf /lbm

**From macab & smith**

Wp = (Z2 -Zl) 4- (P2 -PI) * v + Summation of F
= (70 - 36 ) + (23.4-14.7) * 0.01550+9.97 = 44.10
ft lbf/lbm Hp required= (Wp * mo)/ efficiency of pump
= (44.10* 0.131 * 64.2)/(0.4*550)
=3 hp

For design pupose wc also required 3 hp

## 4.3 Prehaeter (before pasteurization)

Cold Milk

Mass flow rate= 30485.4lb/hr
Temp. In = 50 F
Temp Out =144.5F Cp =
0.933 Btu/lbF
Q = mCpAT

Hot MILK

&

mass flow rate= 20675 lb/hr Temp In = 176F Temp out = 68 F Cp = 0.933Btu/lbF

Q = mCpAT

Q = (30485.4)*(0.933)*( 144.5-50) = 2689308.8 RTU

Q = (26675)*(0.933)*(176-68) = 2689308.8 BTU

LMTD =( 31.5-18)/ln (31.5/18)
= 24.12 F
T avg = 50+144.5 /2 = 97.25 F
I.D = 0.172 ft (dia. Of inner pipe)
Flow area, $A_p$ = 3.14 * 0.172$^{0.5}$
= 0.0232 ft$^2$
T vg = 17
Avg. T 176 + 68/2=122 F
I.D, D2 = 0.256 ft (inner dia of outer pipe) D1 = 0.198 ft (from table 11 of Kern) $A_p$= 3.14($D_2^2$-$D^2$)
= 0.02ft$^2$

Cip = m° / $a_p$
= 1314025.86 Ih /hr It$^2$
De = 0.133

At Tavg. 97 F°

f.i = 5.07 lb / ft hr NRe = D Gp / n
= 44578 (fiom kern **FIG** 24 )
Jh = ( hi D/kX^/k)$^{1/3}$ ( m/ H.)$^{014}$From kern

$J_H$= 140

Conductivity at Tavg,97 F°
K = 0.32 Btu / hr ft F°

(H Cp/k) = 2.43

hi =( $J_H$k/D)(nCp/k)$^{l/3}$(n/ n,,)$^{014}$ =
632.93 Btu / hr ft$^2$ F°
At Tavg. 122 F$^{l)}$

ft Ga = m° / $a_a$
= 1270238.1 lb **/HR** ft$^2$

H = 4.34 lb/ft hr $N_{RC}$ = D Gp / ja =389426

$J_H$= 100

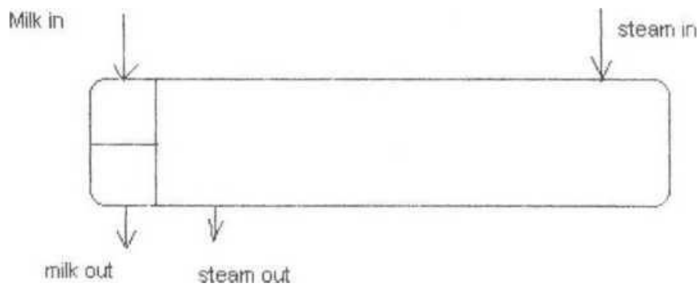
K = 0.33 Btu / hr ft F°

Cp/k) = 2.28

ho =( J11 k /D)( |i Cp/k)$^{1/3}$(|a/ $n_w$)$^{u'14}$= 565 I5tu / hr IV F° hio = hi I.D/O.D
= 549.8 Btu / hr ft$^2$ F°

Uc = hio * ho / hio + ho = 278.64 Btu /hr ft$^2$ F° 1/Ud = 1/Uc + Rd Rd = 278.64 Btu / hr ft$^2$ F° Q = ud A LMTD A = Q /Ud LMTD = 623.23 ft$^2$

# 4.4 Pasteurizer




Shell Side (Hot fluid)

ID =10.02 in
Baffle space B - 2
in Passes Pt = 1
Clearance C'
=0.25

Steam

$\lambda = 969.4$ Btu/lbm (at 14.7psi)

T =212 °F

Tube Side (Cold fluid)

No. of tube Nt
=52 Length =16
ft
OD =J/4 in
BWCJ =16
Pitch = 1 in square
Passes n =2

Milk

$m_m$ = 26675 lb/hr
tl = 144 °F t2 =
176 °F Cp = 0.933
Btu/lb °F pm —
64.21 lb/ft $^3$

(1)

Qs = $m_s$**X**

As Qm = Qs

435536 = $m_s$
969.4 $m_s$ = 449
lb/hr

Qm = me At
= 435536 Blu/hr

**(2)**

At = ?

At = LMTD = 50 ”F ( ai R = 0)

**(3)**

Tc = Ta =212 °F

tc = ta = 160 "F

(4)

as = ID *C’ B/144*Pt =0.0347 $ft^2$

at’ =0.302 in

at =Nt * at7144n = 0 IV = .0545 $ft^2$

**(5)**

Gs = $m_s$ / as
= 12939 lb/hr. $ft^2$
Gt = $m_m$ / at
= 489449.5 lb/hr. $11^2$

Gt/3600 $p_m$
=2.11 ft/s

**(6)**

AtTa = 212 °F (table 14) j.i
water =0.34 cp =.34*2.42
=0.82 lb/ft.hr Ds
=0.95/12 =0.079 ft (fig 28)
Res =Ds*Gs/ p.
= 1246

lb/hr.ft

D = ID = 0.62/12
=0.0517JU table 10)

**(7)**

Jli =18(fig 28)

**(8)**

K = 0.4 btu/br. $ft^2$ (°F/ft)

Ret = D.Gt/ (j, milk = 19025.9

**(9)**

at ta = 160 °F JJ. milk = 1.33

ho = $(J_H k/DXnCp/k)^{1/3}(\mu/\mu_w)^{0.14}$ = 115 Btu/hr. $ft^2$ °F

(fig 25)
hi = 790 Btu/hr. $ft^2$ °F

hio= hi *ID/OD =653 Btu/hr. $It^2$ °1

**(10)** Uc =hio*ho/(hio+ho) = 97.78 Btu/hr. $ft^2$ °F

**(11)**

a” =0.1963 (table 10)

A = L*N* a”

= 163 $ft^2$

**(12)** Ud =Q/A (LMTD) = 53 Blu/hr. $ft^2$F

Rd = (Uc - Ud)/UcUd
=0.0086 hr. $ft^2$ °F/Btu

# 4.5 Cream Separator (Centrifuge)

**Data**

Pm = 1030 $kg/m^3$

No. of rpm = 6500

(O = 6500 * 0.1047

= 680 rad/s

R1 = lm

R2 = 0 bowl full of liquid

Centrifugal Pressure

= Pf = !/2 * $p_m$* g$)^2$*($R1^2$ - $R2^2$ )

Pf =2.38 * $10^8$

**StorageTankafterpasteurization**

**Basis:**
20 hr. operation
Mass to be handled = 12125 Kg/h
Totle Mass =12125*20-242500 Kg

Volume of the Milk(Vm) = 242500/1030=235.4
Clearance $m^3$=10%
Total volume required = 426 *1.10
(Vt) = 258.94$m^3$

**Dimensions:**

1.5 = L/D (by peter Timmerhaus book)
L = 1.5D
V = $\pi$/4 * D2L
= $\pi/4$ * D3 * 1.5
Di = 6.6943m
L = 1.5*6.6943= 10.041m

= 4*258.94/3.14*(6.6943)2 = 7.36 m Pressure due to Milk head = density * g h
= 1030 * 9.8 * 7.36 = 74291.84 Pa = 74.29 KPa Maximum allowable pressure = Atm. Pressure +Pressure due to Milk head
Head of Milk Hm
= 101.3 + 74.29 = 175.59 KPa
Design pressure=175.59 * 1.1
= 193.14 KPa

**Material of construction is Stainless steel**

Working stress (S)
Joint Efficiency
Thickness of cylindrical wall shell

f =165 N/mm2 (R.Coulson Vol.6 page 809)
j =0.90

t = (Dm * Hm * g * Di)/(2 f * j)
=(1030 * 7.36 * 9.8 * 6.6943)/(2 *165* 0.9 *10^3)
=0.16745 m

## 4.6 EVAPORATION TECHNOLOGY

The simplest evaporator is an ordinary open pan heated with steam or direct gas. The evaporation takes place from the surface while the liquid to be evaporated is heated up to the boiling point corresponding to the ambient pressure, which at sea level will be 100°C and in an altitude of approx. 5000 m above sea level 85°C.
As the evaporation has to take place from the surface, which is limited in relation to the content of the pan, the evaporation will naturally take long time. The milk will be exposed to the high temperature with a deterioration of the proteins, chemical reactions such as the Maillard reaction, or even coagulation as a result.

As the development went on, the concentration was carried out in forced recirculation evaporators. In this evaporator the milk streams upwards through a number of tubes or plates. On the outside the heating medium, usually steam, is applied. The heating surface is thus increased in this system, but the evaporation surface is still limited, as the tubes and plates remain filled with product, which therefore becomes superheated in relation to the existing boiling temperature.
Not until the product leaves the top of the tubes, are the vapors released and the product temperature decreases. For the separation of liquid and vapors, centrifugal separators were preferred. In order to obtain the desired degree of evaporation the product was recycled in the system. The concentration was thus controlled by the amount of concentrate discharged from the plant.

## 4.7 Falling Film Evaporators

Over the past 40 years the falling film evaporator has practically replaced the forced recirculation evaporator. The falling film evaporator is desirable from a product point of view, as it offers a short holding time. Further, the amount of product in the evaporator is reduced and the surface from which the evaporation takes place is increased. Fig. 2 shows a diagram of a falling film evaporator.

### EVAPORATION OF LIQUID

The liquid to be evaporated is evenly distributed on the inner surface of a tube .The liquid will flow downwards forming a thin film, from which the boiling/evaporation will take place because of the heat applied by the steam. See Fig. 3. The steam will condense and flow downwards on the outer surface of the tube. A number of tubes are built together side by side. At each end the tubes are fixed to tube plates, and finally the tube bundle is enclosed by a jacket, see Fig. 3a. The steam is introduced through the jacket. The space between the tubes is thus forming the heating section. The inner side of the tubes is called the boiling section.

Together they form the so-called calandria. The concentrated liquid and the vapour leave the calandria at the bottom part, from where the main proportion of the concentrated liquid is discharged. The remaining part enters the subsequent separator tangentially together with the vapour. The separated concentrate is discharged (usually by means of the sam pump as for the major part of the concentrate from the calandria), and the vapour leaves the separator from the top. The heating steam, which condenses on the outer surface of the tubes, is collected as condensate at the bottom part of the heating section, from where it is discharged by means of a pump.

In order to understand the heat and mass transfer, the basis for the evaporation, it is necessary to define various specific quantities.

From a given quantity of feed (A) part of the solvent is evaporated (B) leaving the concentrate or the evaporated product (C). And thus

$$A = B + C \quad (1)$$

See Fig. 4, showing specific quantities and the corresponding heat flow diagram. The evaporation ratio (e) is a measure for the evaporation intensity and can be defined either as the ratio between the amount of feed and concentrate or the ratio between the solids percentage in the concentrate and in the feed.

$$e = A/C = \text{C-Concentrate}/\text{C-Feed} \quad (2)$$

If the concentrations or the evaporation ratio are known the quantities A, B or C can be calculated, if one of them is known.

| **Given Quantity** | **To be Found** | **Formula** |
| --- | --- | --- |
| Quantity to be treated A | B | $B = A * (e-1)/e$ (3) |
| | C | $C = A * 1/e$ (4) |

As the development went on, the concentration was carried out in forced recirculation evaporators. In this evaporator the milk streams upwards through a number of tubes or plates. On the outside the heating medium, usually steam, is applied. The heating surface is thus increased in this system, but the evaporation surface is still limited, as the tubes and plates remain filled with product, which therefore becomes superheated in relation to the existing boiling temperature.\

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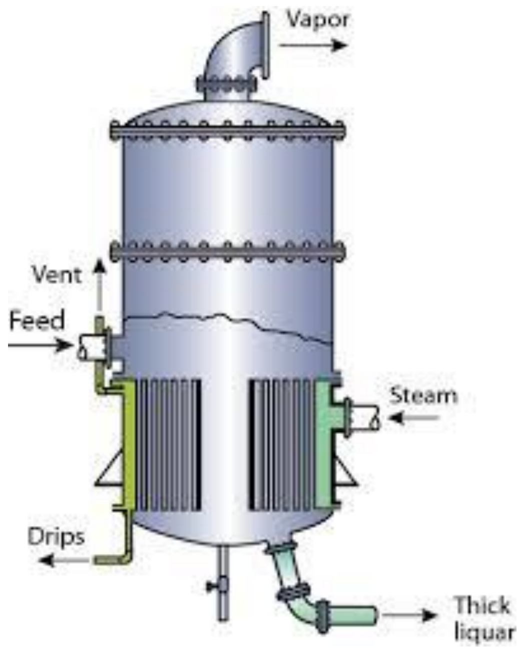

Fig. 6 Evaporation in a falling film evaporator calandria

From a given quantity of feed (A) part of the solvent is evaporated (B) leaving the concentrate or the evaporated product (C). And thus

$$A = B + C \quad (1)$$

See Fig. 4, showing specific quantities and the corresponding heat flow diagram. The evaporation ratio (e) is a measure for the evaporation intensity and can be defined either as the ratio between the amount of feed and concentrate or the ratio between the solids percentage in the concentrate and in the feed.

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| **Given Quantity** | **To be Found** | **Formula** |
|---|---|---|
| Quantity to be treated A | B | $B = A * (e-1)/e$ (3) |
| | C | $C = A * 1/e$ (4) |

| | | | |
|---|---|---|---|
| Evaporated quantity B | A | A= Bxe/e-1 | (5) |
| | C | C= b*1/e-1 | (6) |
| Concentrate quantity C | A | A= Cxe | (7) |
| | B | B= C*(e-1) | (8) |

Where A: feed in kg/h
B: evaporation in kg/h
C: concentrate in kg/h evaporation
e: ratio See (2)formula

Since milk, due to the protein content, is a heat-sensitive product, evaporation (i.e. boiling) at 100°C will result in denaturation of these proteins to such an extent that the final product is considered unfit for consumption. The boiling section is therefore operated under vacuum, which means that the boiling/evaporation takes place at a lower temperature than that corresponding to the normal atmospheric pressure. The vacuum is created by a vacuum pump prior to start-up of the evaporator and is main-tained by condensing the vapour by means of cooling water. A vacuum pump or simi-lar is used to evacuate incondensable gases from the milk.

At 100°C the evaporation enthalpy of water is 539 Kcal/kg and at 60°C it is 564 Kcal/kg. As the milk has to be heated from e.g. 6°C to the boiling point and as en-ergy, approx. 20 Kcal/kg, is required for maintaining a vacuum corresponding to a boiling point of 60°C, we get the following energy consumption figures, provided we estimate the heat loss to be 2%:

| | | | |
|---|---|---|---|
| Boiling temperature | °C | 100 | 60 |
| Heating | Kcal/kg | 94 | 54 |
| Evaporation | Kcal/kg | 539 | 564 |
| Vacuum | Kcal/kg | --- | 20 |
| Net energy consumption | Kcal/kg | 633 | 638 |
| Heat loss, approx. | Kcal/kg | 15 | 15 |
| Total energy consumption | Kcal/kg | 648 | 653 |

**corresponding to about 1.1 kg steam/kg evaporated water.**

To simplify the following examples we will use 1 kg steam/kg evaporated water. As vapour, from the evaporated milk contains almost all the applied energy, it is obvious to utilize this to evaporate more water by condensing the vapour. This is done by adding another calandria to the evaporator. This new calandria - the second effect - where the boiling temperature is lower, now works as condenser for the vapours from the first effect, and the energy in the vapour is thus utilized as it condenses.

In order to obtain a temperature difference in the second effect between the product and vapour coming from the first effect, the boiling section of the second effect is operated at a higher vacuum corresponding to a lower boiling

A third effect heated by vapour from the second effect, and so forth, can of course be added. The limit is the lowest vacuum obtainable, and that is decided from the amount and temperature of the cooling water (usually 20-30°C) condensing the vapour from the last effect, whereby the vacuum is maintained. Using ice-water or direct expansion of freon to bring down the last effect boiling temperature is of course theoretically possible, but other factors such as viscosity of the product, volume of the vapours, and crystallization of lactose determine the practical limit being about 45°C.

| **Boiling point °C** | **Vacuum m WG** | **corresp. to mm Hg abs** | **~m above sea level** | **Volume of water vapour** |
|---|---|---|---|---|
| 100 | 0 | 760 | 0 | 1,7 $m^3$/kg |
| 85 | 4,5 | 434 | 5,200 | 2,8 $m^3$/kg |
| 70 | 7,2 | 233 | 10,000 | 4,8 $m^3$/kg |
| 60 | 8,3 | 149 | 14,000 | 7,7 $m^3$/kg |
| 50 | 9,1 | 92 | 18,000 | 12,0 $m^3$/kg |
| 40 | 9,6 | 55 | 22,000 | 19,6 $m^3$/ko |

From Fig. 5 we can see that 1 kg of steam can evaporate 2 kg of water and by applying a third effect 3 kg of water is evaporated using only 1 kg of steam.

## 4.8 MECHANICAL VAPOUR RECOMPRESSION MVR

### EVAPORATORS IN THE DAIRY INDUSTRY

As an alternative to the thermo-compressor, the mechanical vapor compressor has experienced extensive use in evaporators within the dairy industry during the past fifteen years. Electricity is often the selected source of energy for the compressor, but also diesel motors are used. Other processes may require steam at low pressure, and the compressor can be driven by a steam turbine acting as a reducing valve. All procedures are determined by local price policy for energy. However as a rule of thumb, an MVR solution is profitable, if the price/kW <price/kg steam x 3. The decision as to which type of compressor to use, is traditionally influenced by the desired quality of the end product - the milk powder - and in the MVR evaporator there is a very short residence time, resulting in low viscosity of the concentrate.

### MECHANICAL VAPOUR COMPRESSOR FEATURES

The mechanical vapour compressor is a fast revolving high pressure fan (*3000 rpm) capable of operating under vacuum. At low boiling temperatures the volume of the vapours is enormous. Consequently, there is a limit as to the lowest temperature levels used in practice. As the energy applied to the compressor is utilized most efficiently by low compression ratios, the obtained temperature/pressure in-crease is limited. Therefore, a large heat transfer surface is required, which tends to increase the capital costs of the equipment.

As it is essential to operate an MVR unit at a low overall temperature difference between the vapour evolved from the product and the heating medium as a result of the compression, it is essential that the boiling point elevation of the product is kept at a minimum. Otherwise this could further minimize temperature differences available for the evaporation. This, too, limits the maximum concentrations aimed at in evaporators of this kind.

## 4.9 PROCESS

To begin with the incoming cold milk is preheated by concentrate, then by condensate from the heating section of the calandria, followed by a final pasteurization by live steam. The vapour is compressed in the MVR unit and used as heating medium, as it releases the latent heat by condensation. A vacuum pump, together with a small amount of cooling water, maintains the desired vacuum in the system.
As it can be seen no energy leaves ihe plant as warm condensate, and only a minor part via the cooling water (depending on the pasteurization temperature desired). The MVR evaporator is in this context very often used as precondenser of milk products for transport purposes, where the required solids content is in the range of 30-35% and thus the boiling point elevation is limited. With the concentrate leaving the plant at low temperature, this kind of installation is a strong competitor to hyper-filtration.
The working cycle of a mechanical compressor is shown in Fig. 13. The vapour is sucked from the separator represented as point A at a given temperature/pressure level ta/Pa and compressing it to point B':t'r/Pr. The compressed vapour is desuperheated to B:tr by spraying water into the outlet of the compressor. The compressed vapour is condensed on the heat exchanger surface in the calandria from point B to C, where it is discharged as condensate. Simultaneously, water is evaporated from the milk and separated in the separator from where it leaves at point A.

The MVR evaporator offers much better capacity flexibility / turn-down capability, as only the RPM on the fan needs to be adjusted. Usually, the MVR evaporator is combined with a TVR unit, if solids contents suited for a spray drying plant are desired. The steam consumption per kg evaporated water is of course less than in a multi-effect evaporator, but if the MVR unit is driven by an electric motor, the electrical energy consumption will increase. Since only limited amounts ot cooling water is required, this combination offers a very attractive solution, however, a higher investment should be anticipated. Under special energy price conditions it is advantageous to replace the TVR unit with an additional MVR unit to compress the vapor over the last effect. It is therefore recommended that each case is studied carefully taking local conditions such as steam, electricity and cooling water prices into consideration.

## Comparison of Energy Consumption in Different Evaporators

| Evaporator | 5-effect TVR | 7-effect TVR | 1-effect MVR/ 2-effect TVR |
|---|---|---|---|
| **Product** | Skim milk | Skim milk | Skim milk |
| **Capacity kg/h** | **15000** | **15000** | **15000** |
| **Solids in/out %** | **9/50** | **9/50** | **9/50** |
| **Evaporation, kg/h** | **12300** | **12300** | **12300** |
| **Pasteurization temp, C** | **90** | **90** | **90** |
| **Holding time, sec** | **30** | **30** | **30** |
| **Steam consumption, kg/h** | **1610** | **1190** | **375** |
| **Steam Pressure, bar** | **10** | **10** | **10** |
| **Condensate, kg/h** | **13400** | **13400** | **12800** |
| **Condensate temp, C** | **54** | **51** | **22** |
| **Power Consumption** | | | |
| - **MVR, kW** | **--** | **--** | **150** |
| - **Motors, kW** | **75** | **75** | **50** |
| **Cooling water cons, $m^3/h$** | **35** | **3.5** | **2*** |
| **Cooling water temp, in/out, C** | **28/35** | **28/35** | **12/50** |
| **Power Cons Cooling tower, kW** | **10** | **2.5** | **--** |
| **Residence time, min** | **10** | **18** | **6** |

Note ; * to be used only if the temp of raw milk is above 5C.

*Design of Industrial Evaporators*

The increased demand for large **multi-effect evaporators** requiring bigger heating surface in order to obtain better specific consumption figures, can be met by using an increased amount of tubes. This would, however, mean that less liquid reaches each tube, and the produced film is too thin. At high solids contents the viscosity will increase, the film will not flow any more, and there is a risk of burnt deposits. This will result in a concentrate with small jelly lumps, often discolored and found in the powder as "scorched particles", as these won't dissolve when the powder is reconstituted. In extreme cases the tubes will be completely blocked and manual cleaning is necessary. The designer therefore operates with the so-called coverage coefficient defined as:

'

Product kg/h at the lower end of the tubes / Periphery of the tubes (10)

## MANUFACTURING OF THE CALANDRIA

The trend has therefore been to manufacture the calandria with longer tubes in order to obtain more heating surface, maintaining the coverage coefficient at the same level. About thirty years ago the evaporators were equipped with 3-4 m tubes and operated with a temperature difference of about 15°C, whereas evaporators 10 years ago had tubes with a length of up to 14 m and a temperature difference down to 2°C. Today most new evaporators have tube lengths up to 18 m. The advantage is that less product passes are needed to obtain sufficient coverage, fewer pumps, and reduced residence time.

## MODERN EVAPORATORS

The requirement tc a modern evaporator is also flexibility and thus an ability to operate with various products and therefore with different capacities. The problem is a different solids content in the product to be evaporated, and that the spray drier will have a different capacity when drying different products.
Furthermore, the evaporator will have different evaporation capacities because of different K factor for the various products.
When designing an evaporator/spray dryer the main product is therefore always selected, and the evaporator calandrias are designed, so that optimal coverage coefficients are ensured, also for the other products.

As the K value is approx. 20% lower for whole milk than for skim milk, the evaporation capacity will be about 20% less on whole milk. As the solids content is also different in skim milk and whole milk, the feed input to the evaporator decreases when whole milk is evaporated. This requires special attention to the design of the calandrias, as the coverage coefficient will be too low, especially in the first effect due to the lower amount of feed input. If, on the other hand, the evaporator is designed for whole milk as main product, and skim milk has to be evaporated, the coverage problem occurs mainly in the last effect due to the low solids content in the product yielding less amount of concentrate of 48% TS. The coverage problem was some years ago overcome by recalculating part of the feed from the outlet of the calandria to the inlet of same, thus increasing the amount of liquid sufficient to cover all the tubes.

From a technical point of view this is the ideal solution, as it is cheap and simple, but from a product point of view it should not be tolerated, as it means that part of the product is exposed to the hiqh temperature for a Iona uncontrollable time This means that the final concentrate will aet increased viscosity and possiblv protein denaturation, both resultina in a powder with an inferior solubility

In modern falling-film evaporators, the so-called "single-pass" evaporators, the problem is solved by dividing the effects with low coverage coefficient in two or more separate calandrias with same boiling temperature and often one combined separator.

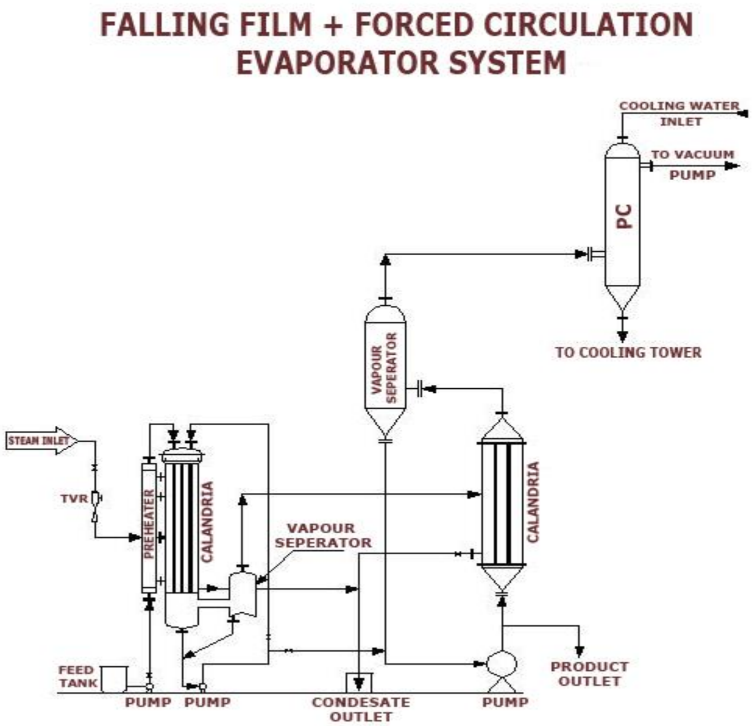


Fig. 7

In a forced circulation boiler, an extra pump is used to increase the circulation rate as compared to that of natural circulation boiler. In some forced circulation boilers, the water is circulated twenty times the rate of evaporation.

The example of forced circulation boiler is a La Mont boiler. Such boilers are used in cases where there is high pressure for more than above 30 Mega Pascal.

Another method is to split the calandria by dividing it into two or more sections in a "multi-flow" evaporator. The product is pumped to one section, from the outlet of which it is pumped direct to the next section, and so forth. Having passed through the last section it is pumped to the next effect, see Fig. 17. This system is almost as cheap as the recirculation, but has the advantage of the divided calandria and no circulation is necessary.

## 4.11 Auxiliary Equipment for the Evaporator

In order to make the evaporator work as an integral unit the following auxiliary equipment is needed:

- Separators
- Product distribution system
- Preheaters
- Pasteurization/holding equipment
- Low thermophilic heating/pasteurizing equipment
- Condensation and vacuum equipment
- Cooling towers
- High-concentrators
- Flash coolers
- Sealing water equipment
- Instrumentation and automation

**Separators:**

Separators with tangential vapor inlet or Wrap-Around Separators.

Manual rotation of the separator handle turns a worm gear mechanism which causes the separator bowl to spin at thousands of revolutions per minute.

When spun, the heavier milk is pulled outward against the walls of the separator and the cream, which is lighter, collects in the middle. The cream and milk then flow out of separate spouts. Some floor model separators were built with a swinging platform attached to the stand. The bucket for collecting the cream was put on the platform, and a much larger bucket was set on the floor to collect the milk. Some floor model separators had two swinging platforms. Smaller versions of separators were called table-top models, for small dairies with only a few cows or goats.

Gustaf de Laval's construction made it possible to start the largest separator factory in the world, Alfa Laval AB. The milk separator represented a significant industrial breakthrough in Sweden. Within the first decade of the 1900s, there were over twenty separator manufacturers in Stockholm. Separators in modified form are also used on ships to purify oil, which may have been their original use, because in its original form de Laval proposed the separator for use in his steam turbine. De Laval's turbine used mechanically lubricated journal bearings which weren't insulated from the inside of the turbine. When the steam condensed into water it contaminated the oil. To purify the oil a centrifugal separator was used, which was later adapted to the dairy industry.

The original design had a manual bowl that required manual cleaning. Most modern separators use a self-ejecting centrifuge bowl that can automatically discharge any sedimentary solids that may be present, and that allow for clean-in-place (CIP). The self-draining vessel feature is mandatory for machinery designated for 3A approval (an industrial sanitary standard).

## SEPARATORS WITH TANGENTIAL VAPOUR INLET

As the vapors generated from the evaporation are used as heating source in the "following" calandria, any product must be separated, seeing how it would otherwise contaminate the condensate and represent a loss. The majority of the concentrate is discharged from the bottom of the calandria below the tube bundle. Due to the high vapor velocity some of the concentrate will be carried along with the vapor as small droplets. The separation is done in a separator with tangential vapor inlet, see Fig. 17a, connected to the calandria below the tube.

Special care is taken to design the separator to avoid product carry-over at lowest possible pressure diop, as a drop in the pressure is equal to drop in heating enthalpy in the following calandria with an all-over drop in the*efficiency as a result.

**Product Distribution System**

An introduction to two different systems, the Dynamic distribution system, and the Static distribution system.

An evenly distribution of the production into all the tubes in the calandria is required for a good coverage. The product distribution system requires special attention during the design of an evaporator.

**DYNAMIC D5STRIBUTION SYSTEM**

In the dynamic distribution system**,** the necessary **kinetic energy for distribution** is obtained by a drop in pressure of the product over a full-cone nozzle. As the product is superheated in relation to the pressure inside the tubes, flash vapor is instantaneously formed. The mixture of product and vapor is sprayed into the inlet of the tubes thus being covered by product.

The ability of a nozzle to spray optimally depends on the pressure drop determined by the quantity of the liquid to be handled and the degree of flashing when entering the room above the tubes. This distribution system is not considered adequate in modern evaporators where flexibility, and thereby differences in the feed quantity are required. Further, in multi-effect evaporators the flashing, and therefore the distribution, is minimal due to low Δt.

## STATIC DISTRIBUTION SYSTEM

In the static distribution system the incoming superheated **product is first separated in flash vapour and product.** The product enters a **distributor plate**placed inside an open cone, when entering the **calandria.**The cone is placed above a distributor bowl with a number **of** holes, where a certain level of product is maintained. The product flows through the holes in the plate bv qrayjty. Each hole is placed just above the area between the tubes. Thus the product flows onto the tube plate and then over the edge down alonq the surface of each tube. The flash vapour also enters the tubes and pushes the product aqainst the inner surface of the tubes qivinq it its initial velocity. This distribution system is much more flexible in respect of capacity, as an increase in the level within the distributor bowl - as a result of increased capacity will make the product flow through the holes at a higher velocity, thus maintaining the level.

## 4.12 Preheating System

A preheating system can technically be carried out in two different ways, either as a Spiral tube preheater or as Straight tube preheaters.
Preheating of the milk to boiling temperature is the first step in the process, where steam is saved for evaporation. This process requires that the milk is passed through a vapour preheater / cooler, placed between the last effect's separator and the condenser, thereby saving cooling water as well. From the vapour cooler the milk is passed through the preheating system section of the last effect and then backwards to the first effect, before it enters the boiling section of the first effect.

## 4.13 Spray DryIng

By definition, **spray drying** is the transformation of feed from a fluid state into a dried form by spraying the feed into a hot drying medium. The process is a one step continuous operation. The feed can be either a solution, suspension or a paste. The spray dried product conforms to powder consisting of single particles or agglomerates, depending upon the physical and chemical properties of the feed and the dryer design and operation. During the last three decades spray drying has undergone an intensive research and development, so that modern spray drying equipment can meet the requirements to produce a powder with perfect specifications required by the end-user.

## 4.14 Types of DryIng

### 4.14.1 One Stage DryIng

One-stage drying is defined as the spray drying process where the product is dried to the final moisture content in the spray drying chamber, see Fig. However, the fundamental theory about the droplet formation and the evaporation of the initial moisture is the same in this and the following processes and therefore discussed here.
The initial velocity of the droplets from the rotary atomizer is about 150 m/sec. Most of the drying takes place while the droplets are decelerated by their friction to the air. Droplets with a diameter of 100 microns have a deceleration path of less than 1 m, and for droplets with a 10 micron diameter it is only a few centimeters. The main temperature drop of the drying air, due to the evaporation of the water from the concentrate, takes place during this period. An enormous heat and mass transfer therefore takes place in the particles during an extremely short period of time, and the product quality may be seriously harmed, if the factors promoting degradation are not known, or are disregarded. During the removal of water from the droplets a considerable reduction in weight, volume, and diameter of the particle takes place. Under ideal drying conditions the weight will decrease to about 50%, the volume to about 40%, and the diameter to about 75% of the created droplet from the atomizer.

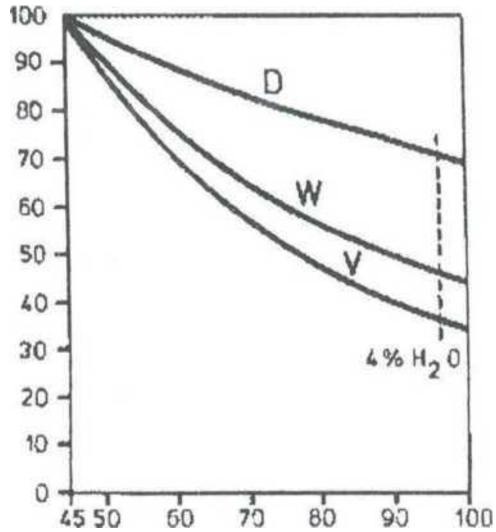


Fig.8 % Solid of droplets

However, the ideal droplet creation and drying technique have not yet been developed. There will always be some incorporation of air in the concentrate during pumping from the evaporator, and especially when the concentrate is pumped into the feed tank due to splashing. But also during the atomization a lot of air is incorporated into the concentrate in the rotary atomizer, where the wheel besides atomizing the concentrate is acting as a fan sucking in air and whipping it into the concentrate. Specially designed wheels will,

However, counteract the incorporation of air in the concentrate. In the curved vane wheel (the so-called high bulk density wheel), the air is partly separated from the concentrate again due to the centrifugal force, whereas in the steam-swept wheel, the problem is partly overcome by replacing the liquid/air interface with a liquid/steam interface.
It was generally believed that the nozzles during the atomization incorporated no or very little air into the concentrate. However, it has been found that some air incorporation takes place during the very early stage of atomization, both outside and inside the spray cone due to the air friction prior to the droplet formation. The higher the capacity of the nozzle (kg/h) the more air will be whipped into the concentrate.

Droplets of pure water (water activity 100%) will, when exposed to air at a higher temperature, evaporate keeping wet bulb temperature until completely evaporated, while solids containing products dried to the extreme (i.e. with a water activity approaching zero) are heated to the temperature of the surrounding air at the end of the drying, which in a spray dryer means the temperature of the outgoing air.

Not only from the centre to the surface is there a concentration gradient, but also from one point of the surface to another resulting in different water concentrations and thus different temperatures between different regions on the surface. The overall gradient intensity is bigger, the bigger the particle diameter, due to the smaller surface/mass ratio. Thus small particles dry in a more uniform way.
During the drying the solids content naturally increases due to the removal of water - and so does the viscosity and surface tension. This means that the diffusion coefficient, i.e. the water-

vapour diffusion/time and area, becomes smaller and overheating occurs due to the slower evaporation rate. In extreme cases the so-called case hardening will take place, which is the formation of a hard crust on the surface through which the remaining water-vapour or occluded air will diffuse very slowly. If case hardening occurs, it is usually at a residua! moisture content of 10-30% in the particle, at which stage the proteins, especially the caseins, are very sensitive to heat and easily denature resulting in a powder with poor solubility properties. Moreover, the amorphous lactose will become hard and almost impenetrable to water vapour, and the particle temperature increases further as the evaporation rate, i.e. diffusion coefficient, approaches zero.

As there will be more water vapour and air bubbles in the particle this will now get superheated, if the surrounding air temperature is high enough resulting in the vapour and air to expand. The pressure will increase, and the particle will blow up to a completely round ball with a smooth surface, see Fig. 73. The particle will have a lot of vacuoles inside, see Fig. 74. If the surrounding air temperature is high enough the particle may even explode, but even if it does not, the particle will have a very thin crust, about 1 micron, and it will not survive the mechanical treatment in the cyclones or in the conveying system and thus leave the dryer with the exhaust air. See Fig. 75.

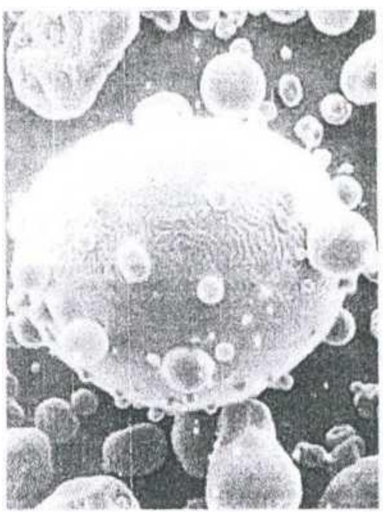

Fig. 73 Typical particle from One stage drying

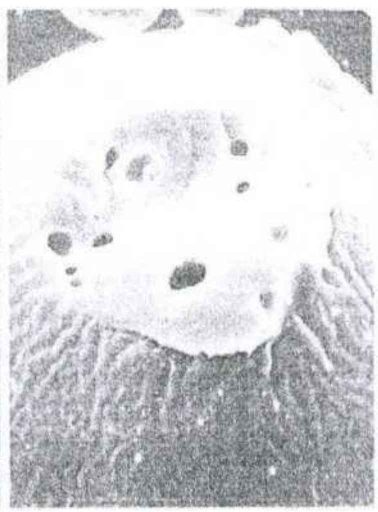

Fig. 74 Spray Particle from one stage drying

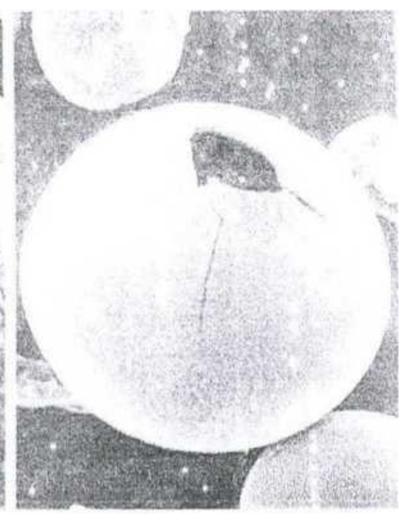

Fig.75 Over headed particle. One-stage drying

If there is only a small content of air bubbles in the particle the expansion will, in spite of the overheating, not be too extensive. The overheating as a result of case hardening will, however, have a detrimental effect on the caseins resulting in bad solubility.

If the surrounding temperature, i.e. the outlet temperature, is kept low during the drying, the particle temperature will be equally low.

The outlet temperature is determined by many factors of which the most important ones are:

- Moisture conteni in the final powder
- Temperature and moisture content of the drying air
- Solids content in the concentrate
- Atomization
- Viscosity of the concentrate

### 4.14.2 OVERALL DRYING EFFICIENCY

The overall drying efficiency is expressed in the following approximated formula:

$$\varepsilon = Ti - To / Ti - Ta \quad (17)$$

Where:
Ti = air inlet temperature
To = air outlet temperature
Ta = ambient temperature

It is thus obvious that the only possibility of increasing the efficiency of spray drying operation is by increasing ambient temperature by preheating using condensate from the evaporator, or by increasing the inlet temperature or decreasing the outlet temperature.

The relation £ is at the same time a good indication of the dryer performance, as the outlet temperature is determined by the residual moisture content which has to fulfill certain standards. A high outlet temperature will indicate that the drying air is not utilized in an optimal way due to various reasons such as bad atomization, bad air distribution, high viscosity, etc.

The $\varepsilon$ will in normal spray dryers operated on skim milk (Ti = 200°C, To = 95°C) be around 0.56.

### 4.15 Two-Stage DryIng

As discussed previously the particle temperature was given by the surrounding air temperature (outlet temperature). As the last water is the most difficult to remove by the conventional drying, the outlet temperature has to be high enough to ensure a driving force (At or temperature difference between particle and air) capable of removing the last moisture. That this will very often have a detrimental effect on the particles has been discussed earlier. It is therefore not astonishing that a completely different drying technology has been developed especially to evaporate the last 2-10% moisture from the particles already formed at that stage.

As the evaporation will go very slowly in this range, due to the diffusion coefficient being low, the drying equipment or after-dryer should be designed so that the powder will get a long residence time. It can be done in a pneumatic conveying system using hot air thus increasing the driving force. However, as a velocity of =20 m/sec. is required in the duct, it takes a considerable length of duct if it should be efficient. Another system consists of the so-called "Hot Chamber" with tangential inlet for pro-longing the holding time. After the drying is completed, the powder is separated in a cyclone and passed on to another pneumatic conveying system with cold or dehumidified air for cooling. The powder is separated in a cyclone and is ready to be bagged off.

Another system for after-drying is a VIBRO-FLUIDIZER®, which is a big horizontal box divided in an upper and a lower section by a perforated plate welded to the side wall of the box. For drying, alternatively cooling, warm and cold air is introduced into the air plenum chamber and is distributed evenly over the whole area of a special perforated plate, the BUBBLE PLATE™, with the following advantages:

The air is directed downward towards the plate surface, therefore particles will be kept moving on the plate, which has few, but large holes and can therefore operate longer time between cleaning. Further, it has demonstrated a very good emptying effect. The manufacturing method prevents crevices. The BUBBLE PLATE™ is therefore sanitary, and as such accepted by USDA.

The perforation and amount of air are determined by the necessary air velocity needed for the fluidizing of the powder, which in turn is determined by the nature of the powder such as the moisture content and thermo plasticity.

The temperature is determined according to the required evaporation duty. The hole size in the perforated plate is chosen, so that the air velocity will be high enough to fluidize the powder on the plate. The air velocity should not be so high that the agglomerated powder is destroyed due to attrition. However, it can never be avoided (and in some cases it is even desirable) that some particles, especially the small ones, leave the fluid bed with the air. The air is therefore passed through a cyclone or bag filter, where the particles are separated and returned to the process.

With this new equipment in hand it is possible to evaporate the last few per cent of moisture from the powder in a gentle way. This means that the spray dryer can be op-erated in a different way from the one previously described, where the powder left the chamber with the final moisture content.

### 4.16.1 Advantages of Two Stage DryIng

- Higher capacity/kg drying air
    - Better economy
    - Better product quality such as:
        - Good solubility
        - Highbulk density
        - Low free fat
        - Low content of occluded air
- Less powder emission
- The fluid bed can be designed either as a vibrating plug-flow bed (Vibro- Fluidizer) or a static back-mix bed.

## 4.16.2 Two Stage DryIng WIth VIBRO-FLUIDIZER PLUG FLOW

In the Vibro-Fluidizer the whole fluid bed is vibrating. The perforations of the plate are made so that the drying air is directed with the powder flow. To avoid that the perforated plate will vibrate with its own frequency, supporting is necessary.In the spray dryer the outlet temperature is decreased resulting in an increase of the moisture content and a decrease of the particle temperature. The moist powder enters by gravity from the drying chamber into the Vibro-Fluidizer.

There is, however, a limit as to how far it is operationally possible to go, as the powder will become sticky with the increased moisture content despite the lower temperature, and the powder will form lumps and deposits will occur in the chamber. Usually a reduction in the outlet temperature of 10-15°C may be achieved. This results in a much gentler drying especially during the critical drying stage (30% to 10% moisture), the shrinkage will continue, , not interrupted by any case hardening thus reaching conditions close to the optimal drying example. The lower droplet temperature is achieved partly due to the lower surrounding temperature, but also due to the higher moisture content in the particles thus being closer to the wet bulb temperature. This has naturally a positive influence on the solubility properties of the final powder.

The decrease in the outlet temperature means a correspondingly higher capacity in the drying chamber due to the increased At. Very often the drying temperature and the solids content in the feed are increased thus increasing the efficiency of the dryer even more. This means, however, a necessary simultaneous increase in the outlet temperature, but the higher moisture content and lower particle temperature protect the particles, so that overheating and case hardening can be avoided.

Experimental wise, the drying temperature has reached 250°C or even 275°C when drying skim milk, in which case the drying efficiency is as high as 0.75 When the chamber fraction reaches the base of the chamber it has higher moisture content and lower temperature than obtained from the conventional drying, as described previously. From the base of the chamber the powder should drop directly into the drying section of the Vibro-Fluidizer and be fluidized immediately. Any hold-up or conveying will cause the warm, moist and thermoplastic particles to stick together and lumps being hard to break will be formed. This has a direct negative influence on the drying efficiency in the Vibro-Fluidizer and part of the powder will leave the equipment with a too high moisture content, detrimental for the keeping quality of the powder.

Only the chamber fraction enters the Vibro-Fluidizer gravimetrically. The main cyclone fraction and the Vibro-Fluidizer cyclone (or CIP-able bag filter) fraction still have to be collected and conveyed to the Vibro-Fluidizer.

As the fines fractions consist of particles of a less mean diameter than particles from the chamber fractions, they will have a lower moisture content and thus do not require the same after-drying. Very often they are even dry enough, but despite that they are usually passed to the last third of the drying section of the Vibro-Fluidizer to make sure they become dried to the desired moisture content.

When the cyclone fractions are collected, the collection point cannot always be arranged directly above the Vibro-Fluidizer, so that it can be fed directly by gravity into the drying section. A pressure conveying system is therefore often installed to handle the powder. A pressure conveying system is very flexible in relation to where the powder is conveyed, as the conveying line is an ordinary 3 or 4 inch dairy pipe. The system consists of a low-volume/high-pressure air blower, a blow-through valve, al-lowing the air to pass through picking up the powder, and a conveying line. The amount of air is small in relation to the powder to be conveyed (only 1/5).

During production a small part of this powder becomes airborne again in the Vibro-Fluidizer and will leave with the air, collected in the cyclone and returned to the Vi-bro-Fluidizer again. During shut down of the plant it will therefore take some time before this recycling has stopped, if special arrangements are not foreseen.

The problem is for example handled by a change-over valve in the conveying pipe to another pipe passing the powder on to the very end of the Vibro-Fluidizer system, which is then emptied in a few minutes. The powder is finally sifted and bagged off. As the powder may contain some primary agglomerates, it is recommended to use another pressure conveying system to a silo in order to obtain the maximum density. It is a well-known, accepted fact that, when evaporating water from milk, the energy consumption/kg evaporation increases as the residual moisture approaches zero.

It has already been shown that the efficiency of the spray drying can be influenced by the inlet and outlet temperatures. While the steam consumption is 0.10-0.20 kg/kg evaporated water in the evaporator, it is 2.0-2.5 kg/kg evaporated water in a conventional one-stage dryer, or in other words 20 times as high as in the evaporator. Attempts are therefore always made to increase the solids content from the evaporator. This means that the evaporator will remove more water at a low energy consumption. It will of course lead to a slight increase of the energy consumption/kg evaporated water in the spray dryer, but the total energy requirement will be less.

The above mentioned steam consumption/kg evaporated water is an average figure, as the steam consumption at the beginning is very low increasing towards the end of the drying. A calculation shows that a powder with 3.5% moisture required 1,595 Kcal/kg powder, while for a powder with 6% moisture it is only 1,250 Kcal/kg powder. In other words this last evaporation corresponds to about 23 kg steam/kg evaporation. The table on the next page illustrates the calculation. The first row of figures shows the conditions when operating the plant under ordinary conditions with pneumatic cooling and conveying of the powder leaving the drying chamber and cyclones.The next row of figures shows the conditions when running the plant as a two- stage drying unit, in which the powder is dried from 6% moisture to 3.5% moisture in a Vibro-Fluidizer. The third row of figures shows the two-stage drying with high inlet temperature.

| DRYING SYSTEM Dryer at temp fldzr | Spray Dryer With pneumatic Conveying | System Spray with Vibro Fluidizer | Spray operated high Vibro |
|---|---|---|---|
| **SPRAY DRYER** | | | |
| Inlet air temp, C 200 | 200 | 230 | |
| Drying air, kg/h | 31500 | 31500 | 31500 |
| Skim milk with 8.5 % solids, kg/h | 12950 | 16150 | 19800 |
| Concentrate with 48% solids, kg/h | 2290 | 2860 | 3510 |
| Evaporation in chamber, kg/h | 1150 | 1400 | 1720 |
| Powder from chamber | | | |
| 6 % moisture, kg/h | -- | 1460 | 1790 |
| 3.5 % moisture , kg/h | 1140 | -- | -- |
| Fuel oil consumption, kg/h | 175 | 175 | 210 |
| Power Consumption, kg/h | 120 | 125 | 130 |
| Energy Consumption, | | | |
| Spray Drying Total, Mcal | 1818 | 1823 | 2120 |
| Energy/kg powder in Chamber, Kcal | 1595 | 1250 | 1184 |
| **VIBRO-FLUIDIZER** | | | |
| Drying air, kg/h | | 3430 | 4290 |
| Inlet air temp, C | | 100 | 100 |
| Evaporation in VF, kg/h | | 40 | 45 |
| Powder from VF, kg/h | | | |
| 3.5 % moisture | | 1420 | 1420 |
| Steam consumption, kg/h | | 135 | 167 |
| Power consumption, kW | | 20 | 22 |
| Energy Cons, total in VF, Mcal | | 95 | 115 |
| **DRYING TOTAL** | | | |
| Energy Consumption, Mcal | 1818 | 1918 | 2235 |
| Energy/kg powder total, Kcal | 1595 | 1350 | 1280 |
| Energy relation, % | 100 | 85 | 80 |
| Dryer efficiency | 0.54 | 0.62 | 0.66 |

By using the figures marked with *) we obtain:

1,595 - 1,250 = 345 Kcal/kg powder

The evaporation per kg powder is: 0.025 kg (6% - 3.5% = 2.5%)

The energy consumption per kg evaporation is then:

345/0.025= 13.800 Kcal/kgcorresponding to 23 kg steam/kg evaporated water.

In the Vibro-Fluidizer the steam consumption is in average about 4 kg steam/kg evaporation, all naturally depending on the amount of air and temperature that can be used. Even if the steam consumption is about twice as high in the VibroFluidizer as in the spray dryer, it is still (due to the special design allowing a residence time as long as 8-10 min. compared to 20-25 sec. in the spray dryer) far below the energy requirement, if the same water should have been evaporated in the spray dryer. At the same time it should be remembered that the plant will get higher capacity, produce a better product, the powder emission will be lower, and top of that the plant will be very flexible.

## 4.17 OPERATION OF A CONVENTIONAL SPRAY DRYER

The feed is pumped from the product feed tank to the atomizing device, located in the air disperser at the top of the drying chamber. The drying air is drawn from the atmosphere via a filter by a supply fan and is passed through the air heater to the air disperser. The atomized droplets meet the hot air and the evaporation takes place, while cooling of the air happen simultaneously. After the spray is dried in the drying chamber, the majority of the dried product falls to the bottom of the chamber and enters a pneumatic conveying and cooling system.

The fines, which are the particles with a small diameter, will remain in the air, and it is therefore necessary to pass the air through cyclones to separate the fines. The fines leave the cyclone at the bottom via a locking device and enter the pneumatic system, too. The air passes from the cyclone to the atmosphere via the exhaust fan. The two fractions of powder are collected in the pneumatic system for conveying and cooling and are passed through a cyclone for separation, after which they are bagged off. The instrumentation comprises indication of the temperature of the inlet and outlet air, as well as automatic control of the inlet temperature by altering the steam pressure, amount of oil or gas to the air heater, and automatic control of the outlet temperature by altering the amount of feed pumped to the atomizing device.

A conventional spray dryer consists of the following main components:

- Drying chamber (1)
- Hot air system and air distribution (2)
- Feed system (3)
- Atomizing device (4)
- Powder separation system (5)
- Pneumatic conveying and cooling system (6)
- Fluid bed after-drying/cooling (7)
- Instrumentation and automation (8)

## 4.18 Powder Separation System

As the drying air will contain a small proportion of powder (10-30%) when it leaves the chamber, it is necessary for economic reasons, but also because of pollution problems, to clean the drying air by separating the powder particles. This powder fraction is usually referred to as the fines, as they normally represent the smallest particles.

The most used separators in the milk powder industry are:

- Cyclone
- Bag filter
- Wet scrubber
- CIP-able bag filter

**Cyclone**

The **cyclone has some obvious advantages,** such as high efficiency, if it is constructed properly, it is easily maintained as there are no moving parts, and, furthermore, it is easy to clean, if the construction is with a fully welded centre cyclone,

The operation theory is based on a vortex motion where the centrifugal force is acting on each particle and therefore causes the particle to move away from the cyclone axis towards the inner cyclone wall. However, the movement in the radial direction is the result of two opposing forces where the centrifugal force acts to move the particle to the wall, while the drag force of the air acts to carry the particles into the axis. As the centrifugal force is predominant, a separation takes place.

Powder and air pass tangentially into the cyclone at equal velocities. Powder and air swirl in a spiral form down to the base of the cyclone separating the powder out to the cyclone

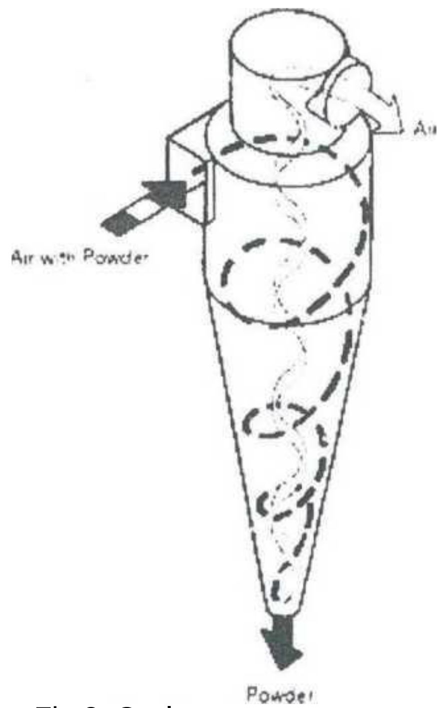


Fig.8 Cyclone

wall. Powder leaves the bottom of the cyclone via a locking device. The clean air spirals upwards along the centre axis of the cyclone and passes out at the top. See Fig. 52.

The centrifugal force each particle is exposed to can be seen in this equation:

$$C = m \times V_t^2 / r \quad (16)$$

Where:

C = centrifugal force

m = mass of particle

$V_t$= tangential air velocity

r = radial distance to the wall from any given point

From this equation it can be concluded that the higher particle mass, the belter efficiency. The shorter way the particle has to travel the better efficiency, and the clossr the particle is to the wall the better efficiency, because the velocity is highest and the radial distance is short.

However, time is required for the particles to travel to the cyclone wall, so a sufficient air residence time should be taken into consideration when designing a cyclone. From above equation it is evident that small cyclones (diameter less than 1 m) will have the highest efficiency, a fact generally accepted.

However, the big tonnage dryers in operation in the dairy industry nowadays would require many cyclones (a cyclone battery). As each cyclone has to have an outlet for powder in form of a rotary valve, pneumatic valve or flap valve, this means that there is a big risk of air leaks which will reduce the cyclone efficiency. The small cyclones can also be connected to one central hopper, and only one valve is then necessary, see Fig. 53. This means however, that unless there is exactly the same pressure drop over each cyclone, air and powder will pass from one cyclone to another via the bottom outlet. This will result in decreased efficiency and increased powder loss. Cleaning the many small cyclones is a problem, as it is a time consuming job, and with the many corners there is a risk of a bacterial infection.

For above reasons the cyclones have become bigger and bigger and are now constructed with diameters of 2.5-3 m, each handling 25,000-30,000 kg of air/h. When designing a cyclone various key figures should be taken into account in order to obtain the highest efficiency. This is achieved if

Cyclone diameter / exit duct diameter ~ 3
Cyclone height / exit duct diameter ~ 10

Air through-put (velocity $V_t$) and increased pressure drops will also increase the efficiency, but the energy requirement will increase simultaneously, so in general the upper limit is 175-200 mm WG for skim milk powder. 140-160 mm WG is the maxi-mum for whole milk in order to avoid deposits and final blocking. In most cases rotary valves are used as air lock and product discharge at the bottom of the cyclone. The conical type allowing for easy adaption of the gap between the housing and the rotor should be preferred as the powder loss may be reduced.

In order to know a cyclone's efficiency the following terms have to be defined:

a) The critical particle diameter
b) The cut size
c) The overall cyclone efficiency

a) The critical particle diameter is defined as the particle size that will be completely removed from the air flow (100% collection efficiency). However, as there is no sharply defined point where a particle size is 100% separated or 100% lost the critical particle diameter is not very valuable.

b) The cut size is defined as the size for which 50% collection is obtained and is a much better value for stating the efficiency of cyclones to determine a cyclone's cut size, grade efficiency curves are worked out by systematically operating a cyclone with a uniform particle size dust.

c) The overall cyclone efficiency is the one obtained when handling a product of definite size distribution. Knowing the grade efficiency curve of the cyclone and the product size distribution of the powder passing to the cyclones, the overall efficiency can be calculated, i.e. the powder loss can be predicted. Another method of learning the cyclone efficiency is by a simple powder loss measurement after the cyclone.

## 4.19 Bag Filters

A very small fraction of the out-going air is passed through a high-efficient mini cyclone or through micro dust filters. The amount of powder collected is directly proportional to the powder loss, which will mainly be a result of:loss of <10 mg/Nm$^3$. Final cleaning of the air is therefore necessary. This is usually done in bag filters consisting of numerous bags or filters arranged so that each bag receives equal quantities of air. The direction of the air is from outside in through the filter material to the innei part of the bag from where the cleaned air enters an exhaust manifold. With a correct selection of filter material high efficiencies can be obtained and collection of 1 micron particles is reported from the manufacturers the collected powder is automatically shaken off by blowing compressed air via a Coanda venturi nozzle positioned inside the top part of each bag. The powder is collected at the bottom via a rotary valve.

The bag filter may also replace the cyclones, a solution often chosen for one- stage dryers for whey protein powder or egg white. To prevent condensation, especially on the conical part of the filter housing, warm air or heat tracing is established.

## 4.20 Comparison of Powder Separators

**CycloneCyclone +Cyclone+SANICIP™**
**Bag FilterWet Scrubber**

| | | | | |
|---|---|---|---|---|
| Emission<br>mg/Nm$^3$ | 20-400<br>Mg/Nm$^3$ | 5-20 mg/Nm$^3$ | max.20<br>mg/Nm$^3$ | 5-20 |
| Pressure loss<br>mm WG<br>Exhaust system<br>(Incl. Ducts etc) | 280 mm WG | 340 mm WG | 340 mm WG | 170 |
| Auxiliaries<br>cyclone | none | compressed air | liquid circulating<br>Steam | |
| Cleaning<br>Suitable for CIP | suitable for CIP | difficult | Suitable for CIP | |
| Hygroscopic Products<br>insensitive | insensitive | sensitive | insensitive | |
| Use of Separated<br>grade<br>Products | first grade | First and Second<br>grade | not recommended | First |
| Maitenance<br>and change<br>bags | minimal | system and change<br>Of bags | minimal | system<br>of |
| Sanitary Conditions | good | relatively good | less good | good |

## FLUIDIZED BED AFTER DRYING & COOLING

In order to improve the drying economy the drying is divided in two or more steps. The first step is done in a spray drying chamber transforming the liquid into powder particles and evaporating the main portion of the water. As it will be discussed later, the evaporation of moisture from a particle will become more difficult and require more time, as the residual moisture content approaches 0%.

The subsequent drying is done in a fluid bed, The fluid bed drying technology has proved especially suited, as the residence time in the fluid bed is so long that the moisture from the center of the particle can reach the surface from where the evaporation takes place.

In a fluid bed the drying air is introduced to the powder through a special perforated plate, the BUBBLE PLATE™. Special features of the BUBBLE PLATE™ are:

- The air is directed downwards towards the plate surface.
- The bubble plate has few, but large holes.
- The unique manufacturing method prevents crevices.
- The bubble plate has shown a very good emptying effect.

The fluid bed can be vibrating, or stationary. The fluid bed offers at the same time a very efficient and lenient tool for cooling of fat containing and agglomerated products.

### 4.20 AIrFIltratIon

Until a few years ago no special requirements were given as to the filtration of the process air for the spray drying process. Today, however, very strict requirements are presented by local authorities in order to ensure a cleaner operation and it is important to refer to the test method when specify-ing the filter efficiency in %. Common for the different requirements is that: heater/cooler. Some countries have even stricter requirements demanding a filtration of up to 99.995%, corresponding to EU13/14 (or H13/14). '

- Current practice is as follows:
  - Dairy like products

-Prefiltration EU4 (or G4) =35% Dust-spot efficiency -Main air filtration EU7 (or F7) =90% Dust-spot efficiency •Secondary air filtration EU7 (or F7) =90% Dust-spot efficiency -Baby food products, equal to or better than IDF:

-Prefiltration EU6 (or F6) =70% Dust-spot efficiency -Main air filtration EU7 for F7) =90% Dust-spot efficiency -Secondary air filtration EU9 (or F9) >95% Dust-spot efficiency.

### 4.21 AIR HEATING SYSTEM

## HOT OIL LIQUID PHASE AIR HEATERS

Hot oil liquid phase air heaters are used either alone, or when high inlet drying air temperatures are required, or the steam pressure is not high enough. The heater system consists of a heater, which can be gas- or oil-fired, and an air heat exchanger. Between these two components a special food-grade oil or heat transfer fluid, which does not crack at high temperatures, is circulated at high speed. The main advantage of hot oil liquid phase is the open pressure-less system.

## 4.22 AIR DISTRIBUTION SYSTEM

In dryers with horizontal chamber, the air disperser is arranged like a plenum chamber, and each nozzle will be surrounded by an air stream. The same system is also seen in vertical cylindrical dryers.

However, the most common is that the air disperser is situated on top of the dryer ceiling, and the atomizing device is placed in the middle of the air disperser thus ensuring an optimal mixing of the air and the atomized droplets. In cylindrical vertical dryers it is also seen that the whole ceiling is perforated thus creating a plug-flow air stream - numerous nozzles are situated in the perforated plate in order to ensure that the air is cooled by the concentrate. This system, however, makes fines return complicated, and the obtainable air velocity/nozzle position is not optimal for an efficient drying. It should be noted that an air disperser should have the ability to guide the air and the atomized droplets in the right direction in order to avoid deposits in the drying chamber.

On big capacity dryers equipped with nozzles, the so-called "multi-neck" air disperser is seen, i.e. the dryer is equipped with 3-5 air dispersers and nozzle units. The center area in the ceiling between the air dispersers is, however, impossible to keep free from deposits, and uniform fines return is difficult.

## PLUG-FLOW AIR STREAM

The air enters radially through one side and is distributed through an adjustable air guiding arrangement.

This type of air disperser is used for nozzle atomizers, where a laminar plug-flow air stream is wanted. As for the rotary air disperser cooling air is also used here. As the nozzle rods are placed in the middle of the hot air stream, cooling air is also provided for the nozzles lances to keep the product from over-heating.

The aim of atomizing the concentrate is to provide a very large surface, from which the evaporation can take place. The smaller droplets, the bigger surface, the easier evaporation, and a better thermal efficiency of the dryer is obtained. The ideal from a drying point of view would be a spray of drops of same size, which would mean that the drying time for all particles would be the same for obtaining an equal moisture content. In practice, however, no atomizing device has yet been designed to produce a completely homogenous spray, although present designs have a high degree of homogeneity. From a powder bulk density point of view a homogenous spray is not wanted, as this would mean a powder with low bulk density, and that would mean an increase in packing material. It is, however, so that today's achievement of atomizing facilitates both the drying and the powder bulk density.

As mentioned previously the air distribution and atomization are the key factors to a successful utilization of the spray dryer. The atomization is directly responsible for many distinctive advantages offered by the spray drying. First, the very short drying time of the particles can be mentioned, secondly a very short particle retention time in the hot atmosphere and low particle temperature (wet bulb temperature) and finally the transformation of the liquid feed into a powder with long storage stability ready for packing and transport. Summarized, the prime function of atomizationis:

- a high surface to mass ratio resulting in high evaporation rates,
- Production of particles of the desired shape, size and density.

### 4.25 Rotary Atomization

In rotary atomizers the liquid is continuously accelerated to the wheel edge by centrifugal forces, produced by the rotation of the wheel. The liquid is distributed cen-trally and then extends over the wheel surface in a thin sheet, discharged at high speed at the periphery of the wheel. The degree of atomization depends upon peripheral speed, properties of the liquid, and feed rate.

The wheel should be designed, so that it will bring the liquid up to the peripheral speed prior to the disengagement. Very often the wheels are therefore with vanes of different design to prevent liquid slippage over the internal surface in the wheel. The vanes also concentrate the liquid at the disc edge, producing there a liquid film analogous to the one considered in pressure nozzles. The wheel will act as a fan and air is sucked into the concentrate due to the rotation. Different wheel designs and properties decide how much air is incorporated in the atomized droplets.

In spite of intensive Investigations into the mechanism of atomization from rotating atomizer wheels, the prediction of spray characteristics still remains uncertain. The effect of individual variables has been established over a limited range and there is only a few dealing with high capacity, high speed industrial atomizers. However, the relation between droplet size and various products and operation characteristics is as follows:

**LIQUID FEED RATE**

Droplet size varies directly with feed rate at constant wheel speed, and will increase with increased feed rate (power of 0.2)

**PERIPHERAL SPEED**

The peripheral speed is depending on the diameter of the wheel and the wheel speed and is calculated as follows:

$$V_p = n^x D * N / 1000x60 \quad (14)$$

Where:

$V_p$ = Peripheral speed (m/sec)
D = Diameter of the wheel (mm)
N = Speed of the wheel (r.p.m.)

The peripheral speed is widely accepted as the main variable for adjustment of a specified droplet size. However, it has been shown that droplet size does not necessarily remain constant, if equal peripheral speeds are produced in wheel designs of various diameter and speed combinations, and there is a tendency that bigger wheels produce bigger particles all other things being equal.

However, in the choice of wheel diameter one should rather look at the reliability of the atomizer, as the differences in spray characteristics are negligible. Further, smaller wheels are easier to handle when cleaned.

**Advantages**

- Flexibility as to through-put
- Ability to handle large quantities
- Ability to handle highly viscous concentrates
- Different wheel designs giving different powder characteristics
- Ability to handle products with crystals
- Higher solids content in the feed is possible, therefore better economy

To decide whether to use pressure nozzles or rotary wheel is therefore a question of type of product.

For conventional milk products as well as crystallized whey concentrate the rotary wheel will be the preferred atomizing device, whereas for very high density powders and instant whole milk powder and other products with high fat content, the high-capacity low-pressure nozzles should be used in connection with two- stage drying.

As it is impossible to predict what type of product should be produced tomorrow, there has been a tendency to select dryers capable of using both systems, i.e. they should be directly interchangeable.

## 4.26 AgglomeratIon

Agglomeration means getting smaller particles to adhere to each other to form a powder consisting of bigger conglomerates/agglomerates, which are essential for an easy reconstitution in water.

The agglomeration is improved by:

- High solids content in the concentrate
- Bigger quantity of fines returned to the atomizing device
- Fines introduction closer to the atomizing device
- Shorter distance from nozzle to fluidized layer in a static fluid bed
- Higher moisture content from the primary drying stage
- Bigger primary particles
- Lower pasteurization temperature of the milk prior to the evaporation

When leaving the sifter the powder should not be exposed to strong mechanical conveying, neither by means of air nor by fast moving mechanical scceyys. However, today's lenient vacuum-low speed air systems are used without too much damage to the agglomerates. The best thing, however, is to install the plant so high tnat filling into bags or tote-bins is possible by gravity.

**REWETAGGLOMERATOR™**

Rewet agglomeration plant is shown in Fig. 92, which illustrates the principle of a method developed by Nestle for agglomerating milk powders, chocolate- flavored beverages and soups. When agglomerating skim milk powders the tank

(1) would contain a 10% solution of skim milk solids in water cooled to about 6°C. The liquid is sprayed at a pressure of 20 bar by means of the pump

(2) and nozzle

(3), which is designed to give a flat jet with a high velocity of up to 8 m/sec. Skim milk powder, which is fed by means of a vibrator/screw conveyor

(4) , is dispersed over the jet where the single powder particles become rewetted to a moisture sufficiently high (10-15%) to make them sticky on the surface, so that any collision between particles will result in an agglomeration in the chamber

(5) The powder is finally dried at 90°C to 3% moisture

(6) And bagged off.

The main features of the REWET AGGLOMERATOR™ process are:

- Wetting of the surface of the particles
- Agglomeration
- Redrying
- Cooling
- Sizing

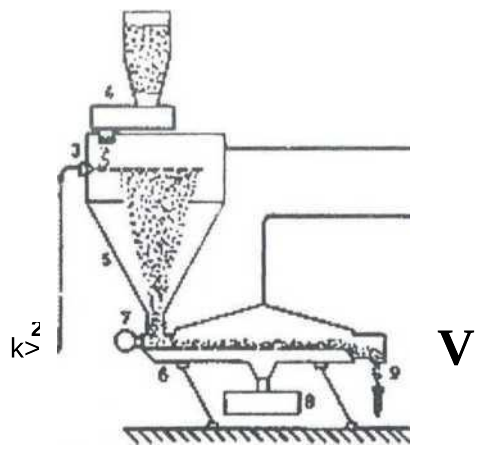


Fig. 92 REWET AGGLOMERATOR™ plant (Nestle)

## WETTING

Wetting of the surface of the particles is done with humid air, steam, atomized water either pure or containing milk solids, sugar or other soluble components. The water may further contain additives such as vitamins (water soluble), minerals, colour and surface-active agents. The atomization of the moistening agent can be carried out by means of nozzles or a rotary atomizer. If-a-rotary atomizer with two feed pipes is used, it is possible to use a combination of steam and water or use two moistening agents, which cannot be mixed for various reasons.

If the product is insoluble, an adhesive can be dissolved in the moistening agent. When doing so products otherwise impossible to agglomerate can be agglomerated with a good result.

## AGGLOMERATION

Agglomeration, whereby the moist sticky particles collide due to the turbulence and adhere to each other forming agglomerates, is essential for the rewet process. As powders with different compositions do not behave in the same way during the rewetting and agglomeration process, different equipment is needed to obtain an optimal agglomeration.

In principle there are two ways of performing the agglomeration:

- Droplet agglomeration
- Surface agglomeration

**DropletAgglomeratIon**

In the droplet agglomeration process the powder particles are wetted with droplets of liquid atomized by means of a nozzle or a rotary atomizer while suspended in air, as described in Fig. 93. The powder may either be introduced around the rotary atomizer or the nozzle by means of gravity or pressure air conveying, or from below by means of pressure conveying.

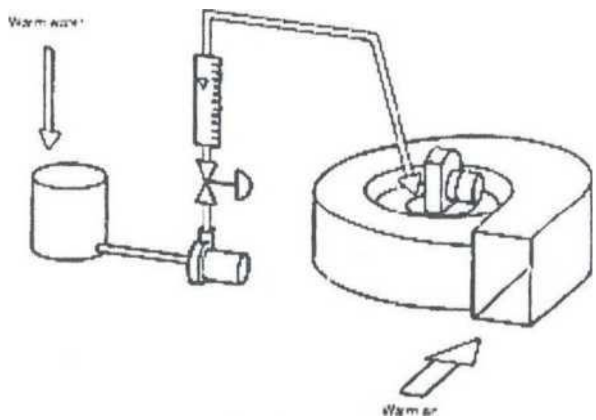


Fig. 10 Feed system for a rewet plant (wetting by means of warm water Atomized by an atomizer)

The actual agglomeration takes place by collision of the single particle setted and sticky on the surface, and when they reach the agglomeration chamber wall they will roll down whereby the compactness of the agglomerates is obtained.

Droplet agglomeration can also be performed by spraying the wetting agent through a number of nozzles positioned right above the fluidized powder layer in a Vibro-Fluidizer. To obtain stable agglomerates the powder should contain sufficient binding material, like carbohydrates. Some powders (containing a high content of fat and sugar) become so sticky when wetted, that heavy deposits in the conical part of the agglomeration chamber develop. A mechanically revolving scraper or similar is therefore necessary in order to get the powder out of the chamber. Another and technically better solution is to let the conical part of the agglomeration chamber rotate slowly and have a stationary scraping device such as a knife scraping off the powder. The rotating cone is mainly used when the powder contains cereals and starch, such as baby foods.

The droplet agglomeration process is especially used for powders containing fat such as whole milk powder and powders with a high content of sugar such as

- The air should be prefiltered and supplied by a separate fan to the fan/filter/heater room. This room must be under pressure to avoid unfiltered air to enter.
    - Filtration degree and filter position depend on the final temperature of the process air as follows:
      - For main drying air to be heated above 120°C only coarse filtration up to 90% is needed. The filter should be placed on the pressure side of the fan.
      - For secondary air to be heated below 120°C or not heated at all.

**Surface Agglomeration**

In the surface agglomeration either steam or warm moist air with a high relative humidity is used as the moistening agent. The surface of the individual dry particles is wetted due to condensation of the water vapor on the colder particles, whereby the stickiness required for the agglomeration is created. The subsequent agglomeration will take place, if the particles are exposed to sufficient mechanical impact. The impact can for example be accomplished in a vortex tube into which the moistening medium is introduced tangentially and the powder to be agglomerated along the center axis. It is very important that the humid air/steam used for the rewetting does not contain any droplets of water, as that, in combination with the intensive mechanical impact, will result in over wetted agglomerates being too compact for a quick rate of rehydration.

The warm humid air is usually made by spraying steam into warm air at a given temperature to obtain a relative humidity of 100% Any water droplets are removed in a demister, after which the air is heated further to give the desired relative humidity. By changing the air temperature prior to the steam injection and the subsequent air temperature, it is possible to obtain air with a given temperature and relative humidity. See Fig. 94.

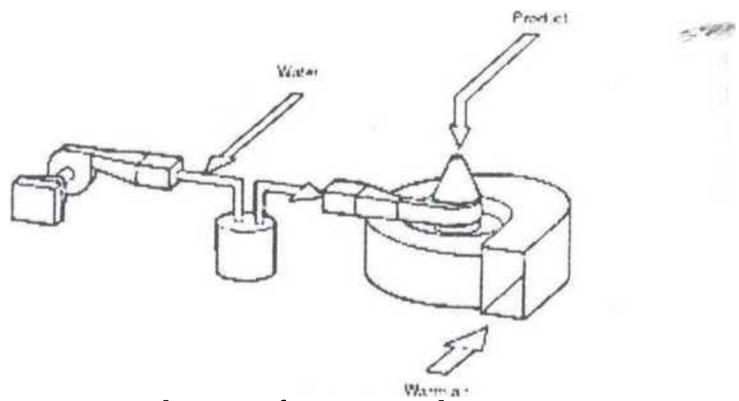


Fig. 10 Feed system for a rewet plant.
Wetting by means of warm moist air

The surface agglomeration is mainly used for skim milk powder when large agglomerates are aimed at. The final product properties depend to a great extent on the raw material used for the rewetting, and below is shown a specification for a recommendable basis powder:

| | |
|---|---|
| Bulk density, tapped 1250x | 0.80g/$cm^3$ |
| WPNI: | 2-3 mg/g powder * |
| Insolubility index: | Greater than 0.1 ml |
| Particle density: | 1.35 g/$cm^3$ |
| Mean particle size: | approx. 50 $\mu m$ |
| Amount above 100 pm: | max. 25% |

*corresponding to a pasteurization temp of 90C prior to evaporation.

The surface agglomeration can also be used for whole milk powder, but the agglomerates get too compact for obtaining a powder with good rehydrating properties.

**REDRYING**

As the basis powder used for agglomeration is remoistened to obtain the desired surface characteristic for an optimal stickiness, this additional moisture has to be evaporated again in order to reach the specified moisture content.

The agglomerates may break down again, if they are exposed to extensive mechanical handling, such as in a pneumatic conveying system. It is therefore necessary to perform the drying in a Vibro-Fluidizer as mentioned on page 11S. However, as the rewetted powder is to be compared to a layer of wet snow when entering the Vibro-Fluidizer, a relatively high air velocity is required to fluidize the powder. Otherwise, lumps will be formed, and the drying efficiency of-the Vibro- Fluidizer will decrease.

**COOLING**

Like the redrying the cooling is performed best in a Vibro-Fluidizer.

**SIZING**

Usually, there is a well defined requirement to the agglomerate size distribution of the final powder. It is therefore necessary to sift the powder. This is done in a sieve with two different net sizes placed above each other. Thus it is possible to remove any agglomerates/lumps considered to be too big in the final product. This oversize fraction may be milled and returned to the process. Powder passing through the upper ne* may be further fractionated on the lower net into a main fraction and a fines fraction consisting of single particles and agglomerates being too small. This fines fraction is together with the cyclone fraction from the Vibro-Fluidizer recycled back to the process.The actual powder feeding system consists of a silo and a screw conveyor with variable speed. The powder is by means of a rotary blow-through valve fed into a high-pressure airline conveying the powder to the agglomerating module.

It is usually a requirement to most rewet installations that they are product flexible. Therefore, both droplet and surface agglomeration methods are often installed in the same plant. The rotating cone may also easily be incorporated in the plant thus giving the possibility of agglomerating any milk based product. Lecithination may naturally also be applied to this process, if cold water fat- containing products are aimed at. In Fig. 95 a flow sheet of a rewet plant NIRO design is shown, with the possibility of all above mentioned agglomeration systems.

# CHAPTER 5

# Heat Recovery & Optimization of the Process

## Heat Recovery in Milk Powder Production:

Having discussed the main factors influencing the heat economy of the individual equipment, we can now look at the complex production line, where a considerable amount of heat is disposed of into the environment in form of warm condensate from the evaporator and warm air from the spray dryer. There are several possibilities of utilizing this energy:

### 5.1 Preheating

#### (i) Preheating the Drying Air with Condensate:

From an evaporator, a substantial amount of condensate is discharged with a temperature of 50-70°C depending upon from which stage of the evaporator it originates.

A simple method is to utilize this energy for preheating the drying air. The condensate from the first effect of the evaporator with temperature of about 70°C is normally returned to the steam boiler, where it is used as feed water. This is advantageous because it is warm and soft. But the condensate from the last effects can be used. The temperature is typically 56°C.The drying air is preheated to 47°C reducing the fuel oil consumption to 170 kg/h, however, a bigger condensate pump and supply fan are needed due to the bigger .pressure drop across the system. Below mentioned figures illustrate the total net saving:
Ambient air preheated from 10°C to 47°C
Condensate cooled from 56°C to 32°C:

**Without Preheater:**

| | |
|---|---|
| Fuel consumption: | 205 kg/h |
| Steam consumption: | 167 kg/h |
| Electric energy consumption: | 152 Kw |

Corresponding to 1,280 Kcal/kg powder

| | |
|---|---|
| Fuel consumption: | 170 kg/h |
| Steam consumption: | 167 kg/h |
| Electric energy consumption: | 159 kW |

Corresponding to 1,090 Kcal/kg powder or a net saving of 15%.

Another advantage is that the condensate is cooled to 32°C and can thus be led direct into a bacteriological waste water cleaning plant, where too high temperatures are not allowed.
If we compare with the saving in a one-stage dryer it will amount to about 32%.
In MVR evaporators with preheating/heat treatment of the milk from 5°C to 72°C, the applied energy through the compressor is just enough for the evaporation and a discharge temperature of the concentrate at «50°C and the condensate at «10°C. Only if a heat treatment higher than 72°C - by using additional steam - is wanted, the temperature of the condensate will be high enough, so that it can be used for preheating the drying air.

**Preheating the Drying Air with Vapour from the Evaporator:**

The vapor from the last effect of the evaporator (temp. 45-50°C) is usually passed through a tubular heat exchanger, where the vapor is cooled by means of the cold incoming product, which is reheated. The precooled vapor is passed on to a condenser, where it is condensed using cooling water either from a cooling tower or a natural water reservoir.
It is an obvious idea to utilize the drying air instead of cooling water in a heat exchanger for condensing the vapor simultaneously preheating the drying air.

In the four-effect evaporator operating in conjunction with the two-stage spray dryer at a drying temperature of 230°C, as described on page 145, there is approximately 800 kg/h vapor with a temperature of about 47°C available. However, by means of 31,500 kg/h air at 10°C it is only possible to condense 400 kg/h.

Therefore, an additional condenser, operated with water, is necessary. Another inconvenience of this system is that the additional condenser should have sufficient capacity to cope with the extra duty in case the ambient temperature increases. Further, during start-up of the evaporator it is necessary to have at least the fans of the spray dryer operating to get stable conditions in theevaporator. Therefore, this way of saving energy in the spray dryer is not used in practice, but only included, as there is a patent describing it as a possibility.

## 5.2 Heat Recuperation

**Wet Scrubber**

The heat contained in the exhaust air can be recovered in different ways. If the wet scrubber is operating with milk or whey as washing medium, an evaporation is achieved. The **main purpose of a wet scrubber** is of course to prevent air pollution by recovering the powder contained in the exhaust air. However, in the scrubber the exhaust air is cooled from the outlet temperature to the wet bulb temperature, i.e. to about 45°C, thus utilizing the heat for pre-evaporation of the milk before this enters into the evaporator. The effect of the wet scrubber on the total heat economy of the milk powder production line is substantial, and the savings together with product recovery are covering running costs inclusive of the relatively short return of the investment.

The temperature in the scrubber offers favorable conditions for bacterial contamination. The scrubber should therefore be used only when milk of first class is available. If the equipment is operated according to the instruction manual, which describes intermediate cleaning after 10 hours, the bacteriological activity will be minimal, as the retention time is considerably less than the generation time of the bacteria.

As it was the case with preheating with condensate, the wet scrubber offers a multiple advantage, as besides the heat recuperation it solves the pollution problem, and further the system has a substantial evaporation capacity. Part of the advantage is, however, lost again due to the needed intermediate cleaning after 10 hours. Use of wet scrubbers circulated with product is therefore not used very often in the industry.

The above mentioned systems for saving energy, apart from two-stage drying, have all required that the evaporator and spray dryer are operated at the same time. However, in some cases only the spray dryer is operated. Attempts have therefore been made to develop a heat recuperator for the spray dryer alone.

## 5.3 Heat Recuperator:

The aim of a heat recuperator is to transfer the heat contained in the outlet air, having temperatures of 80-95°C, from the spray dryer and to utilize it e.g. to preheat the drying air. But it is also possible to use the recuperated heat to heat water for cleaning purposes or air for heating rooms. In the following only preheating of the drying air is discussed.

In principle, there are **two different recuperating systems:**

- Air-to-Air
- Air-Liquid-Air

Both systems are incorporated after the fines separator. However, incorporating a bag filter

prior to the heat recuperator increases the efficiency, as deposits on the heat surface cannot be completely avoided even with correctly selected air velocities in tne dust-loaded air. It is possible to operate the recuperator several days without cleaning, but should it prove necessary to clean the equipment, this is done by means of a built-in CIP system.
If the heat recuperator is designed to cool the outgoing air below the condensation temperature (depending upon moisture content per kilo dry air), also the condensation enthalpy is used for preheating. In this case a bag filter is installed prior to the heat re-cuperator to avoid deposits in the intermediate zone between the diy and wet area. Even bigger savings are then possible than the ones described below, which are all calculated without condensation.

- **AIR TO AIR HEAT RECUPERATOR**

In the heat recuperator type air-to-air, see Fig. 98, the drying air is preheated by means of the outgoing air passing counter-currentiy over the heat surface of the recuperator. This surface is formed as a number of tubes, inside of which the outgoing warm air is passing while the cold air is passing on the outside.

The incorporation of this equipment in an existing plant may prove difficult and ex-pensive, as it may require large and long air ducts from which part of the recuperated energy is lost due to radiation, if the ducts are not insulated. In new installations it is easier to incorporate this type of heat recuperator, as the arrangement can be optimized with short air ducts. See Fig.

The temperature to which the air can be preheated depends upon the temperature of the outgoing air. Therefore, this type of heat recuperator is most beneficial in combination with a one-stage spray dryer where the temperature of the outgoing air is high. The figures mentioned below are based upon a one- stage plant as mentioned in the table on page 139. Ambient air preheated from 10°C to 52°C Outgoing air cooled from 93°C to 51°C:

**Without Recuperator:**

Fuel consumption: 175 kg/h
Electric energy consumption: 120 kW
Corresponding to 1,595 Kcal/kg powder

**With Recuperator:**

Fuel consumption: 140 kg/h

Electric energy consumption: 135 kW
Corresponding to 1,305 Kcal/kg powder or a net saving of 18%.

- **AIR LIQUID AIR HEAT RECUPERATOR**

Another system, more flexible regarding the installation, is the air-liquid-air heat re-cuperator, see Fig. 100. This system is divided iri two heat exchangers, in between which a heat transfer liquid is circulated, for example water. See Fig. 100a. If, due to low air temperatures during winter, it may be expected that the temperature of the water gets beiow zero, an anti-freeze agent is added to the water. As the heat transfer coefficient is higher for air-liquid than for air-air, this system is more efficient than the air-to-air heat recuperator despite the fact that two heat surfaces are needed.

The heat transfer surface placed in the outgoing air is formed as a bundle of tubes inside which the dust-loaded air is passed. On the outside of the tubes the water streams counter-currently. The heat transfer surface placed in the inlet air is a normal finned tube heat exchanger. Water is recycled by means of a centrifugal pump.
If a recuperator of this type is installed in a one-stage spray dryer, the below mentioned heat savings are possible:

Ambient air preheated from 10°C to 60°C
Outgoing air cooled from 93°C to 44°C:

**Without Recuperator:**

| | |
|---|---|
| Fuel consumption: | 175kg/h |
| Electric energy consumption: | 120 kW |

Corresponding to 1,595 Kcal/kg powder

**With Recuperator:**

| | |
|---|---|
| Fuel consumption: | 130 kg/h |
| Electric energy consumption: | 142 kW |

Corresponding to gas-fired air heaters are used, the heat transfer liquid can - after the passage through the exhaust air heat exchanger - be passed through a heat exchanger placed in the combustion air duct, whereby even further savings can be achieved.

### 5.4 Other Means of Saving Energy

When a new milk powder factory is designed there is a very simple method of pre-heating the drying air, namely by locating the air inlet filters inside the building where the dryer is. Then the incoming air is picking up the radiation heat from the dryer and possibly also from the evaporator and other equipment, especially if the air inlet to the building is placed at the top, and the air filter is placed at the bottom of the building or vice versa. A potential disadvantage of this method is the danger that the cold air from outside may hit and cool some parts undesirably, cyclones for example, causing the risk of condensation and deposits. Besides, the incoming air is picking up not only heat, but also moisture resulting in an increase in the outlet air temperature, which means a lower capacity.

If indirect oil or gas-fired air heaters are used, it is possible to install a process air/combustion air heat recuperator directly on the air heater. The combustion air has typically a temperature of >300°C, but the quantity in kg/h is low; further there will always be a risk that in a leaking heat exchanger some of the combustion air will enter the process line stream. A heat exchanger with recycling water can be used as an alternative.

All above mentioned heat exchange systems work in the same temperature level and therefore cannot be used simultaneously.

Another way of saving energy is to start up the equipment needed for the production of milk powder in the right sequence, i.e. to ensure that the spray dryer is started so late that it will not be "waiting" for concentrate, as a considerable amount of energy is wasted during such a waiting time. Computerized instrumentation including automatic start-up is a remedy to overcome such problems.

When milk powder is sold, it will always have to fulfil maximum moisture contents, which in most cases is 4% for skim milk powder. During storage of the powder there will always be a certain moisture absorption depending upon the ambient conditions and the packing material. The powder therefore has to be manufactured at a lower moisture content to compensate for this absorption. Needless to say, the closer the manufacturer can get to the limit the more energy is saved, as the moisture content in the powder is direct related to the outlet temperature. Thus higher moisture content means more capacity/Kcal.

The decision as to what heat recuperation system to select depends upon local conditions such as prices for steam, oil and electricity. Further, different levels of rate of interest should be taken into consideration. Each case should therefore be calculated thoroughly in order to find the optimal solution, thus ensuring the shortest return of the investment.

### 5.5 Possibility of the line optimization

When we survey the flow chart of the designed line (see part 1), we find out that some given parameters are not optimal and there are possibilities to enhance its quality. These possibilities will be shown, calculated and set theirs effect in the chapter.

• If is the evaporator situated near the pasteurizer (double-pasteurizer) and performances of the pasteurizer, separator and evaporator are good synchronized it is not require to install the tank before the evaporator.
tIn the case it is sufficient to install only a small tank (c. 1001). Milk has not to be cooled till 10 °C. Hot pasteurized milk can flow straight away to the evaporator. We save milk the heating before the evaporator but the regeneration heat is not used.

• If the previous step is not feasible it is possible to improve the degree of regeneration in the pasteurizer. The measure has its effect for a line for drinking milk production (without any evaporator). The measure saves heat, but it is necessary to extend a heat transfer area.

• Installation of an additional evaporator effect or thermo compressor (TK). An evaporator with more effects has lower steam consumption and higher outlet milk concentration and consequently lower steam consumption in the dryer. Decrease of milk powder DM from given 97 % to standard 95 % CSN standard). As there is a control quality of dryer insufficient in the dairy (DM varies c. +/- 2 %), it must be set to c. 97 % (actual values of DM varies from 99 to 95 %). The control quality improvement and more accurate staff can keep an average powder DM near the standard value 95 % (within the limits +/- 0, 5 %). The measure saves heating steam and makes possible to produce of more products.

### 5.6 Hot pasteurized milk flows straight away to evaporator

**Note:** There is not milk cooling before the evaporator in the variant

The mass balance of the line is unchanged but the heat balance of the part of line before the evaporator is different. (Saving of milk cooling before the tank and re heating before evaporator and milk heating before the separator will not be by the hot milk but a vapor.)

Note: We save only (100 - % of degree of regeneration) of heat and cold and a corresponding eat transfer area.

#### Heat needed for milk heating before separator

The calculation is similar like for the basic variant for given data. That is why a procedure of calculations will not be commented.

$Q'_{SMS} = M_M * C_M * (t_{MRo} - t_{Mo})$

$Q'_{sms} = 13857 * 3.9 * (62.5 - 10) / 3600 = 788.1$ kW
$= 56.75$ GJ/d

The heat is needed in addition compared to the basic variant. There is not the regeneration section in the variant (hot pasteurised milk / cold fresh milk).

#### Heat needed for milk heating in pasteurization section

Either temperatures or flow-rates do not change so that the heat is thesame.

**Q'ps = 229.9 kW = 16.55 GJ/d**

#### Heat taken away in cooling section

**Milk is not cooled —>Q'cs = 0 kW = 0 GJ/d**

#### Milk heating before evaporator

Milk is not heated as the pasteurization temperature $t_{M}p = 80$ °C is higher than the boiling temperature in the 1st effect is. In addition heat of superheated milk is utilized (expansion of superheated milk to temperature (pressure) in the $1^{st}$ effect).

$Q'_{HE} = 0$ kW = 0 GJ/d

The effect we include in balance of milk heating and not in evaporator (we have not to have recalculate the evaporator).

$Q'_{se} = M_{SM} * C_M * (t_{MP} - t_{ei}°)$
$Q'_{se} = 12125 * 3.9 * (80 - 70) / 3600 = 131.4$ kW= 9.46 GJ/d 5-7

**Total energy consumption of the part of the line**

Heating

$Q'_{HEAT} = Q'_{SMS} + Q'_{PS} + Q'_{HE} - Q'_{SE}$

$Q'_{heat} = 788.1 + 229.9 + 0 — 131.4 = 886.6$ kW
= 63.84 GJ/d

Cooling, $Q_{CS} = 0$

As all changes of heat consumption are included in the part of the line it is not necessary to recalculate the balances of the evaporator and dryer.

## 5.8 Original energy consumption of the line part

Heating

$Q_{heat} = Q_{ps} + bQ_{he} = 229.9 + 788.1 — 1018.0$ kW
= 73.30 GJ/d

Cooling

$Q_{cs}$ = 131 4 kW = 9.46 GJ/d

**Effect of the variant**

Heat saving in steam for milk heating

$\Delta Q_{heat} = Q_{heat} - Q'_{heat} = 1018.0 — 886.6 = 131.4$ kW
= 73.30 - 63.84 = 9.46 GJ/d (decrease 12.9 %)

We suppose a cost of 1 GJ of heat in steam $C_s$ = 150,- Kc / GJ. In the cost are not included depreciation, wages and maintenance, only cost of fuel as we suppose that an existing source of energy will be used. In the case these costs will be approximately the same for all variants taken into consideration. Than the effect of the variant (total cost of steam per 1 day) is:

$\Delta TCSteam' = \Delta Q'_{heat} * C_s = 9.46 * 150 = 1419.-$ Kc/d

For a cost of 1 GJ of cold in ice water CCW = 230 Kc/GJ (there are not taKen into account depreciation, wages and maintenance, but only electricity for compressors, pumps and fans; as we suppose that an existing cooling system is used for all considered variants). Then the effect in cost of cold (in a cooling system) per 1 day is:

$\Delta CCSyst' = \Delta Q'_{cw} * C_{cw} = 9.46 * 230 = 2176.-$ Kc/d

**Note:**

It is possible to reduce purchase costs (new line installation) as a boiler and cooling system with lower capacity can be installed. Lower depreciation is a result of it.

Further effect is a saving of the cooler and heaters before evaporator (lower purchase costs and consequently depreciation too.

## 5.9 Saving of heat transfer area – cooler

Heat transfer coefficient (HTC) in the cooler is estimated (or set by calculation Nu =f(Re, Pr)) to kCS = 3000 $W/m^2K$.

$\Delta t_{LCS}$ = ((20 - 10) - (10 - 5)) / In ((20 - 10) / (10 - 5)) = 7.2 °C

**AQ’cs ~ kcs * AAcs * Ati.cs ~ 131.4 kW**

**AAcs =** AQ’CS **/ kcs * Ati.cs = 131400 / 3000*7.2 = 6.1 $m^2$**

Because heat exchangers (HE) are designed with c. 15 % of reserve, it is heat transfer area saving in the cooler c. $AA_C$b =7.0 $m^2$. Cost of 1 $m^2$ of heattransfer area (stainless piates)
is c. 6000,- Kc/'$m^2$ (costs in 1997/98). Then is the effect in purchase cost of the cooler

ΔPCCool’ = 7.0 * 6000 = 42000.- Kc

## 5.10 Saving of heat transfer area - milk heating beforeevaporator

A procedure is the same like in the previous item. By reason of simplification we assume HTC k = 3000 W/m$^2$K too. A milk heating in the basic variant was designed gradually, using 4$^{th}$, 3$^{rd}$, 2 and 1$^{st}$vapors from the evaporator (with temperatures c. 40 °, 50 °, 60 ° and 70 °C) and finally steam 80 °C. Milk was in the 5 HE heated with vapors from 10 °C to 22, 5°C, further to 35,0°C, to 47,5 °C, to 60,0 °C and finally with steam to required 70 °C. Often it is useful to design a milk heating system in that way to be all healers the same (for tubularHE). The last HE, heated with steam, is over-designed as there is the maximal fouling forming. In addition there is a milk outlet temperature controlled^ Temperatures in an typical average
HE - vapor 50 °C, milk 22.5 °C -> 35 °C (in reality we have to calculate every HE but in our example we will calculate only 1 HE = simplification of the long example).

Note: In practice an optimization of system of liquid heating before an evaporator is done.

$\Delta t_L Ø_{HEAT}$ = ((50.0 - 22.5) - (50.0 - 35)) / In ((50.0 - 22.5) / (50.0 - 35)) = 20.3 °C

In all 5 HE is an heat transfer area saving (ΣAi)

$$\Delta A_{HEAT} = \Delta Q_{HEAT} \ / \ k_{HEAT} \ * \ \Delta T_L \phi_{HEAT}$$

$$= 131400 / 3000*20.3 = 2.16 \text{ m}^2$$

Considering the 15 % of reserve it is c. $\Delta_{A'heat}$ = 2.5 m$^2$. Considering the same cost of heat transfer area is the effect to the purchase cost of HE before evaporator

Note: - We suppose that an area of a heater before the separator (instead the regeneration section) is equal to the area of the regeneration section).

- The calculation is very simplified. When plate HE are used they are designed exactly based on requirements. Heat of vapors from "back" evaporator effects is used more. The measure improves an evaporator economy
- Evaporators usually do not work with equal temperature differences in all effects as with a higher liquid concentration and lower boiling temperature is lower value of an overall heat transfer coefficient k. A solution of a real evaporator design has to be adapted.

**Depreciation and maintenance saving per year**

Let us assume depreciation rate of machinery 8.5 % (= 12 years of service life), maintenance costs c. 5.5 % from a purchase cost (in some cases they are comparable with depreciation rate - in a real case it is necessary to use a realistic data). That are yearly costs c. 8.5 +5.5 = 14 % of the purchase cost.

Depreciation and maintenance saving is then

ADM' = (ΔPCCool' + ΔPCHeat') * 0.14
= (42000 + 15000) * 0.14 = 7980.- Kc/year

Effect of the variant per year

Let us assume working time *t* = 200 days per year and 20 hours per oay. Than is an effect per year

YE' = *t* * (ATCSt' + ACCSyst') + ADM'
YE' = 200 * (1419 + 2176) + 7980 = **726980.- Ke per year**

From these calculation follows that a saving of purchase costs (depreciation and maintenance) are insignificant in comparison with energy saving. A pay-back period is 0 as the variant does not need practically any purchase costs (PBP =0)

## 5,11 Degree of regeneration in pasteurizer

The variant is advantage for an existing line optimization. As it is said above the variant is more advantageous for line for drinking milk production. For the line it is more advantageousthe previous variant. Nevertheless we do following calculations to review its effect. The part of our example may be useful for solution of other lines.
An increase of number of plates, or using of plates with better characteristics (> k, <A pZ, < forming of fouling etc.), or substitution of an older type of HE for a new one, make itpossible to lower a temperature difference in regeneration section from 10 °C to 5 °C.
Because the difference is only 5 °C. it is possible to cool the pasteurized milk in regeneration section from 80 °C to 10 + 5 = 15 °C (inlet milk t. + t. dif.)

### Thermal Balance of Regeneration Section

First of all we have to set the temperature of milk after the regeneration section. As well as in the first part we consider the same heat capacity of milk and omit heat losses. Then is the thermal balanc

$Q_{REG\ HEAAT} = Q_{REG\ COOL}$ ($Q_{RS\ HEAT} = Q_{RS\ COOL}$)

$M_M * C_M * (t''_{MRO} - t_{Mo}) = M_{SM} * C_M * (t_{MP} - t'_{mrp})$

$13.857 * 3.9 * (t_{MRO} - 10) = 12.125 * 3.9 * (80 - 15)$

$T_{MRO}$ = (12.125 * 65 + 13.857 * 10) / 13.857 = 66.9 °C
milktemperature after the regeneration section (for basic var. 62.5 °C)

$Q'_{REGheat}$ = 13857 * 3.9 * (66.9 - 10) / 3600

= 854kW

$Q'_{REGcool}$ = 12125 * 3.9 * (80 - 15) / 3600

= 854 kW

**Specification of degree of regeneration in pasteurizer**

$$DR" = Q_{used} \,\text{I}\, Q_{delivered} = (t_{MP} \text{ " } t"_{MRp}) / (t_{MP} - t_{Mo})$$

$$DR" = (80.0 - 15.0) / (80.0 - 10.0) * 100 = 92.9 \%$$

The degree of regeneration is higher (basic variant 85.7 %). It means that c. 92.9 % of delivered heat is reused for milk preheating in the regeneration section (considering the same heat capacities of both flows).

**Heat needed for milk heating in pasteurization section**

Milk inlet to the section with temperature 66.9 °C and there it must be heated up to pasteurisation temperature 80 °C. With the temperature it flows to the holder and back to the regeneration section where is cooled with fresh cool milk. Similar as in previous the thermal balance is performed.

$$Q'_{PS} = Q'_{PAST} = M_{SM} * C_M * (t_{wp} - T_{MRO})$$

$$Q'_{PS} = 12125 * 3.9 * (80.0 - 66.9) / 3600 = 172.1 \text{ kW}$$
$$= 172.1*3600*20/106 = 12.39 \text{ GJ/d}$$

Heat saving in pasteurisation section

$$\Delta Q'_{PS} = Q_{PS} - Q"_{PS} = 229.9 - 172.1 = 57.8 \text{ kW}$$
$$= 16.55 - 12.39 = 4.16 \text{ GJ/d}$$

**Heat taken away from milk in cooling section**

$$Q"_{cs} \sim M_{SM} * C_M * (t_{MRP} - t_{Mc})$$

$$Q_{cs} = 12125 * 3.9 * (15 - 10) / 3600 = 65.7 \text{ kW}$$
$$= 65.7*3600*20/106 = 4.73 \text{ GJ/d}$$
$$\Delta Q'_{cs} = Q_{cs} - Q"_{cs} = 131.4 - 65.7 = 65.7 \text{ kW}$$
$$= 9.46-4.73 = 4.73 \text{ GJ/d}$$

**Effects of the variant**

The process of the calculation is similar like in previous, so it is present without any comments.

AA cost of steam saved per day is

$$\text{Total Steam}" = \Delta Q"_{PS} * C_s = 4.16 * 150 = 624.\text{- K£/d}$$

For cost of 1 GJ cold in ice water Ccw = 230 Kc/GJ (again without depreciation etc., only electricity for compressors, pumps and fans - we assume an existing machinery utilisation) is a cost of cold saved per day (in a cooling system)

$= AQ'cs * C_{cw} = 4.73 * 230 = 1088$ - Kc/d

An heat transfer area (HTA) in cooling and pasteurisation sections is lower, but a HTA in the regeneration section must be higher.

**Saving of heat transfer area - cooling section**

The value of HTC is estimated like in previous to kCS = 3000 W/m$^2$K. Original was the log. Temperature difference Ati_CS= 7.2 °C. Now it is

$\Delta t_{LCS} = [(15-10) - (10-5)]/\ln[(15-10)/(10-5)]$

$= 5.0$ C

$\Delta A'_{CS} = \Delta A_{CS} - A'_{CS}$

$\Delta A'cs = \Delta Q'cs / kcs * \Delta t''i\_cs - \Delta Qcs / kcs * \Delta tL.cs$

$\Delta A'cs = 131400 / 3000*7.2 - 65700 / 3000*5.0 = 1.7$ m$^2$

Because HE are designed with c. 15 % of reserve, heat transfer area saving in the cooler is c. $AA''_Cs = 2{,}0$ m$^2$ Cost of 1 m$^2$ of heat transfer area HTA (stainless plates) is c. 6000,- Kc/m$^2$. Then is the effect of cost of depreciation and maintenance for the cooler

$\Delta DM'cs - 0.14 * 2.0 * 6000 = 1680$.- Kc/r

**Saving of heat transfer area - pasteurization section**

Value of HTC is estimated like in previous to kPS = 3000 W/m$^2$K. Original log. Thermal difference (LTD) was $\Delta t_L ps = 17.3$ °C.

$\Delta t''_{LPS} = ((90.0 - 66.9) - (90.0 - 80)) / \ln((90.0 - 66.9) / (90.0 - 80)) = 15.6$ °C

$\Delta A'_{PS} = \Delta Q ps / kps * \Delta t \backslash ps - \Delta Qps / kps * \Delta tLPs$
$\Delta A''_{PS} = 229900 / 3000*17.3 - 172100 / 3000*15.6 = 0.75$ m$^2$

Because HE are designed with c. 15 % of reserve, the HTA saving in the pasi. Section is c. $AA'_{PS} = 0.9$ m$^2$. Cost of 1 m$^2$ of heat transfer area (stainless plates) is c. 6000,- Kc/m$^2$.Then is the effect of cost of depreciation and maintenance for the section.

$\Delta DMVs = 0.14 * 0.9 * 6000 = 756$.- Kc/r

**Heat transfer area increase - regeneration section**

Value of HTC is estimated like in previous to kRS = 3000 W/m²K. Original log. Thermal difference (LTD) was $Ati\_{RS}$ = 13,4 °C. In the case a LTD is lower and amount of transferred heat is higher.

$$\Delta t''_{LRS} = ((80.0 - 66.9) - (15 - 10)) / \ln ((80.0 - 66.9) / (15 - 10)) = 8{,}4\ °C$$

$$\Delta A''_{RS} = A_{RS} - A''_{RS}$$

$$\Delta A''_{RS} = \Delta Q_{RS} / k_{RS} * \Delta t_{i\_Rs} - \Delta Q'_{RS} / k_{Rs} * \Delta t''_{i\_Rs}$$

$$\Delta A''_{RS} = 788100 / 3000*13.4 - 853800 / 3000*8.4 = - 14.3\ m^2$$

Because HE are designed with c. 15 % of reserve, is the HTA increasing in the reg. section c. $AA''_{RS}$ = 16.4 m². Then is the effect of cost of depreciation and maintenance for the section.

$$\Delta DM'_{RS} = 0.14 * (-16.4) * 6000 = - 13776.\text{- Kc/r cost increase !!}$$

**Note:**

For a real case is the calculation more complicated as with a temperature change HTC k changes too.
For our illustration the method is sufficient.

**Effect of the variant per year**

Let us assume working time *t* = 200 days per year and 20 hours per day. Than is an effect per year

$$YE'' = t * (\Delta TCSteam'_{ps} + \Delta CCSyst''_{cs}) + \Delta DM''_{PS} + \Delta DM'_{cs} + \Delta DM'_{RS}$$

$$YE'' = 200 * (624 + 1088) + 756 + 1680 - 13776$$

**= 331060.- Ke per year**

It follows from this that the effect of the variant is c. 50 % then for the previous variant. Nevertheless of it the pay-back period of the variant is short. We assume only purchase costs, depreciation and effects mentioned above, without "future cost of money" these are interests etc. = Cost - Benefit Analysis.

**The pay-back period PBP** is for purchase costs PC (HTA = additional plates; frames and stand are the same)

$PC'' = (\Delta A'rs - \Delta A''cs - \Delta A'ps) * C_A$

= (16.4 - 2.0 - 0.9) * 6000 = 87000 K£

PBP" = PC" / YE" = 87000 / 331060 = **0.26 year** = **3 months**

ΔA"rs increasing of HT A in reg sec AA"ps saving of HTA in pasteurizing section

$\Delta A''_{CS}$ saving of *HTA* in cooling section

CA cost of 1 $m^2$ of HTA

## 5.12 Installation of an additional evaporator effect and thermocompressor TK

Approximately it is possible to say that an installation of a TK **has** the same effect like an installation of another evaporator effect. Such the 5th effect's evaporator with TK has a steam consumption practically the same like 6th effect's evaporator without TK. An exact evaporator calculation is done in a course DHP (Dehydrating processes) and in the example about sugar juice evaporator. In this example a result of a balance is presented. The evaporator modification lowers the specific steam consumption for example to d'" = 0,19 kg of steam/ kg evap. water. Installation of the TK results in higher amount of water evaporated in the 1st effect and consequently requirements for higher heat transfer area in the effect (part of the 1st vapor flows to the TK and then back to the 1st effect - see fig. on next page). An installation of the 5th effect results in higher HTA too.

A total amount of evaporated water is divided into more effects (lower specific load of effects) but temperature differences in effects are lower too (the difference between heating steam t. and t. of vapor flowing to condenser is the same but now is divided by more effects). An effect of a boiling point elevation changes too and affects more effects. A result of it is that so-called usable temperature difference is lower

Like in previous we will calculate the evaporator. We suppose that 1 kg of steam evaporates 1 kg of vapour from milk, heat losses are omitted etc. Further we calculate with average value of evaporation heat Then is:

**Heat fed as heating steam into the 1st evaporator's effect**

$Q_{TEVAP} = d'' * W_{EVAP} * rp0$

$Q''_{Tevap} = 0.19 * 9969 * 2500 / 3600 = 1315.4$ kW

$= 1315.4*3600*20/106 = 94.71$ GJ/d

**Heat transfer area increase in evaporator**

An average boiling point elevation in evaporator effects is c. 0,5 °C (in 1° is lower (c.0,2 °C), in 5° is higher(c.0,8 °C)). The total amount of evaporated water is the same like for the basic variant (the same amount of milk and its concentrations). The basic simplified balance of the evaporator is.

$W_{evap} \sim W_i + W_2 + W_3 + W_4 \sim 4 * W_j$

(W1 » W2 a W3 » W4 ~ Wi)

$W_{EVAP} = n * W_j$ For the variant is the balance

$W_{evap} = W''_i + W''_2 + W''_3 + W''_4 + W''_5$

Approximately (for our simplified example) it is possible to say that an amount of evaporated water in the 1s effect is double of this amount in other effects (for amount of driving steam equals to amount of drawn vapour). More see in example about sugar juice evaporator.

$W''_i = 2 * W''_j$ amount of evap. water in the 1st effect

The previous equations are transformed in form

$W_{EVAP} = 6 * W''_i = (n^{,M} + 1) * W''_j$ $n''' = 5$ effects

An average value of OHTC **k** is assumed the same like for the basic variant, an average evaporation heat too. As it is said above it is valid that

$t_{pi} - t_{e4} = t''_{pi} - t'''_{B5}$-

**Balance of i- effect of evaporator and HTA estimation - basic variant**

$A_j = Q_j / (k_j * \Delta t_j)$ $Q_j = W_j * r_i = (W_{evap} / n) * r_i$

$\Delta t_j = (t_{pi} - t_{s4}) / n - \Delta_i\phi$ $A_{evapt} = n * A_j$

n = 4 number of evaporator effects $A_{i(}p$ = o boiling point elevation in evaporator (properly it would be calculated for every effect)

$W_{evap} = 9969$ kg/h no = 2370 kJ/kg $\Delta_{i0} = 0.5$ °C

$k_i\phi = 2000$ W/m²K $t_{Pi} = 80$ °C $t_{B4} = 40$ °C

Pressure losses between effects are neglected (vapour temp, drop) as it are similar for both variants. Then it is:

$Qi = (9969 / 4) * (2370 / 3600) = 1640.7$ kW
$\Delta tj = (80 - 40) / 4 - 0.5 = 9.5$ °C
$Aj = 1640700 / 2000 * 9.5 = 86.4$ m$^2$
$Aevapt = 4 * 86.4 = 345.6$ m$^2$
total HTA of the evaporator for the basic variant

**Balance of i- effect of evaporator and HTA estimation - variant (i = 2-5)**

$A''', = Q'''i / (k j * At'''i)$
$Q '''i = W'''i * n = (W_{Evap} / (n'''+1)) * ri$
$\Delta t j = (tpi - tes) / n''' - \Delta_i \phi ( D$ $A'''evapt = (n'''-1) * A'''j + A'''i$

n’’=five (number of evaporator effects)

Wevap = 9969 kg/hr$_i\phi$ = 2370 kJ/kg$\Delta_i\phi$= 0.5°C
k i $\phi$ = 2000 W/m$^2$K $t_P i$ = 80 °C $t_{35}$ = 40 °C

Like in the previous we neglect vapour temperature drop between effects (pressure losses in piping for vapour). An average boiling point elevation is assumed the same too. Then is:

For 2. to 5.° of evaporator

$W'''i = Wevap / (n''' + 1) = 9969 / 6 = 1661.5$ kg/h

$Q'''i = 1661.5 * (2370 / 3600) = 1093.8$ kW

$\Delta t''_i = (8C- 40)/ 5-0.5 = 7.5$ °C

$A'''i = 1093800 / 2000 * 7.5 = 72.9$ m$^2$

For i° of evaporator

$w'''_1=2* W'''i$ —> $Q'''i = 2 * Q'''j$ $At'''_1 = At'''i$ $k'\% = k'''i *$

$A'''i = 2 * A'''i = 2 ' 72.9 = 145.8$ m$^2$ A total HTA of the evaporator for the variant is
$A'''evapt = A'''i + 4 * A'''j = 145.8 + 4 * 72.9 = 437.4$ m$^2$

Wevap = 9969 kg/h**r,** « = 2370 kJ/kg A|* = 0.5°C
k i » = 2000 W/$m^2$K                    $t_P$i = 80 °C                    $t_{35}$ = 40 °C

Like in the previous we neglect vapour temperature drop between effects (pressure losses in piping for vapour). An average boiling point elevation is assumed the same too. Then is:

For 2. to 5.° of evaporator

*W'"i = Wevap* **I**(n'" + 1*)* = 9969 */* 6 = 1661.5 kg/h

Q'"i = 1661.5 * (2370 / 3600) = 1093.8 kW

AH = (8C- 40)/ 5-0.5 = 7.5 °C

*A'"i* = 1093800 / 2000 * 7.5 = 72.9 $m^2$

For i° of evaporator

**W** « 2 * W'"i —> Q'"i = 2 * Q'"j At'"$_1$ = At'"i k'% = k'"i *

A'"i = 2 * A'"i = 2 ' 72.9 = 145.8 $m^2$ A total HTA of the evaporator for the variant is
*A'"evapt = A'"i* + 4 * *A'"j* = 145.8 + 4 * 72.9 = 437.4 $m^2$

**Effect of the variant per year**

A cost of HTA of the evaporator is c. $C_A$ = 5000,- Kc/m$^2$ (only HTA, without costs of shells, frames, pumps, vapour/droplets separators etc. - these are considered approximately the same for both variants). The depreciation and maintenance cost are considered the same like in the previous chapter: 8.5 + 5.5 = 14 % of purchase costs. A cost of heat in heating steam is $C_P$ = 150 Kc/GJ. An annual service time is *t* = *200* days/year.

<u>Basic variant</u>

Cost of steam per year

*CSevap* = *Cs * Qevap * t CSevap* = 150 * 139.56 * 200 = 4186800.- Kc/r Depreciation and

maintenance costs

$C\,DM_{evap} = A_{evap} * C_A * DM$ = 345.6 * 5000 * 0.14
= 241920.-Kc/v
= 1728000
= cost of evaporatorplates (without frames, pumps, separators, piping, control etc.)

$C\,DM_{evap} = A_{evap} * C_A * DM$ = 345.6 * 5000 * 0.14
= 241920.-Kc/v
__________ = 1728000 = cost of evaporator plates (without frames,pumps, separators, piping, control etc.

Total annual costs

TACevap ~ CSevap CDMevap ¯ 4186800 + 241920
= 4428720,- Kc/y

**Proposed variant Cost of steam per year**

$CS''_{EVAP} = C_s * Q'''_{Evap} * T$

CSj"EVAP = 150 * 94.71 * 200 = 2841300.- Kc/y

Depreciation and maintenance costs

$CDM'''_{evap} = A'''_{evapt} * C_A * DM'''$ = 437.4 * 5000 * 0.14
= 306200,- Kc/y
________= 2187000,- = cost of evaporator plates for the var.

**Proposed variant**

**Cost of steam per year**

O'" — r' * * -r
ub EVAP - U EVAP T

CSj"EVAP = 150 * 94.71 * 200 = 2841300.- Kc/y

**Depreciation and maintenance costs**

CDM'" evap = A'"evapt * $C_A$ * DM'" = 437.4 * 5000 * 0.14
= 306200,- Kc/y
= 2187000 = cost ofEvaporator plates for the var.

TAG " evap = CS " evap + CDM " evap = 2841300 + 306200
= 3147500.- Kc/y (**Total Annual Cost)**

**<u>Note:</u>** - There is an OHTC in the 1st effect ki higher than in others effects (lower viscosity, higher temperature) in reality **> A1 will be lower -> econ. effect will be more favorable

- Because the heating steam consumption in the evaporator was set from the specific steam consumption **<u>d</u>** (heat losses are included too), the steam consumption for both variants is higher than values QS = Qi, set in the part.

The cost of HTA installed in addition was only considered in the preliminary calculations. But the evaporator will be extended of another effect (frame, pump etc ) and thermocornpressor.So an installation will need a piping, supporting structure (SS), control system, droplet/vapor separator, armatures including erection work. An estimation of these costs is in the following table.

| | |
|---|---|
| Additional HTA (437.4 - 345.6) * 5000 | = 459 000,- Kc |
| 5th effect (without HTA), pump, separator, control system, piping, SS, armatures etc. | 1 500 000,- Kc |
| TK incl. piping and control system | 500 000,- Kc |
| Total cost of realisation of this var. "I (investment cost) TIC'" | = 2 459 000,- Kc |

An actual cost is, compared to the previous calculation, higher of value c. (2459000 — 459000) = 2000000,- Kc. Therefore the depreciation and maintenance have to be higher too for the variant - (0.14*2000000 = 280000). Than total annual costs are

$TAC_E$vAPreal = 3147500 + 280000 = 3427500,- Kc/y and the effect of the variant per year in comparison with the basic variant is

$$YE''' = TAC_{evap} - TAC'''_{EVAPreal} = 4428720 - 3427500$$

**= 1 001 200,- Ke / yrar**

**The pay-back period PBP** is for the total investment costs TIC''' (HTA = additional plates; frames and stand of the 5th effect, separator, TK, control system etc.)

PBP" = TIC''' / YE" = 2459000 / 1001200 = **2.5 years**

## 5.13 Higher outlet rnilk concentration

The increasing of HTA of the evaporator from the basic 4° to the recommended 5° evaporator with TC (var. 6.3.) makes possible to increase an outlet milk concentration from given 45 % to 50 % DM. A result of it is a higher amount of evaporated water and consequently a higher steam consumption in evaporator too (compared to var. 6.3.) but a steam consumption in the dryer will be much lower The increasing of HTA and other costs are assumed the same like for the variant 6.3. An average value of HTC k® is assumed to be the same too in reality it will be a little lower -owing to a higher milk concentration viscosity). A more complicated control system is omitted too (variation of the outlet milk concentration has to be kept in narrower limits as a concentration 52-55% brings problems with milk pumping and spraying.

### Steam consumption in evaporator

We go out from results of var. 6.3., it is 5° + TK (d''' = 0.19 kg/kg). Original total amount of evaporated water for $x_{CM}$ = 45 % was $W_{evap}$ = 9969 kg e.w./h. For the higher milk concentration $x''''_{CM}$ = 50 % is a new total amount of evaporated water

$$W''''_{evap} = M_{SM} * (1 - x_{SM} / x''''_{CM})$$
$$W''''_{evap} = 12125 * (1 - 8 / 50) = 10185 \text{ kg/h}$$

Amount of concentrated milk flowing from the evaporator to the dryer is

$$M''''_{CM} = M_{SM} - W''''_{Evap} = 12125 - 10185 = 1940 \text{ kg/h}$$

Owing to a big extend of the example the evaporator is not re-calculated for these conditions. For needs of an approximate economic comparison of the variant it is sufficient to estimate a new HTA of the evaporator. The estimation is done using a change of total amounts of evaporated water. The new HTA of evaporator for this variant is calculated by using following equations

$A''''_{EVAPT} \sim A'''_{EVAPT} * W''''_{EVAP} / W'''_{EVAP}$

$$= 437.4 * 10185 /9969 = 446.9\ m^2$$

An increasing of a heating steam consumption in the evaporator is supposed to be proportional of total amount of evaporated water too. Compared the var. 6.3. are number of effect the same, as well as TK, operating principles of evaporator and vapours taking away for milk heaters. Than a heat consumption (heating steam) in the evaporator according a principle of proportionality is

$Q_{EVAP} \approx Q_{Tevap} * W''''_{evAP} / W'''_{evAP}$

$= 1315.4 * 10185 / 9969 = 1343.9$ kW

$Q''''_{EVAP} \approx d'''' * W''''_{EVAP} * r_{\Phi}$

$= 0.19*10185*2500/3600 = 1343.9 =$ 96.76 GJ/d

Heat consumption in dryer a steam consumption for drying air heating will be lower as a lower amount of concentrated

Milk with higher concentration will be dried. A re-calculation is again done using the presumption that the steam consumption is proportional to the amount of dried off water, (we suppose that temperatures and moistures of drying air are the same, only its amount is lower).

**Note:** For an exact design of a dryer all approximate calculations have to be done once more exact (for an evaporator and dryer) for the selected optimal variation. But for the selection of an optimal variation it is possible to use such approximate calculations.

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$W_{DRY}$ = 1156 kg/d bbasic total amount of dried off water in dryer

DRY DM

**= 1940- 1000**

**= 940kg/h**

$Q_{dry}$ = 1669.8 kW = 120.23 GJ/d basic heat consumption in dryer

$Q_{DRY} \sim Q_{DRY} * W''_{DRY} / W_{DRY}$

$Q''_{DRY}$* 1669.8 * 940/ 1156 = 1358.0 kW new heat consumption in drier.

= 120.23*940/1156 = 97.76 GJ/d

Lower amount of heating air

$M''_{A} = M_{A} * W''_{DRY} / W_{DRY}$ = 32111 * 940 / 1156 = 26111 kg/h

The lower amount of air the lower fan input (P ~ MA). A lower fan input is (supposing the same pressure conditions - but for lower air flow are lower pressure loses too. reserve to a side of higher security)

$P'''W = Pmf * M''''_a / Ma = 27.2 * 26111 / 32.111 = 22.1$ kW
x 27.2 for basic variant

**Effect of this variant per year**

Supposing the same conditions like in previous variants the effect is related to var. 6.3. (‘“) it is 5 ° + TK. Ev. a dryer size reducing is omitted the (the simplification is again on the side of higher security).

**Cost of steam for evaporator**

$CS''''_{EVAP} = 150 * 96.76 * 200 = 2902800$,- Kc/y

**Cost of steam for dryer**

$CS''''_{Dry} = 150 * 97.76 * 200 = 2932800$,- Kc/y

**Depreciation and maintenance of evaporator** (for dryer is * the same - the same dryer for both variants)

$CDM''''_{EVAP} = A''''_{EVAPT} * C_A * DM$

$CDM''''_{evap} = 446.9 * 5000 * 0.14 = 312830$,- Kc/y

**Lower electric energy consumption for 2 motors of fans**

$ACEE''''_{mf} = C_{ee} * AP''''_{mf} * 2 * t$ $C_{ee}$ * 4.00 Kc/kWh

$ACEE''''_{MF} = 4 * (27.9 - 22.7) * 2 * 20 * 200 = 166400$,- Kc/y

**Total costs per year for var. 6.4** (only the changed parts of the line are assumed = evaporator and dryer - other costs are approximately the same)

$TAC'''' = CS''''_{evap} + CS''''_{dry} + CDM''''_{evap} - ACEE''''_{mf}$

TAC““ = 2902800 + 2932800 + 312830 - 166400
= 5982000,- Kc/y

Costs of the compared variant 6.3 (only the changed parts of the line are assumed again =evaporator and dryer - other costs are approximately the same)

Total annual costs for evaporator incl. depreciation, maintenance etc.

$TAC'''_{evap}$ = 3147500,- Kc/y (see previous calculations)

Total annual costs for dryer

(only steam - we assume the same dryer)

$TAC'''_{Sdry} = cs * Q'''_{dry} * t$ =150 * 120.23 * 200
= 3606900,- Kc/y

Total costs per year for variant 6.3
(only for mentioned changed parts)

$TAC''' = TAC'''_{EVAP} + TAC'''_{SDRY}$

= 3147500 + 3606900 = 6754400,- Kc/y

**Effect of the variant per year**

YE““= TAC’“ - TAC““ = 6754400 - 5982000 = 772400,- Ke/y

Because the variant, does not need practically any purchase costs comparison with var.6.3. (only better control system and more accurate staff) is a pay-back period = 0. If the effect is added to the effects of var. 6.3. (it is var. 6.3. + higher milk concentration) we can set a new pay-back period for a combination of var. 6.3. +6.4.

PBP““ = TIC" / (**YE’” + YE““)**
= 2459000 / (1001200 + 772400 ) = 1.4 Years

total investment costs yearly (annual) effects

(for the var. 6.3. the pay-back period was 2.3 y).

## 5.14. <u>Increase of milk powder moisture from 3 % to 5 %</u>

A Czech standard allows the moisture 5 %. Because there is a control quality of dryer insufficient in the dairy (DM varies c. +/- 2 %), it must be set to c. 97 % (actual values of DM varies from 99 to 95 %). The control quality improvement and more accurate staff can keep an average powder DM near the standard value 95 % (within the limits +/- 0.5 %) without a danger of stored milk powder deterioration (micro-organisms breeding etc. in a insufficiently dried batch of powder). The measure saves heating steam for the dryer and makes possible to produce more products (water in product is sold for a cost of milk powder).

Higher amount of product

$M^{v}_{DM} = M_{QM} * X_{DM} / _{DM} = 1000 * 97 / 95 = 1021.0$ kg/h

A wholesale price of milk powder in bags was in 1997 CDM ~ 55 Kc/kg (price in a real dairy where an energetic audit was done). Than is a profit from the production increase:

$AC^{V}_{DM} = AM^{V}_{dm} * C_{dm} * T$ $\quad\quad$ $AM^{V}_{DM} = M^{v}_{DM} - M_{DM}$

$AC^{V}_{DM} = (1021 - 1000) * 55 * 20 * 200 = 4620000$,- Kc/y

Amount of driea off water (related to var. 6.4.)

$W^{v}_{DRY} = M''''_{CM} - M^{V}_{DM} = 1940 - 1021 = 919$ kg/h

$W''''_{DRY} = 940$ kg/h

Accordingly to pievious variant we determine a heat consumption in the dryer (re-calculation usina proportion of amounts of dried off water)

$Q^{V}_{DRY} = Q_{DRY} * _{DRY} / W''''_{DRY}$

$Q^{V}_{DRY} = 1358.0 * 919 / 940 = 1327.7$ kW

$= 97.76*919/940 = 95.58$ GJ/d

An effect of lower fan input is neglected for the variant (lower amount of dryed off water -> lower amount of drying air; the neglect is on a side of higher safety -> reserve in the variant effect - a real effect will be higher).

Than savings of heat and cost of heating steam for the dryer are

$AQ^{v}_{Dry} = Q^{M''}_{dry} - Q^{v}_{dry} = 97.76 - 95.58 = 2.18$ GJ/d

$ACS^{V}_{DRY} = CS * AQ^{V}_{DRY} * T$

$= 150 * 2.18 * 200 = 65400$,- Kc/y

**Note:** - Owing to the higher profit from milk production is this effect insignificant.

- Simplifications have to be done to a side of higher safety (conservatively)

Effect per year comparing with var.

$YE^V = AC^V_{DM} + ACS^V_{DRY} = 4620000 + 65400 =$ **4 685 400,- Ke/y**

Purchasing costs for a realisation of the variant are estimated to c. 1000000,- Kc.- (a newcontrol system, sensors, actuating appliance etc.). Than the pay-back period is

$PBP^V = TIC^V / YE^V = 1000000 / 4685400$ » **0.2** year

## 5.15. Conclusion - comparison of proposed variants of the line optimisation

Results of proposed variants are given in the following table.

| Variant<br>**Description** | Effect per year YE (Kc/y) | Pay-back period of investment PBP (y) | Total effect per year for application of more variants X YE (Kc/y) | Note Variants applied (combination) |
|---|---|---|---|---|
| Basic variant - given data 4°evaporator | 0 | 0 | 0 | 0 |
| Var. 6.1 - milk without cooling to evaporator | 726980 | 0 | 726980 | 1 |
| Var.6.2higher degree of regeneration in past. | 331 060 | 0.3 | 331 060 | 2 |
| Var. 6.3 - 5° + TK | 1 001 200 | 2.5 | 1 728 180 | 1+3 |
| Var.6.4 - higher milk concentration (50%) | 772 400 | 1.4 | 2 384 780 | 1+3+4 |
| Var.6.5 - higher moisture of milk powder | 4 685 400 | 0.2 | 7 185 980 | 1+3+4+5 |

**Results appreciation:**
*** An energy saving has usually higher effect comparing to purchase costs (depreciation).**
**• A production increase (higher yield, losses decrease etc.) has, for the same consumption of raw materials, usually much higher effect than energy savings.**

Note: The work done shows us possibilities of production lines design, calculation and optimization incl. a basic economic appreciation. Simultaneously it shows effects of some optimization steps.

# Chapter 6

# Instrumentation and Line Control

## 6.1 **Design of the line control**

Parameters important for proper line function

It is necessary to measure and file the parameters, as they are important for product quality, line economy and line function check-up. The parameters and their effects are shown in following sections.

**Product quality:**

Pasteurization temperature -> microorganisms content moisture of milk powder durability fat content in dried milk(skim milk) -> line economy quality of milk powder (burned particles, microorganisms. solubility etc.) fat content in cream etc.

**Amount of products:**

(Line capacity) Amount of milk powder

Amount of cream amount of fresh inlet milk

**Line balance & economy:**

Temperatures in regeneration section (+ quality too)
temperatures in cooling section
Temperatures and pressures in evaporator
Temperatures in dryer
Milk concentration in evaporator
Amount of heating steam to evaporator
Amount of steam for drying air heating
Heating steam pressures
Pressure losses (pasteurizer, dryer etc.)

Note:

It is of advantage to specify requirements for the line control to experts for MaR (measuring and regulation = line control). These are for example: above mentioned parameters these are necessary to measure, control, and file etc. incl.

mutual relationships, tolerance limits etc. MaR experts are not usually specialists in the branch of the PL. Relationships between parameters necessary for line control - control circuits

The relationship we examine in simplification and generally. It means that in some lines some system is not used or is used other one. This is only an example what relationships are used not only in dairies. Once again we will examine these relationships from point of view individual important parameters together with a way of control.

## 6.2 Line output and their basic parameters

(monitor dairy management and line workers):

• **Amount of fresh milk input (capacity)**
Flowmeter regular. valve (ev. butterfly valve) in pipe on milk inlet (control + account). Further see milk inlet control.

• **Amount of milk powder (output)**
Scab in bagging (only account).
• **Amount of cream (output)**
Flowmeter for account, it is not possible to control (it is given by amount and fat content of fresh milk and separator setting)

**Parameters for line control and account**
(monitor line operators and check management - calculation of the line economy)

• **Fat content of cream**
It is set for ex. in laboratory or continuously (density meter) - it is affected by function of separator and inlet milk quality.

• **Fat content in skim milk (separating sharpness)**
Ditto - it is affected by separator design, revolutions, amount and milk quality — > measure and adjust separator (balance of fat loss in skim milk + ev. reclamation).

• **Pasteurization temperature (affects product quality)**
- Thermometer ---> account + control (cont. valve etc.).
- According to past. temp, is controlled heating steam inlet to pasteurization section or to hot water circuit.
- For steam (hot water) temperature higher than a set value is pasteurizer set away and switched to cleaning mode (CIP) and the second part of double pasteurizer is switched in operation. Ev. the cleaning mode may be pre-set after the lapse of some time.
-
• **Temperatures in regeneration section**
- temperatures are only measured and account for purpose of PL economy checking (they are indicated - in flow charts are mark TI.
-

• **Cooled milk temperature**
- Maximal temperature is for ex. 10 or 5 °C (else quality deterioration), depends on technology, time of storage in tank (microorganisms breeding, acidity increase).
- Thermometer ---> control valve (degree of opening is monitored)
- Depending on cooled milk temperature is controlled ice water inlet to cooling section. Ice water temperature is usually constant and given by cooling system function.
- When it is impossible to keep needed cooled milk temperature even when valve is fully open cooling section is switched to cleaning regime, (cooler is designed for the same cleaning intervals like pasteurizer or whole line see given data = 20 + 4 h).

• **Milk inlet to evaporator** (there are several relationships here - more complicated system see part “Evaporator”)
- Level in tank (balance tank) before evaporator - for ex. float controls valve for milk inlet to evaporator.
- Level in tank (balance tank) after evaporator - ditto but float controls valve for milk going to dryer
- DM of concentrated milk - owing to fouling goes down -» control of heating steam temperature etc. - see below.
- When all pre-set values are attained (temperatures, milk flow rate, DM) evaporator is switched to cleaning mode.
• Milk heating before evaporator (temperatures after heaters)
- Milk heating with various vapours from evaporator is without any control as it is important to achieve maximal possible heating up with vapours as heat in vapours are cheaper than in heating steam.
- Milk temperature after last heater: thermometer —> control valve on steam inlet to last heater
- Milk heating to boiling temperature in 1$^{st}$ effect is not economic as heat transfer coefficient for heating is lower than for boiling and additional heat to heating up is necessary. Result is lower performance of evaporator. That is why it is necessary to control good function of heeters.
- Heaters are designed for the same cleaning intervals like evaporator (20h+4h).

## 6.3 Evaporator

- Later evaporator had its own control system. Nowadays it is controlled together with all line Computers are used. Relations between parameters and control system are hereunder (in simplified form without equipment).
- Milk inlet to evaporator (max. a minim-> values - see above).
- Concentration (DM) of concentrated milk (max. value = pump able and good spraying -> dryer function, optimal, minimal values . worse economy of dryer operation).
- Heating steam temperature (pressure) in 1$^{st}$ evaporator (optimal and maximal values -» milk quality deterioration.
- Vapour temperature (vacuum) in the last effect (optimal and maximal values it is given by parameters of vacuum pump and condenser = available vacuum).
- Further are indicated and filed all temperatures and pressures in evaporator, milk levels in separators (or in effects), valves position, pumps function, condensate quality

(probe for condensate conductivity control - higher conductivity -> milk in condensate - according condensate quality it goes to boiler plant or to technology (for ex. cleaning etc.) or to drain and waste water treatment plant), ev. Flow rates of heating steam or condensate. Further line state is shown (milk, cleaning), amount of processed milk for day etc., piping system in operation etc.

**Practical way of evaporator control may be as it is shown below:**

- Start-up - optimal milk flow-rate
- Milk concentration is controlled with vacuum in the last effect (control valve in pipe for vapor exhaust to condenser or valve for control of cooling water flow-rate into condenser or small throttle.

Valve for an inlet before vacuum pump (for over-designed vacuum pump) or combination). During operation fouling forms on heat transfer surface. From this follows that pressure in the last effect has to be lower. Higher $A_{EVAP\ total}$ compensates lower k values. This follows from equation

$$Q_{EVAP} = k_{EVAP}\ \phi + A_{EVAP\ total} * \Delta t_{EVAP\ total}$$

- The way of control frequently is not used as condenser and vacuum pump operate without any reserve for regulation.
- Density meter -> vacuum control valve.
- Optimal milk flow-rate, limiting value of vacuum in the last effect is reached
- Milk concentration is controlled with heating steam pressure in 1st effect (control valve in pipe for steam inlet to evaporator opens more).
- Similar like above is further k value lowering compensated with further raising of $A_{EVAP\ total}$• This is way how keeps full evaporator performance.
- Density meter heating steam control valve.
- Optimal milk flow-rate, limiting values of vacuum and heating steam are reached (max. acceptable temp, of heating steam and min. attainable temp, of the last vapor)
- Milk concentration is controlled with milk flow-rate lowering.

Milk flow-rate has lower limit too (min. “wetting” of heat transfer surface -> fouling and a value and line economy).

- Densimeter -> inlet milk control valve.
- Minimal limit of milk flow-rate is reached and limiting temperatures in the 1st and last effects too.
- In the situation it is not possible to control evaporator work. Only falls of milk concentration and dryer performance are monitored.

When milk concentration falls to limit value is line operation uneconomical and line is stopped and switched to cleaning regime (CIP). Standard CIP program: rinsing with warm water (condensate), rinsing with boiling solution of soda lye (NaOH, rinsing with warm water (condensate), rinsing with boiling solution of nitric acid (HN03), rinsing with warm water (condensate) and finally rinsing with drinking water.

Note:

Single control steps may be combined or omitted. There are mentioned only general survey of evaporator control in the example (and not only for evaporator in dairy).

There is common operational regime for evaporators in dairies.: 20 h operation + 4 h CIP, and it is re-run again and again. According line situation is sometimes evaporator opened, visually checked and ev. Mechanically cleaned (spraying with hot high-pressure water).

## 6.4 *Dryer*

- Similar like for evaporator there are described possible ways of control.
- Inlet of concentrated milk depends on evaporator. Therefore it is not controlled.
- There are limits for milk powder moisture - controlled with drying air temperatee and ev. Amount. Temperature is controlled with valve for heating steam cooling to air heater. Powder moisture is set in laboratory (weighting, drying, and weighting more exact but last several hours) or moisture meter (quick but less e>act).
- Heating csir temperature - maximal and minimal temperature - affects performance ;e and economy of dryer (higher t. -> higher effectivity), product quality (burned or too wet). Ditto = reg. valve for heating steam like above.
- Amount of drying air maybe controlled by valves on fan outlet (ev. inlet). It is used in so ne cases. Else designed fan parameters and pressure losses in dryer system dc it.

- Pressure losses in air system are usually only monitored (U manometers with coloured water), sometimes are measured electronically and filed. They are used for checkir g of fans function, filters loading, air flow-rates in various parts of dryer etc.

- Temperature of outlet heating air - affects dryer economy and product quality (lower t. - 7 higher thermal effectivity, but danger of air moisture condensation in copies after dryer. product dampness. microbial contamination).
- Product quality ("burned” particles, colored particles, microbial contamination, powder de isity. solubility, digestibility etc.).

According to test results technical regulations are done (dryer walls hammering, stagnation zones elimination, cleaning process etc.).

- Possible way of dryer control:
- Powder moisture is controlled by
- Valve for heating f!ow-rate to air heater (heating air temperature)
- Ev. flow-rate of heating air (in some cases when fans are over-designed) - valve in air pipe

Ev. flow-rate of dried liquid (for our line it is given by line performance see above); it may be used for separate dryer.

- Pressure losses in dryer parts
- We understand from it for requirement for filer regeneration or cleaning, lamellae in air heater cleaning, fan function etc.
- Outlet heating air temperature is controlled by
- Heating air inlet temperature (valve for heating steam before air heater).
- Ev. flow-rate of dried liquid.
- Ev. flow-rate of drying air (see above).