SHIP Egypt

Session 05

Flowsheets
Energy consuming processes of relevant industry sectors

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Overview

- **Definition of processes**
- **Definition of thermal process engineering**
- **Characterisation of process technologies**
- **Examples of unit operations – theory and practical work**
  - ⇨ Fruit, vegetable, sugar processing
  - ⇨ Dairy
  - ⇨ Flour production
  - ⇨ Textile industry
  - ⇨ Salt and mineral production
  - ⇨ Brewery
  - ⇨ Meat processing
- **Supply systems**

Disclaimer

- **The schemes of the production lines are examples and may vary for production companies depending on process parameters, technologies used, product types, etc.**
- **Unit operations mentioned are examples**
- **Process technologies mentioned are examples**
- **Information on technologies, heat and cold supply, heating and cooling demand, etc. are examples and may vary depending on companies and experience**

Types of engineering

- **Mechanical engineering**
  - ⇨ Dealing with mechanical conversion processes as crushing, agglomeration, seperation and mixing
- **Chemical engineering**
  - ⇨ Dealing with the conversion of substances and systems by chemical reactions
- **Thermal engineering**
  - ⇨ Dealing with thermal separation and cleaning processes as distillation, rectification and extraction
- **Electrochemical engineering**
  - ⇨ Dealing with electrochemical phenomena as synthesis
- **Bio-engineering**
  - ⇨ Dealing with biotechnological processes as bio-synthesis, fermentation, bio-catalytics

Relevant processes

- **In the food and beverage industry processes covering all mentioned types are generally relevant**
- **focus on processes with a thermal energy demand using thermal conversion, electric power, etc.**
- **Processes can be characterised using UNIT OPERATIONS that**
  - ⇨ Involve a physical change or chemical transformation such as separation, crystallization, evaporation, filtration, polymerization, isomerization, and other reactions.
  - ⇨ For example, in milk processing, homogenization, pasteurization, chilling and packaging are each unit operations which are connected to create the overall process.

Characterisation of unit operations (1)

- **Unit operations consist of five classes**
  - ⇨ Fluid flow processes, including fluids transportation, filtration, and solids fluidization
  - ⇨ Heat transfer processes, including evaporation, condensation, and heat exchange
  - ⇨ Mass transfer processes, including gas absorption, distillation, extraction, adsorption, and drying
  - ⇨ Thermodynamic processes, including gas liquefaction, and refrigeration
  - ⇨ Mechanical processes, including solids transportation, crushing and pulverization, and screening and sieving

Characterisation of unit operations (2)

- **Unit operations also fall in the following categories which involve elements from more than one class**
  - ⇨ Combination (mixing)
  - ⇨ Separation (distillation, crystallization, chromatography)
  - ⇨ Reaction (chemical reaction)

Characterisation of unit operations (3)

- **Technologies**
  - ⇨ State of the art
  - ⇨ Innovative
  - ⇨ Process intensification
- **Process parameters**
- **Energy supply**
- **Energy demand**
  - ⇨ Heating, cooling, etc.
- **Batch / continuous**

Unit operations (1)

- **The most important unit operations in the relevant industries are**
  - ⇨ Cleaning
  - ⇨ Washing
  - ⇨ Drying
  - ⇨ Evaporation, Distillation and deodorisation
  - ⇨ Dyeing
  - ⇨ Extraction
  - ⇨ Pasteurisation
  - ⇨ Sterilisation
  - ⇨ Cooking and boiling
  - ⇨ Other process heating
    - **Pre-heating, process water, soaking, thawing, peeling, blanching, finishing, scouring, bleaching**

Unit operations (2)

- **The most important unit operations in the relevant industries are**
  - ⇨ General process heating
    - **Boiler feed-water preheating**
  - ⇨ Heating and cooling of production halls
  - ⇨ Cooling processes
    - **Cooling, chilling, cold stabilisation**
    - **Ageing**
  - ⇨ Melting
  - ⇨ Extraction
  - ⇨ Bleaching
  - ⇨ Fermentation

Unit operations – definition (1)

➢ CLEANING

⇨ Objective

- **The term cleaning in the food industry is used to describe processes that remove undesirable materials and substances from products or other surfaces involved in the production process. The cleaning in the food industry can be divided into three different sub-processes: 1)cleaning of bottles and cases, 2)washing products and 3)cleaning of production halls and equipment. Cleaning results in removal and separation of unwanted components from the food so that the surface of the food can be in a suitable condition for further processing. Additionally, cleaning minimises the microbiological load of reusable food containers, equipment and production halls, according to hygiene and health regulations.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (2)

➢ CLEANING

⇨ Field of application

- **Cleaning processes are widely used in the food industry. Cleaning of production halls and equipment is applied in all food production processes. Dairies, meat, starch/potatoes, fruit/vegetables and fat/oils industries require an additional system for washing the products. For most of these industries, a system for cleaning bottles and cases is also needed.**

⇨ Description

- **Water heated up to 90°C (maximally) can be used, depending on the cleaning application. The cleaning can be performed either manually or by automated systems. The cleaning process often requires detergents to achieve the removal of the unwanted substances.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (3)

- **DRYING**
  - ⇨ Objective
    - **Drying is defined as the application of heat under controlled conditions, to remove the water present in foods by evaporation to yield solid products. It differs from evaporation, which yields concentrated liquid products. The main purpose of drying is to extend the shelf-life of foods by reducing their water activity. Micro-organisms which cause food spoilage and decay and many of the enzymes which promote undesired changes in the chemical composition of the food are unable to grow, multiply or function in the absence of sufficient water.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (4)

➢ DRYING

⇨ Field of application

- **Typical applications for drying techniques include dairy products (milk, whey, creamers), coffee, coffee surrogates, tea, flavours, powdered drinks, processed cereal-based foods, potatoes, starch derivatives, sugar beet pulp, fruits, vegetables and spices. The water removal from the wet germinated grain is applied in the production of malt, a process which is called kilning. For the malting process, the drying step is essential and is required to create the desired colour and flavour**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (5)

➢ DRYING

⇨ Description

- **Hot air drying:**
  - Hot air is used as the heating medium and is in direct or indirect contact with the liquid product. The heat transferred from the hot air to the product causes evaporation of the water content.
- **Surface drying by heat conduction through a heat transfer system (i.e. contact dryers):**
  - The heating medium is not in contact with the wet food but separated from it by a heat transfer surface. The heat is transferred by conduction through the surface, and by convection from the hot surface to the food product for evaporating and removing water from the food. This has two main advantages compared to hot air dryers; less air volume is required and therefore thermal efficiency is higher, and the process may be carried out in the absence of oxygen.

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (6)

➢ EVAPORATION AND DISTILLATION

⇨ Objective

- **In both evaporation and distillation, liquid components are removed from liquid phase food products by applying heat. In the case of evaporation, water is removed from the liquid mixture, while in the case of distillation components of the liquid mixture are separated by partial vaporization. Deodorization is a steam distillation process used for the removal of highly volatile compounds.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (7)

➢ EVAPORATION AND DISTILLATION

⇨ Field of application

- **Evaporation is applied in most food industry sectors like dairies, fruit and vegetable production, sugar production, wine and meat production, while distillation is mostly used in the production of aroma, essences and alcoholic drinks. Deodorization is typically used in the refining of edible oils and fats, while it's also used in other processes, e.g. production of decaffeinated coffee.**

⇨ Description

- **In the case of evaporation, heat is applied to the liquid food and water content evaporates, leaving the surface of the liquid product and increasing its concentration. Different types of evaporation equipment can be used.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (8)

➢ BLANCHING

⇨ Objective

- **Blanching operations are designed to expose the entire product to high temperatures for a short period of time, by using steam heating indirectly for fruit juices and directly for vegetables. The primary function of this operation is to inactivate or retard bacterial and enzyme action, which could otherwise cause rapid degeneration of quality. Two other desirable effects of blanching include the expelling of air and gases in the product, and a reduction in the product volume.**

⇨ Field of application

- **Blanching is a controlled heating process similar to pasteurization and it is used in the processing of fruit juices, fruits and green vegetables.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (9)

➢ BLANCHING

⇨ Description

- **Both pasteurisation and blanching are based on the use of the minimum heat requirement needed to deactivate specific micro-organisms or enzymes, thus minimising any quality changes in the foods themselves**
- **Before blanching, the food is preheated. Depending on the product and/or availability of equipment, blanching may be accomplished direct or indirect heating systems. After blanching, the food is cooled using either water or air.**
- **Direct heating: Direct heating is normally made by immersion in hot water (80 to 100°C) or exposure to live steam.**
- **Indirect heating: For some products direct contact with water is to be avoided thus heat exchangers working with hot water or vapour are applied.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (10)

➢ PASTEURISATION

⇨ Objective

- **Heat treatment of products is one of the main techniques in the food industry for food conservation. Heat treatment stops bacterial and enzyme activity; thus preventing a loss of quality and keeping food non-perishable. Pasteurisation is a controlled heating process used to eliminate any dangerous pathogens that may be present in milk, fruit-based drinks, some meat products, and other foods which are commonly subjected to this treatment. Pasteurization inactivates most viable vegetative forms of micro-organisms but not heat-resistant spores. As well as the application to inactivate bacteria, pasteurization may be considered in relation to enzymes present in the food, which can be inactivated by heat.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (11)

➢ PASTEURISATION

⇨ Field of application

- **Pasteurisation is used to treat all types of food products. These include milk, juices, beer and many others.**

⇨ Description

- **Both pasteurisation and blanching are based on the use of the minimum heat requirement needed to deactivate specific micro-organisms or enzymes, thus minimising any quality changes in the foods themselves.**
- **In heat treatment processes, various time/temperature combinations can be applied, depending on the product properties and shelf-life requirements. Pasteurisation temperatures commonly range from 62 to 90°C, and pasteurisation times vary from seconds to minutes.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (12)

➢ STERILISATION

⇨ Objective

- **Heat treatment of products is one of the main techniques in the food industry for food conservation. It stops bacterial and enzyme activity, thus preventing a loss of quality and keeping food non-perishable.**
  - Sterilisation is a controlled heating process used to completely eliminate all living micro-organisms, including thermoresistant spores in milk or other food. It can be achieved by moist heat, dry heat, filtration, irradiation, or by chemical methods. Compared to pasteurisation, a heat treatment of over 100°C is applied for a period long enough to lead to a stable product shelf-life.
  - UHT (Ultra-High Temperature) sterilisation has a heat treatment of over 100°C during very short times; it is especially applicable to low viscous liquid products. The basis of UHT, or ultra-high temperature, is the sterilization of food before packaging, then filling into pre-sterilized containers in a sterile atmosphere.

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (13)

➢ STERILISATION

⇨ Field of application

- **Sterilisation is used to treat all types of food products. These include milk, juices, beer and many others. UHT sterilization is used for low viscosity liquid products (milk, juices, cream, wine, salad dressings), foods with discrete particles (baby foods, tomato products, fruits and vegetables juices, soups) and larger particles (stews).**

⇨ Description

- **Generally in sterilization, the product is canned or bottled and then heat-treated in a sterilizer. Sterilizers may be batch or continuous. In heat treatment processes, various time/temperature combinations can be applied, depending on the product properties and shelf-life requirements.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (14)

➢ COOKING AND BOILING

⇨ Objective

- **Cooking and boiling are heat processing techniques applied to foodstuffs to alter the texture, colour and moisture content of the food, or to facilitate other later processes.**

⇨ Field of application

- **Cooking and boiling are applied on an industrial scale for the preparation of ready-to-eat products, in the preparation of complete meals, for meal components (such as in various meat products or through heating of the foodstuffs in processing.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (15)

➢ COOKING AND BOILING

⇨ Description

- **Cooking is carried out in ovens:**
  - Water bath ovens allow the best homogeneity of heating to be obtained. The immersion in hot water causes weight loss, and results in proteins and greases being released into the water.
  - Shower ovens allow a good uniformity of heating and include the simultaneous action of water sent through the showers and the saturated steam which rises from the collecting basin, at the bottom of the oven, which is heated, in turn, by coils.
  - In steam ovens, the water shower is eliminated and any heating is due only to the steam produced in the collection basin.
  - Air/steam circulation ovens control surface humidity, steam inlet and a recirculation of hot air. Boiling is carried out by immersion in water at boiling temperature.

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (16)

➢ OTHER PROCESS HEATING

⇨ Objective

- **This unit operation category includes typical processes in the food industry that are not complicated in terms of equipment and are based on a simple heat transfer principle. Pre-heating of food streams, soaking and thawing are included in this category. The objective in all cases is to increase the energy content of the food stream so that it can be further processed. In the case of soaking, seeds are moistened and softened using water in order to reduce the cooking time or enhance the seed coat removal. In case of thawing, frozen food can be de-frozen before it can be further processed.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (17)

➢ OTHER PROCESS HEATING

⇨ Field of application

- **Pre-heating, soaking and thawing can be applied in many food industry sectors, including dairies, breweries, fruit and vegetable industries, meat production and chocolate, cacao and coffee production.**

⇨ Description

- **Heat transfer in these cases can be accomplished either by direct or indirect heating. Water or steam can be used as an auxiliary feed for the process. In the case of soaking, seeds are in direct contact with the water in tanks. In the case of thawing, frozen food is placed in water baths. In the case of pre-heating, water or steam can be in direct or indirect contact with the food. Pre-heating can be accomplished in heat exchangers or in compartments where steam or water can be sprayed.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (18)

➢ HEATING OF PRODUCTION HALLS

⇨ Objective

- **In food industries, energy is needed to heat up the production halls. Depending on the type and the size of the industry, large amounts of heat can be consumed.**

⇨ Field of application

- **Heating of production halls can be applied in the food industries where the product is not heat-sensitive, such as fruit and vegetable, sugar, fat and oil, starch and potato, chocolate and coffee and aroma industries.**

⇨ Description

- **Heating of production halls can be achieved in different ways, depending on the heat needs of the unit. For small-scale production halls, heat exchangers in the form of heat radiators can provide adequate energy transfer. For larger-scale production halls, air conditioning units can be used to increase the temperature level in the production halls.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (19)

➢ COOLING OF PRODUCTION HALLS

⇨ Objective

- **In food industries, heat must be removed from production halls where heat-sensitive food is being processed in order to maintain high food quality. Depending on the type and the size of the industry, large amounts of heat have to be removed.**

⇨ Field of application

- **Cooling of production halls can be applied in the food industries where the product is heat-sensitive, such as dairies, meat, beer, wine and fish industries.**

⇨ Description

- **Cooling of production halls can be achieved in different ways, depending on the cooling needs of the unit. Conventionally, air conditioning units are used to decrease the temperature level of the production halls.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (20)

➢ COOLING PROCESSES

⇨ Objective

- **Reduce or maintain the temperature of the food product in a lower level for a period of time (e.g. cooling, chilling, cold stabilization and ageing).**

⇨ Field of application

- **Cooling processes can be applied in food industry sectors as dairies, breweries, fruit and vegetable industries, meat production and wine production.**

⇨ Description

- **Cooling/freezing is carried out by passing the product through a heat exchanger, cooler or cooling the vessels. A cooling medium is used to achieve the temperature reduction and often the cooling medium is recirculated in the cooling system. For chilling, cold stabilization and ageing, the food product should remain in low temperature levels for a period of time, therefore cooling storage rooms or vessels are needed.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (21)

➢ MELTING

⇨ Objective

- **The objective of melting is to obtain a phase change from solid to liquid, in order to prepare the material for further processing (e.g. for fats, processed cheese) or to recover the melted fraction (i.e. in fat recovery).**

⇨ Field of application

- **The main applications of melting in the food industry are in chocolate moulding, the production of processed cheese, the processing of oils and fats and the recovery of animal fat from meat residues**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (22)

- **MELTING**
  - Description
    - **For melting, processing kettles are used. These can be operated either batch-wise or continuously. Heating may be carried out by direct steam injection or indirectly by steam jackets. Processing kettles are available in various sizes and shapes. In continuous processing, scraped surface heat exchangers are applied.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (23)

➢ EXTRACTION

⇨ Objective

- **The objective of extraction is to recover valuable soluble components from raw materials by primarily dissolving them in a liquid solvent, so that the components can be separated and recovered later from the liquid. It is not always the objective to recover one particular compound in pure form from a raw material, i.e. sometimes extraction is intended to separate all the soluble compounds from the residue; an example of this is the extraction of coffee.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (24)

➢ EXTRACTION

⇨ Field of application

- **Extraction is applied to a wide variety of food products. Typical examples are**
  - The extraction of sugar from sugar-beets or sugar-cane
  - The extraction of oil from oil seeds and from virgin pomace
  - The extraction of coffee extract from coffee beans
  - The extraction of caffeine from coffee beans
  - The extraction of various other compounds such as proteins, pectins, vitamins, pigments, essential oils, aroma compounds, flavour compounds etc. from many different materials.

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (25)

➢ EXTRACTION

⇨ Description

- **Extraction works according to the principle that soluble components can be separated from insoluble or less soluble components by dissolving them in a suitable solvent. Commonly the extract is the product or intermediate product and the residue is a waste or by-product.**
- **Raw materials that are suitable for extraction may contain either solids only, solids and a solution, or solids and a liquid. Solid/liquid extraction is sometimes called leaching. When the soluble component is incorporated in a liquid, liquid/liquid extraction may be applied to recover the valuable soluble component.**
- **The efficiency of the extraction process depends on the selectivity of the solvent.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (26)

➢ BLEACHING

⇨ Objective

- **The objective of bleaching is to remove pigments, metals, e.g. nickel or iron from other oil refinery process; residual soaps and phospholipids from the oil or fat.**

⇨ Field of application

- **Bleaching is applied in the refining of edible oils and fats and also in fruit and vegetable canning.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (27)

➢ BLEACHING

⇨ Description

- **Edible oils and fats are mixed with bleaching earth that has an affinity for adsorbing the above mentioned undesirable compounds. The oil is mixed under vacuum conditions with 0.1-3% of bleaching earth. This is a clay mineral, such as bentonite or montmorillonite, that has been activated by thermal and/or acidic or other treatments. These earths, sometimes mixed with small amounts of activated carbon, have a very high adsorbing capacity. After bleaching for 30-90min the oil is separated from the bleaching earth using filters. The spent earth contains high amounts of oil, up to 30%. A steam stripping process can recover a part of the oil or fat. Used bleaching earth can be added to the meal in integrated installations. The bleached oil is further treated in other refinery processes. The equipment used for bleaching consists of mixing vessels, vacuum generators and filters.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (28)

➢ FERMENTATION

⇨ Objective

- **Fermentation is the controlled action of selected micro-organisms to alter the texture of foods, to preserve foods by the production of acids or alcohol, or to produce or modify flavours and aromas. It also preserves products by lowering the pH tolerance limits of many micro-organisms.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (29)

➢ FERMENTATION

⇨ Field of application

- **Fermentation is an important processing step for a number of products. Typical applications include beer, wine, various dairy products, vegetables, meat and fish. Alcoholic fermentation is used in beer and winemaking and for the production of spirits, mostly with cereals, grape musts, sugar juices and molasses as a raw material. Lactic acid fermentation is used for making yoghurt and other fermented dairy products, fermented meat products such as certain types of sausages and vegetables, i.e. sauerkraut. In the lactic acid fermentation of vegetables, the sliced raw material, e.g. green cabbage in the case of sauerkraut production, is salted and then fermented under anaerobic conditions.**

⇨ Description

- **There are two types of fermentation processes, i.e. alcoholic fermentation and lactic acid fermentation.**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (30)

- **DYEING**
  - ⇨ Objective
    - **Dyeing is a method for colouring a textile material in which a dye is applied to the substrate in a uniform manner to obtain an even shade with a performance and fastness appropriate to its final use. A dyestuff is a molecule which contains a chromophoric group (conjugated system) capable of interacting with light, thus giving the impression of colour**

Source: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 2005

Unit operations – definition (31)

➢ DYEING

⇨ Field of application:
Textiles can be coloured at any of several stages of the manufacturing process so that the following colouring processes are possible

- **flock or stock dyeing**
- **top dyeing: fibres are shaped in lightly twisted roving before dyeing**
- **tow dyeing: it consists in dyeing the mono-filament material (called tow) produced during**
- **the manufacture of synthetic fibres**
- **yarn dyeing**
- **piece (e.g. woven, knitted and tufted cloths) dyeing**
- **ready-made goods (finished garments, carpet rugs, bathroom-sets, etc.).**

Unit operations – definition (32)

➢ DYEING

⇨ Description

- **Various dyeing techniques exist:**
  - mass dyeing/gel dyeing, in which a dye is incorporated in the synthetic fibre during its production
  - pigment dyeing, in which an insoluble pigment, without affinity for the fibre, is deposited onto the textile substrate and then fixed with a binder;
  - dyeing processes which involve the diffusion of a dissolved or at least partially dissolved dye into the fibre.
- **Dyeing can be carried out in batch or in continuous/semi-continuous mode. The choice between the two processes depends on the type of make-up, the chosen class of dye, the equipment available and the cost involved.**
- **Both continuous and discontinuous dyeing involve the following steps: preparation of the dye; dyeing; fixation; washing and drying**

Characterisation of unit operations

- **Unit operations can be characterised by**
  - ⇨ Heating demand / cooling demand
  - ⇨ Batch / continuous
- **Heating demand / cooling demand**
  - ⇨ Process medium has to be heated up or cooled down to a certain process temperature
  - ⇨ A bath, vessel, storage, etc. has to be heated up or cooled down to a certain process temperature in which the process takes place
  - ⇨ Temperature changes caused by losses have to be compensated (heating or cooling)

Energy balance

- **Energy content in input and output streams based on reference temperature**
- **Energy demand of a process**
  - ⇨ Heating or cooling input streams (circulation energy)
  - ⇨ Heating or cooling e.g. baths or ovens before process start (initial heating or cooling at start-up)
  - ⇨ Heating or cooling during processing (controled temperature changes)
  - ⇨ Heating or cooling a process to keep a temperature level (maintenance energy) to compensate losses

$$P = \dot{m} * c_p * \Delta T$$

P… capacity [kW]

c_p… heat capacity [kJ/kgK]

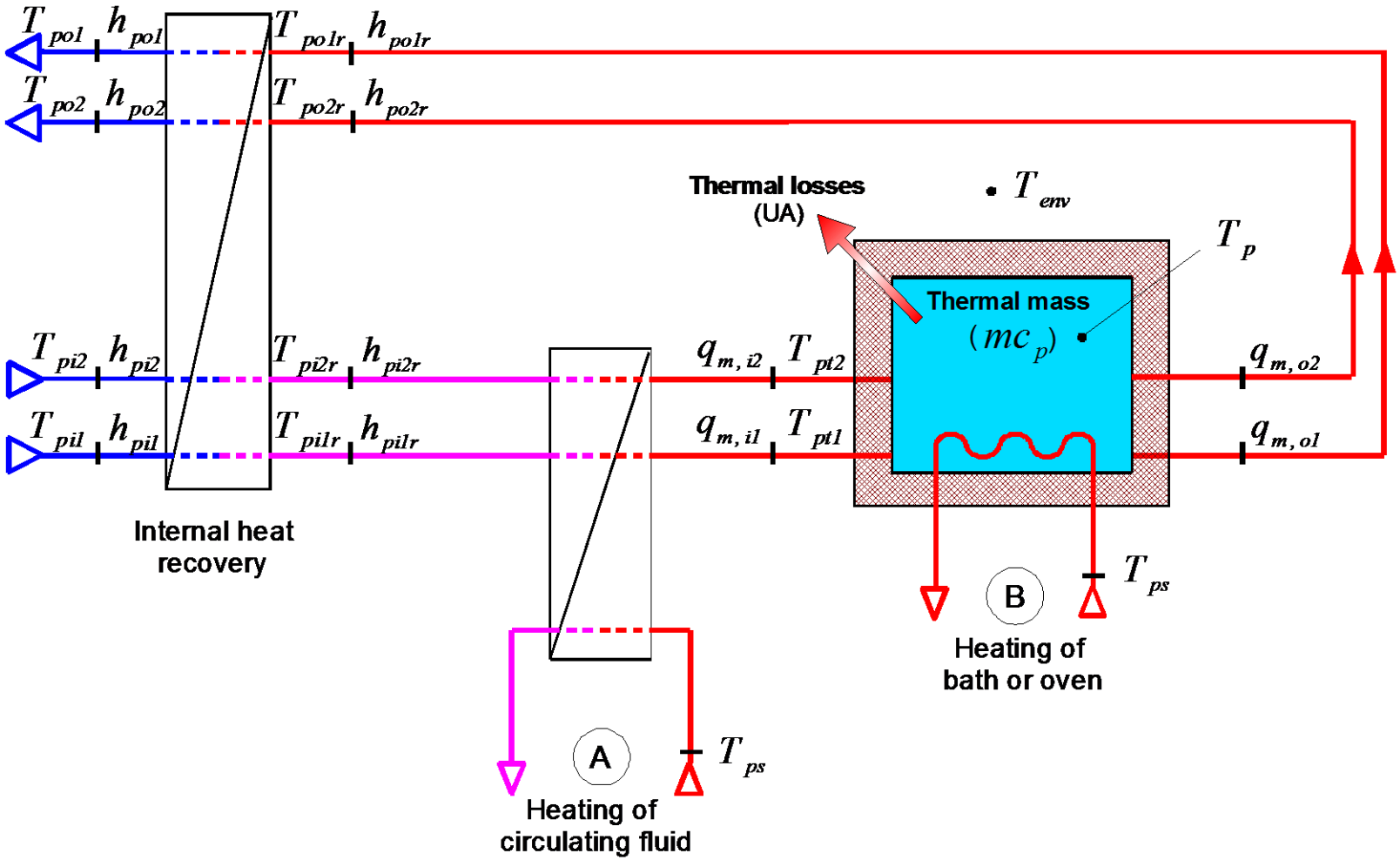
ΔT… temperature difference [K]

$$Q = \mathrm{P} * \mathrm{h}$$

Q… energy [kWh]

h… operating hours

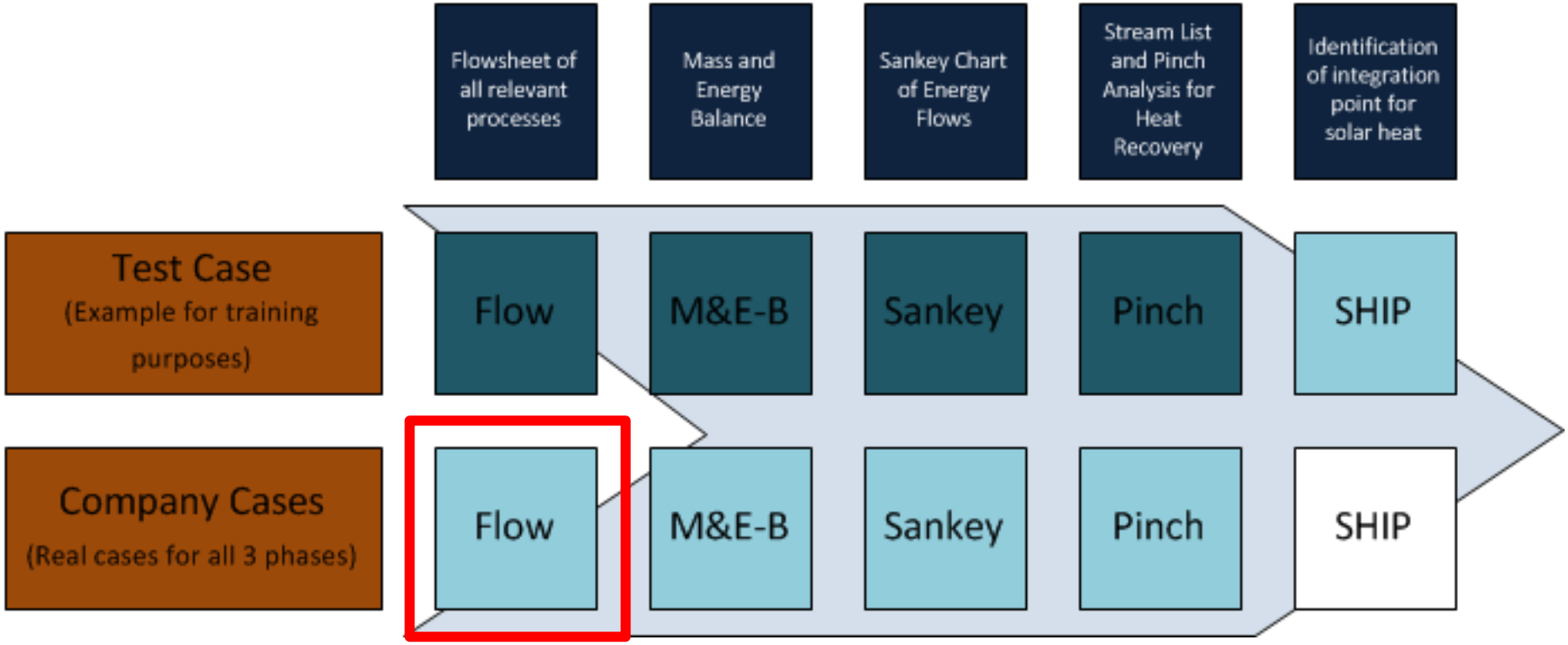
EINSTEIN model of a process - example



Discussion and group work

- **Discuss and describe the flow sheets**
- **Define processes and unit operations regarding**
  - ⇨ Heat and/or cooling demand
    - **How to calculate**
    - **Start-up energy demand**
    - **Circulation energy demand**
    - **Maintenance energy demand**
  - ⇨ Batch / continuous process
  - ⇨ Necessary energy supply system
    - **Hot water, steam, cooling medium, storages, heating/cooling rates, etc.**
  - ⇨ Known process technologies and process parameters
  - ⇨ Innovative process technologies
  - ⇨ Influence on product quality

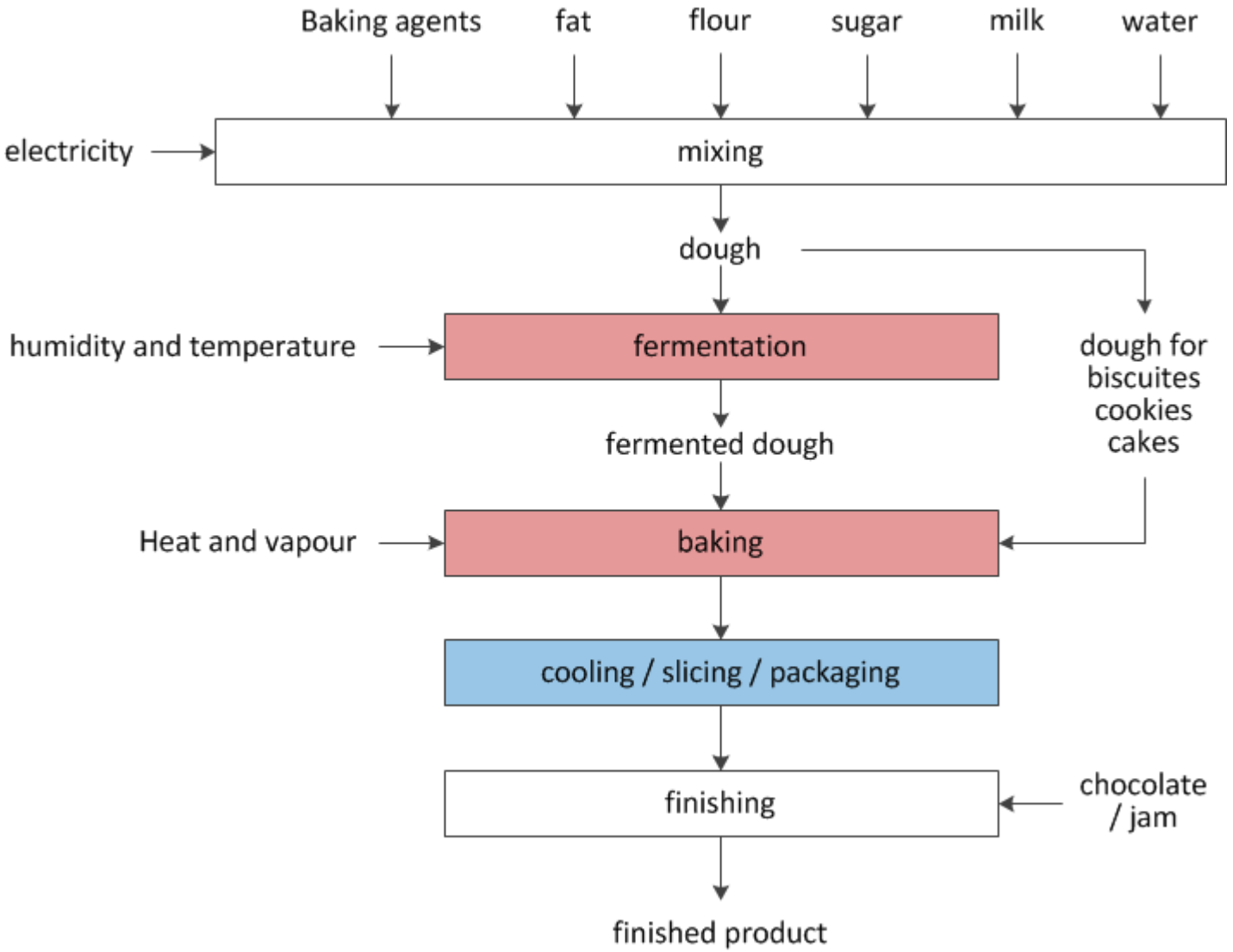
Objectives Phase I



Sub-sector bakery

- **Main bakery products are**
  - Bread
    - **Wheat bread, mixed wheat and rye bread, mixed rye and wheat bread, rye bread, bread specialities**
  - Fine bakery
  - Confectionary
    - **Biscuits**
    - **Cakes**
    - **Cocoa**
    - **chocolate**

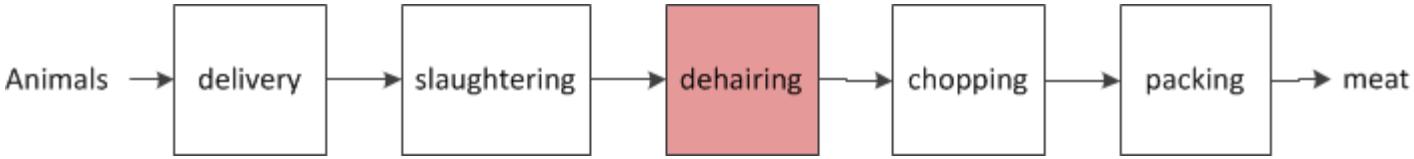
Flow sheet – unit operations / processes



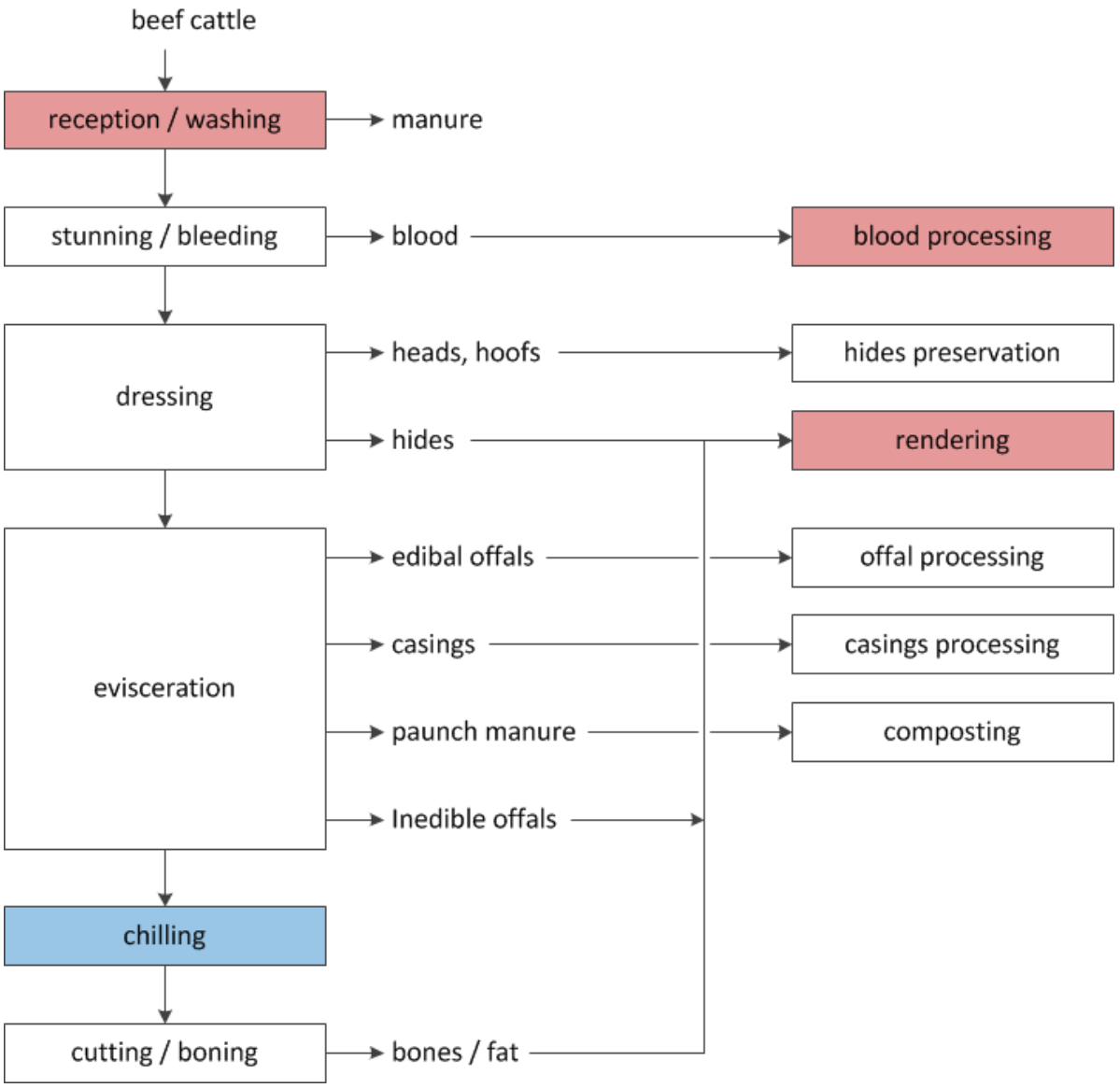
Sub-sector meat processing

- **Beef, pork and poultry are the main types of meat processed in Europe. The activities of the meat sector can be divided into three areas, slaughtering (covered by the "Slaughterhouses and animal by-products BREF" [181, EC, 2003]), meat cutting and further processing**
  - ⇨ Beef
  - ⇨ Pork, poultry
  - ⇨ Canned meat
  - ⇨ Cooked ham
  - ⇨ Cured ham
  - ⇨ Salami, sausages

Flow sheet – unit operations / processes



Flow sheet – unit operations / processes



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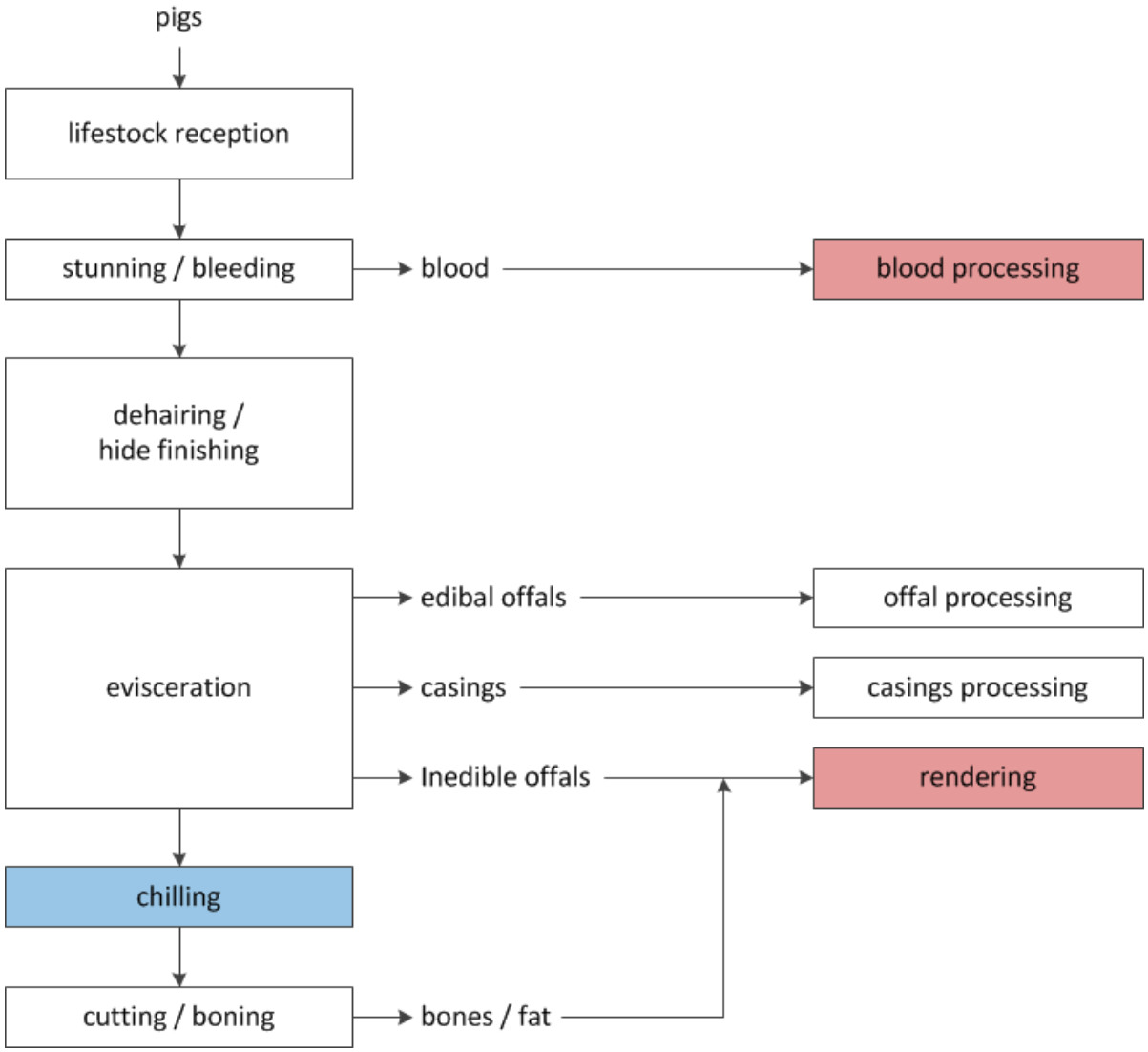

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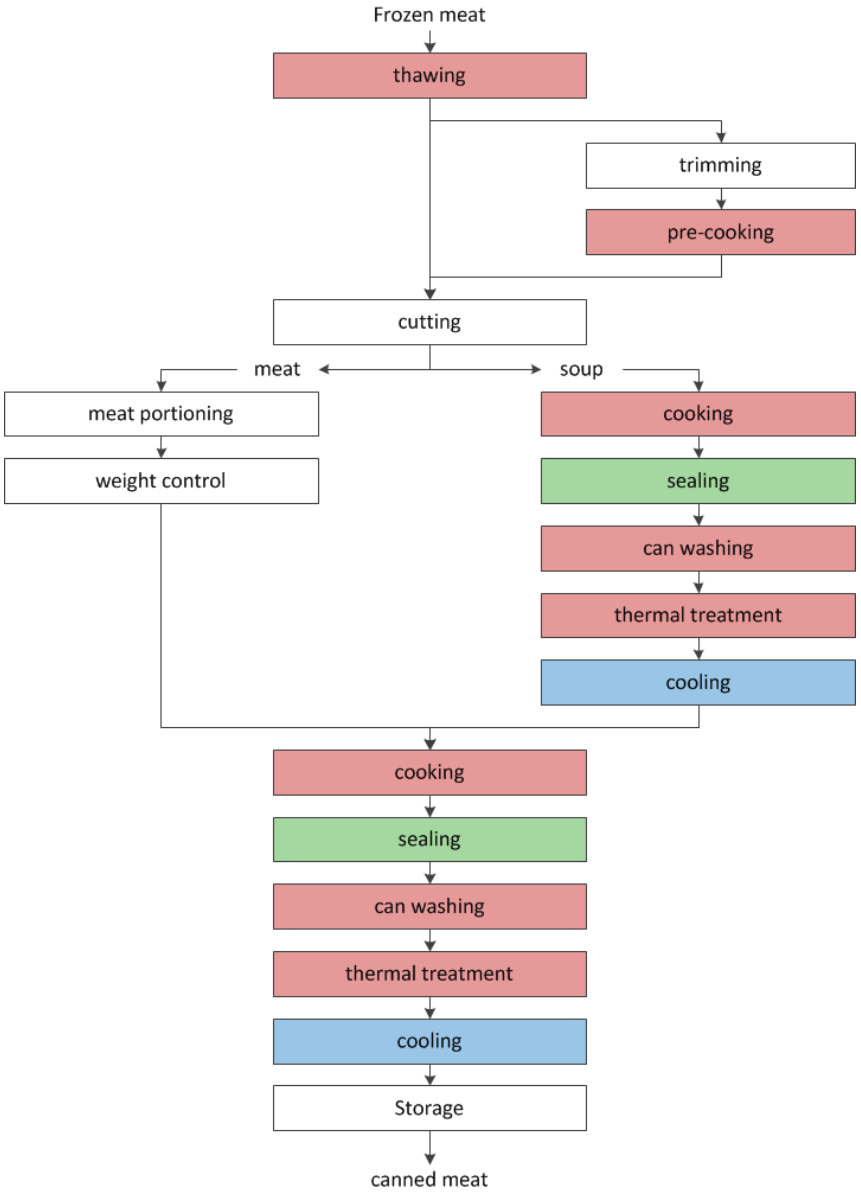

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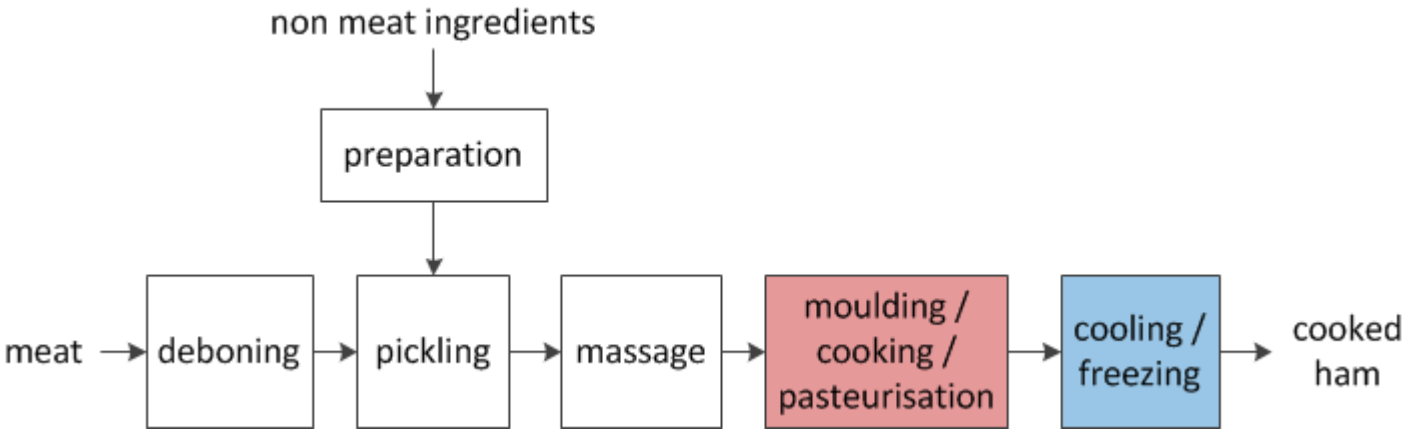

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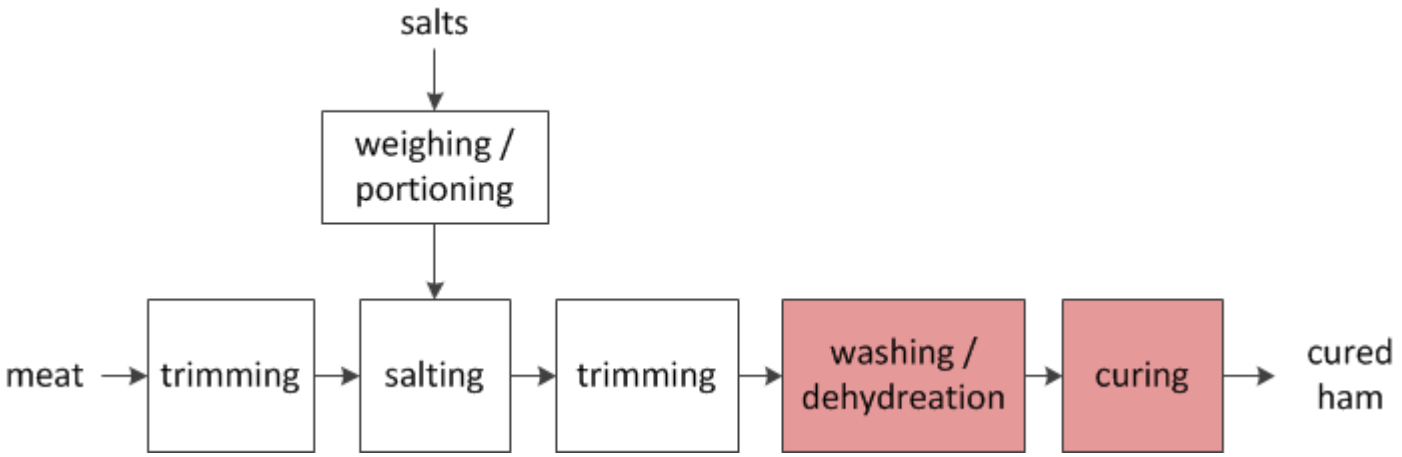

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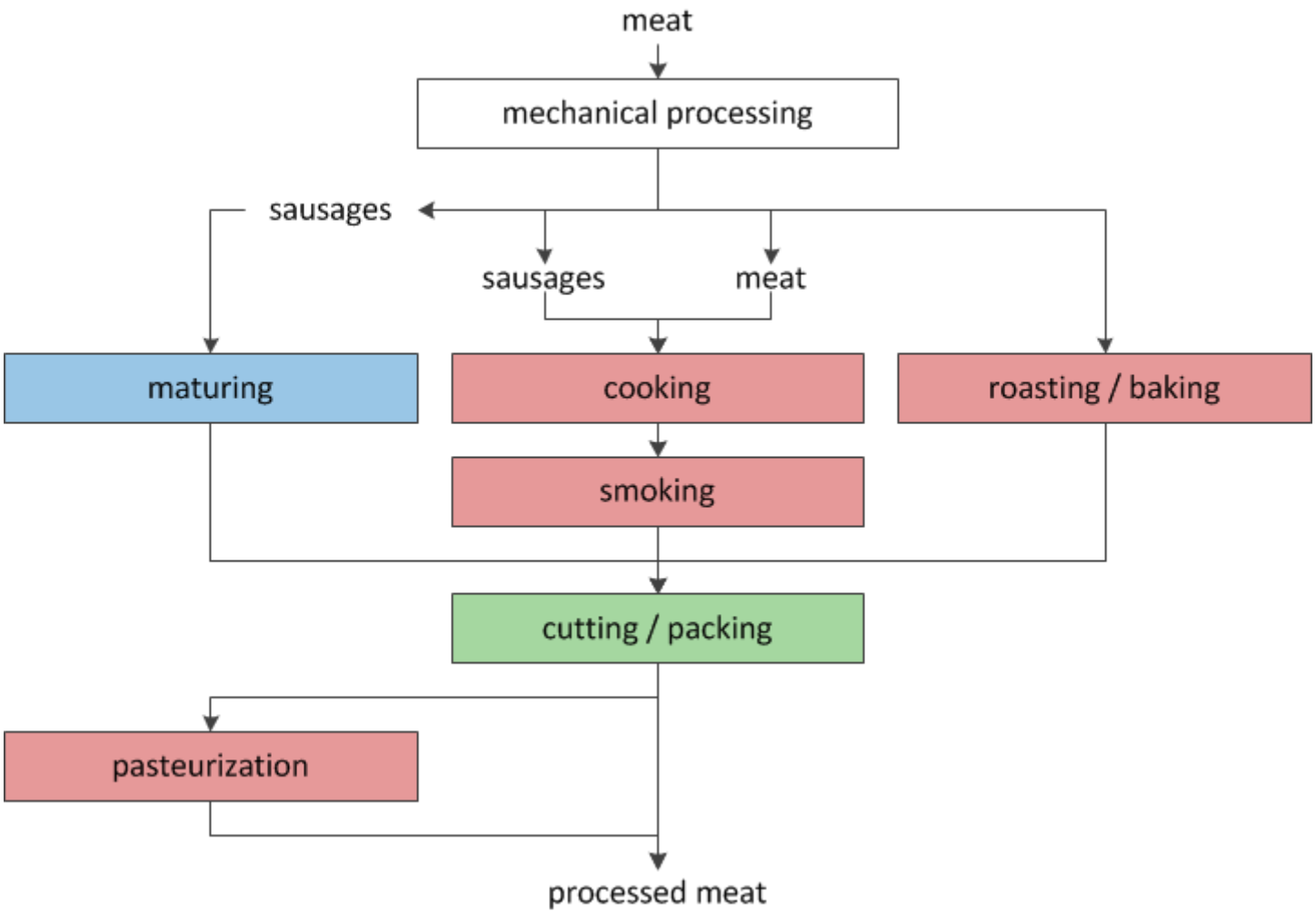
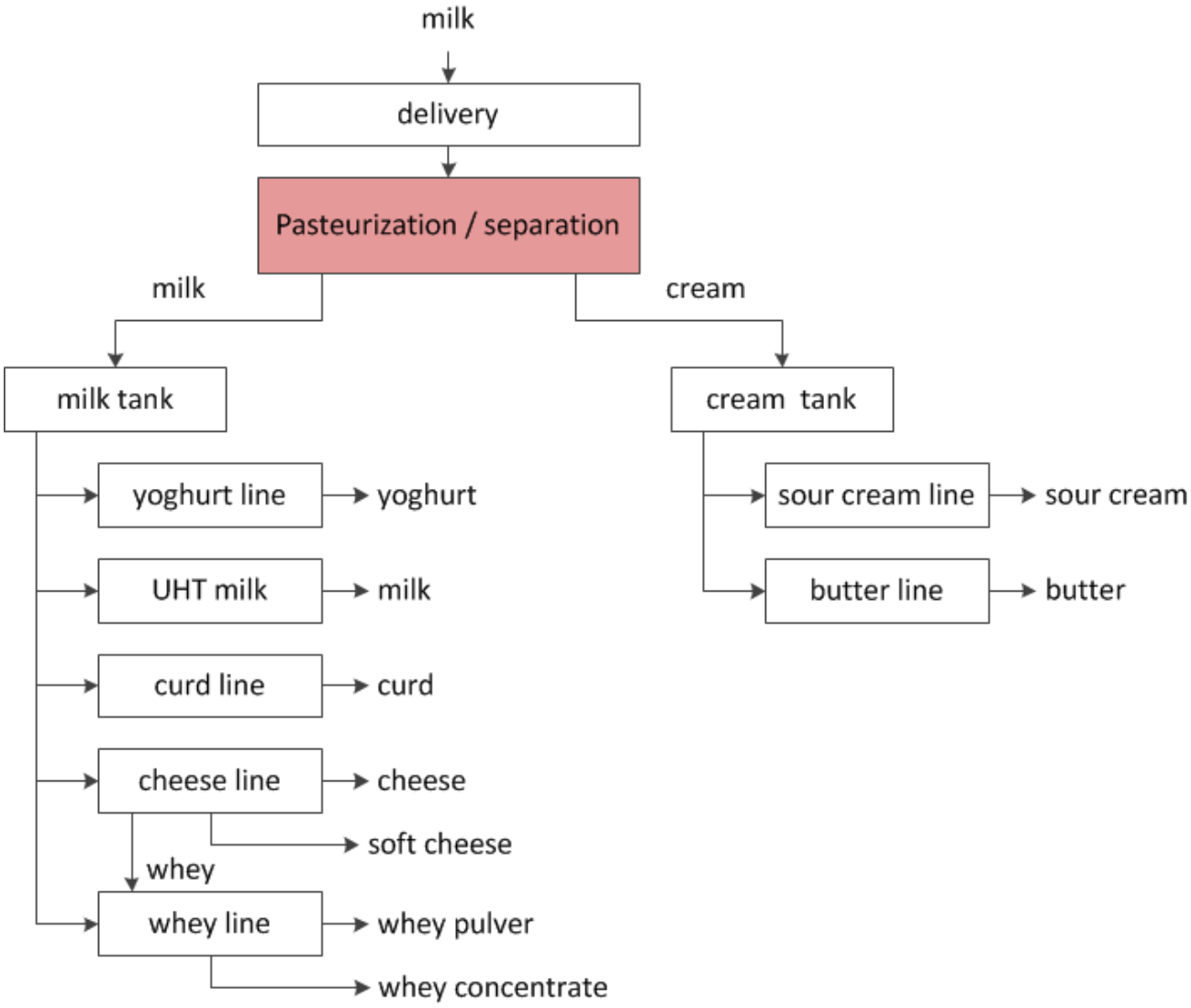


Sub-sector dairy

- **Milk is approximately 87% water, with the remainder being protein, fat, lactose, calcium, phosphorus, iron and vitamins. Cows milk is primarily consumed, but goats and sheep milk are also consumed in significant quantities. A number of dairy products such as cream, cheese and butter are produced from milk.**
  - ⇨ Milk and cream
  - ⇨ Condensed and powdered milk
  - ⇨ Butter
  - ⇨ Cheese
  - ⇨ Yoghurt
  - ⇨ Ice-cream
  - ⇨ Whey

Flow sheet – unit operations / processes



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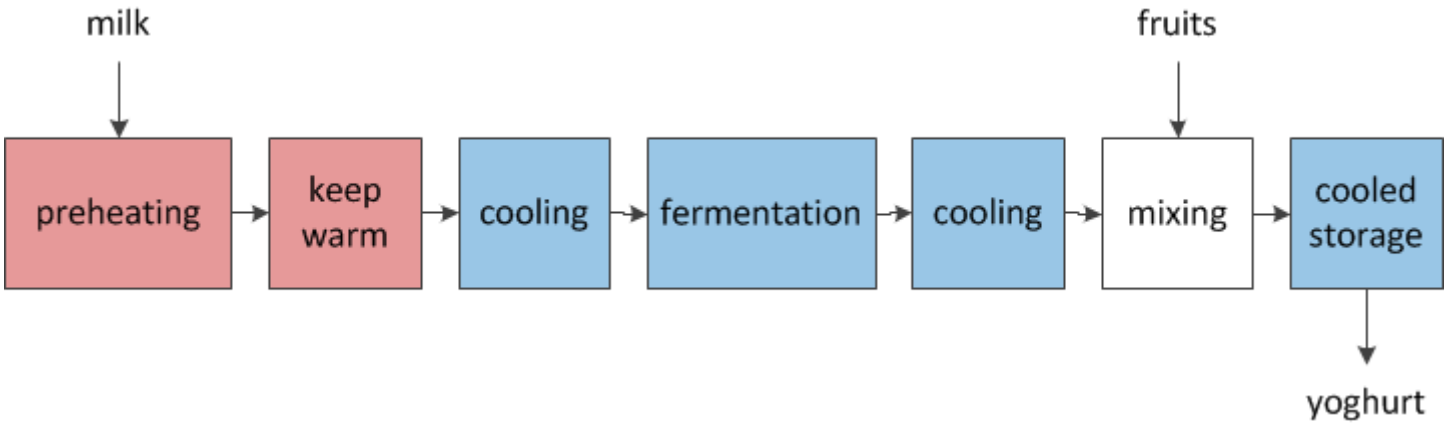

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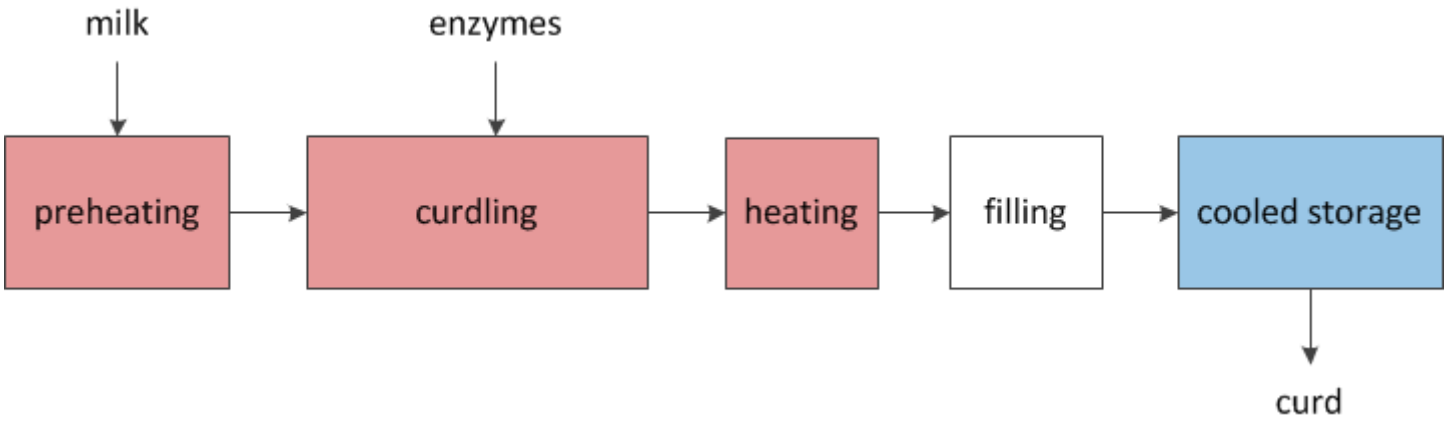

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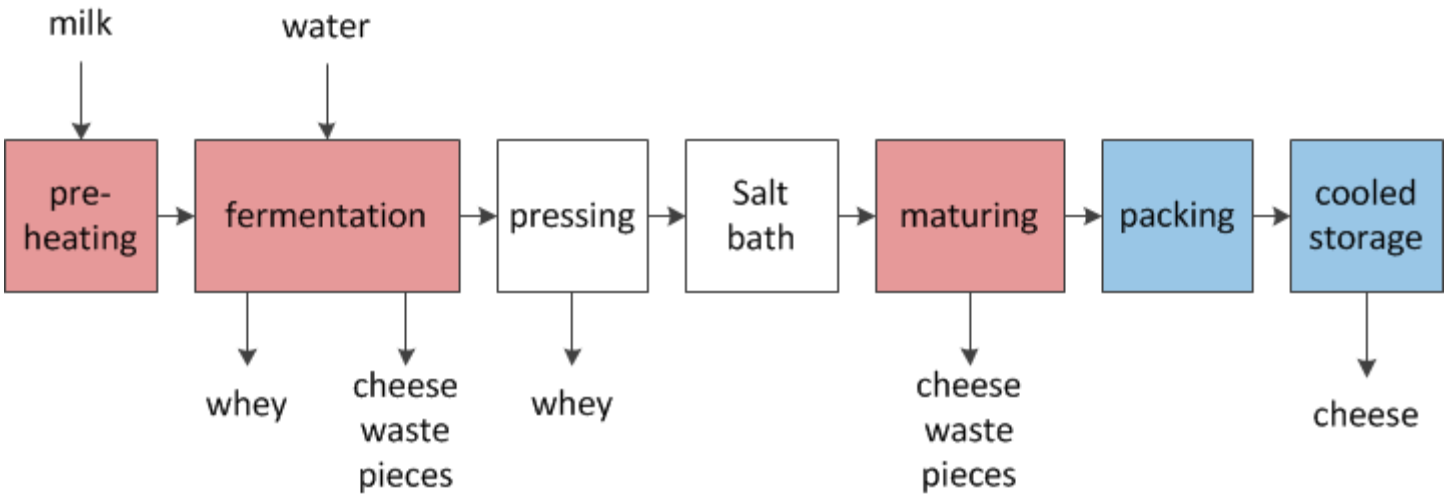

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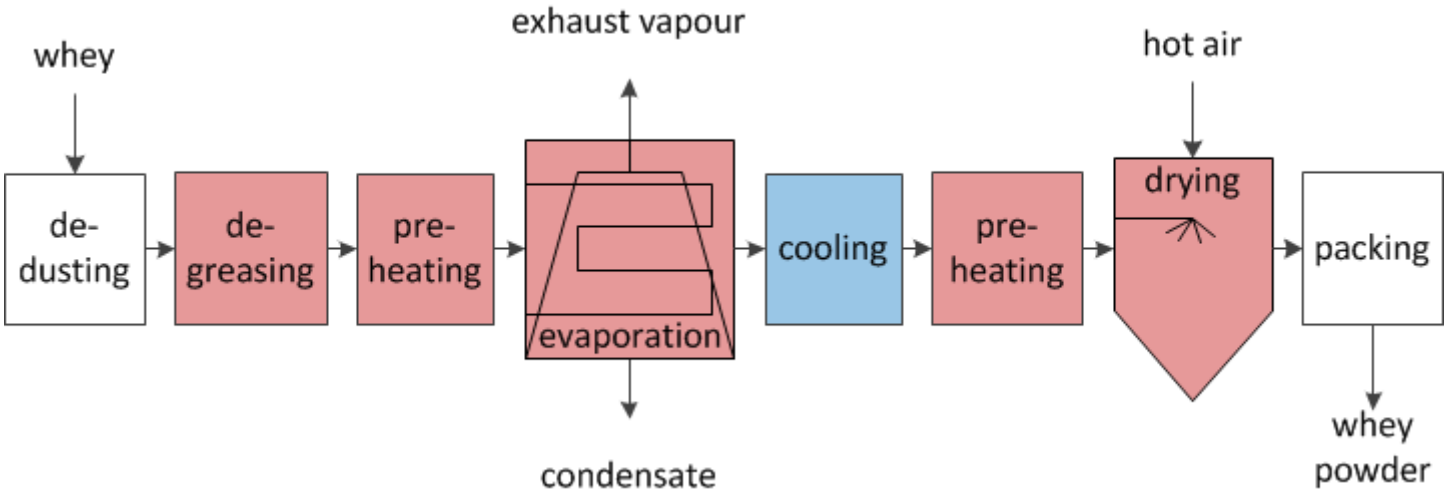

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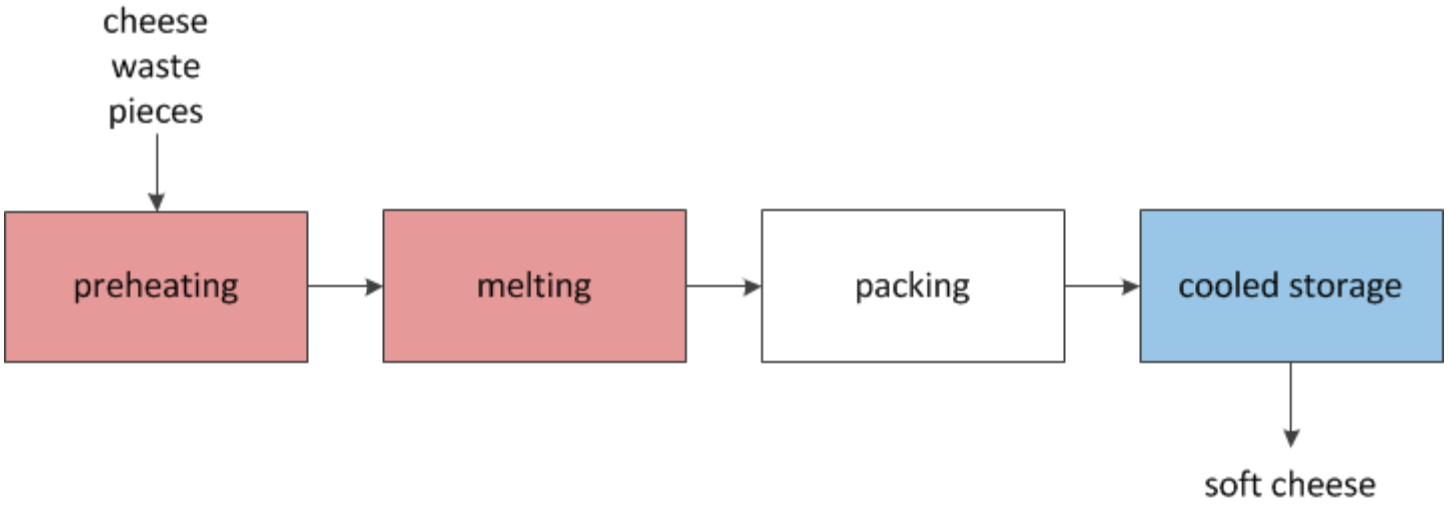

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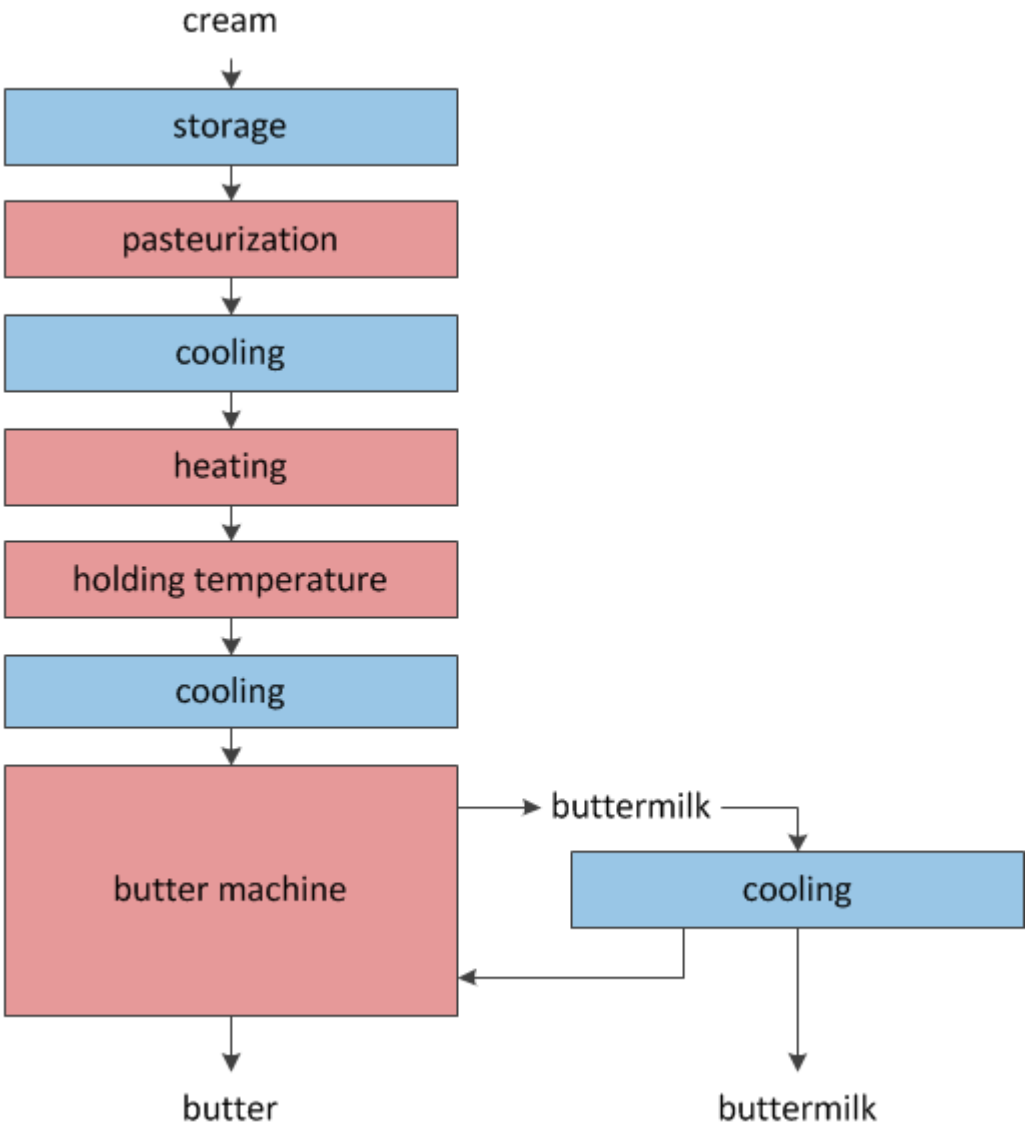
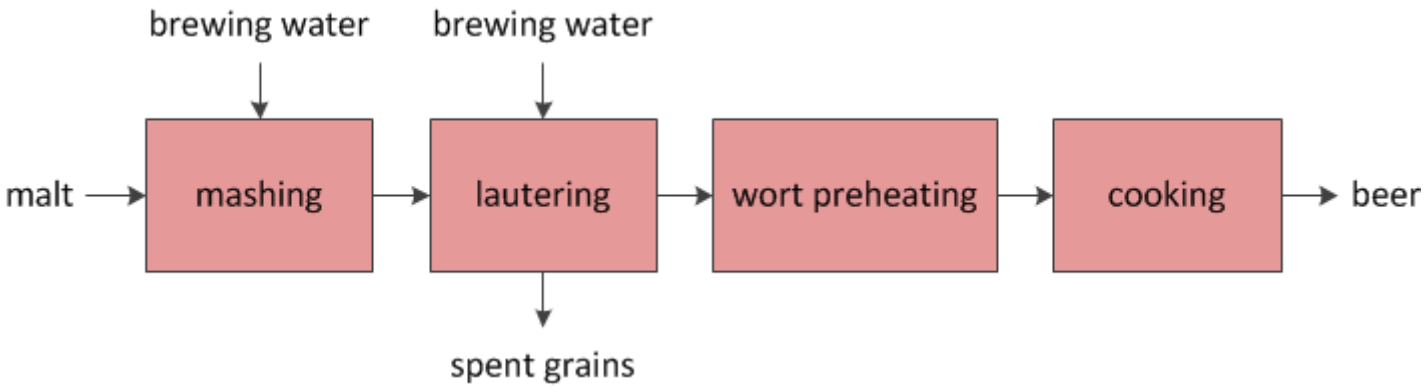


Sub-sector brewery

- **Beer is traditionally considered to include products such as lager, e.g. Pilsner malt and Munich malt, ale, porter and stout. It is an alcoholic drink derived from malted barley, with or without other unmalted cereal grains, and flavoured with hops. Sugar may also be added. There are three basic steps in the process:**
  - ⇨ Mashing,
  - ⇨ Fermentation and
  - ⇨ Maturation/conditioning

Flow sheet – unit operations / processes



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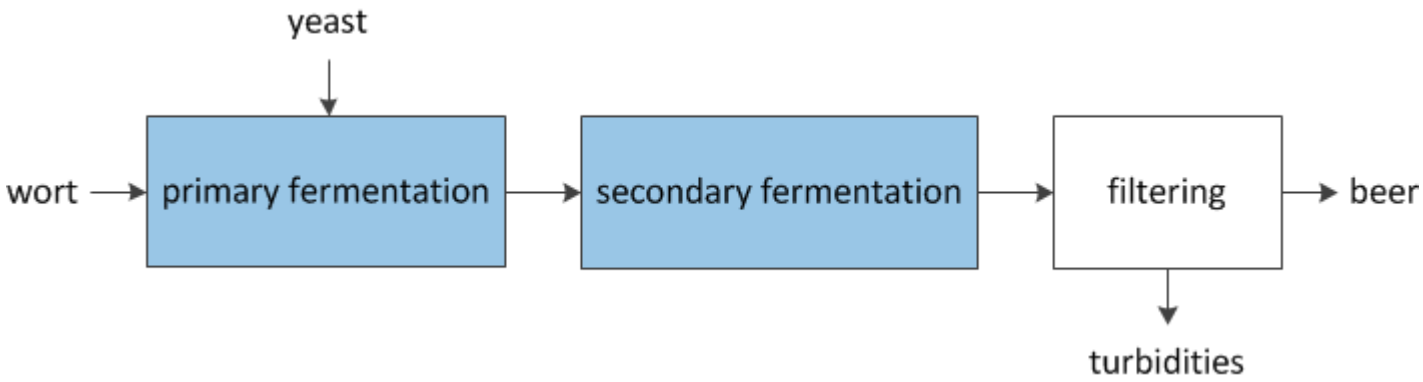

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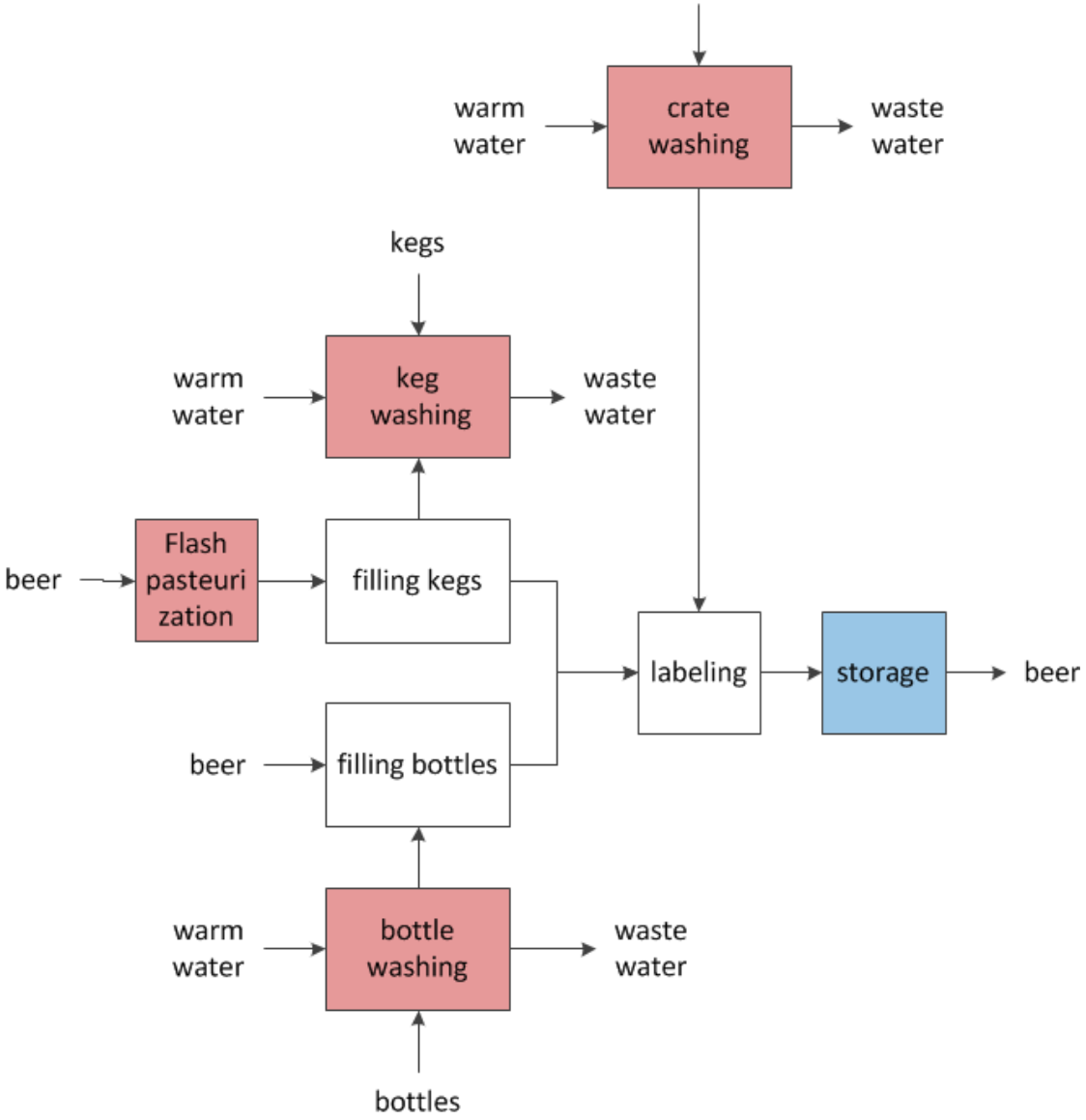

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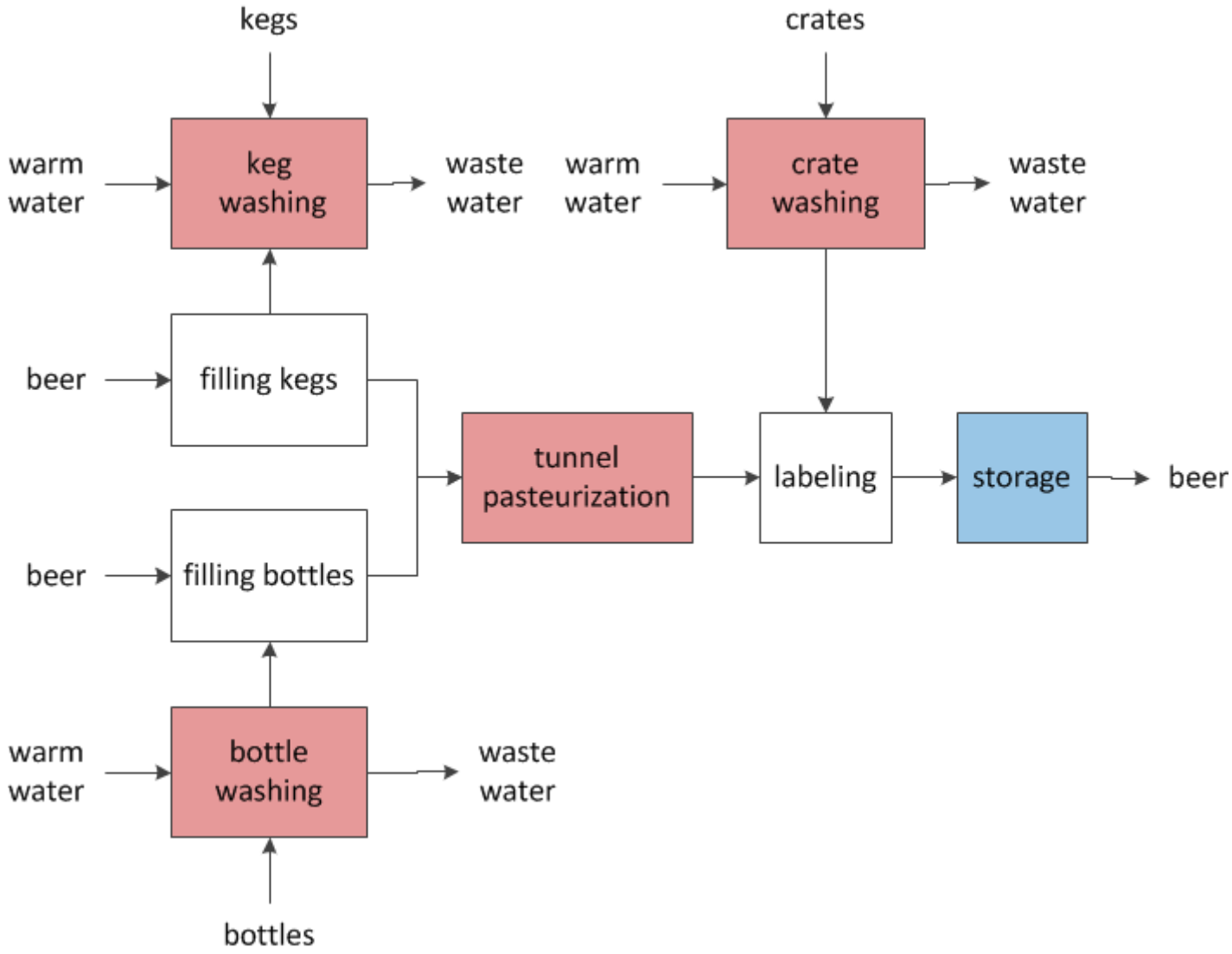
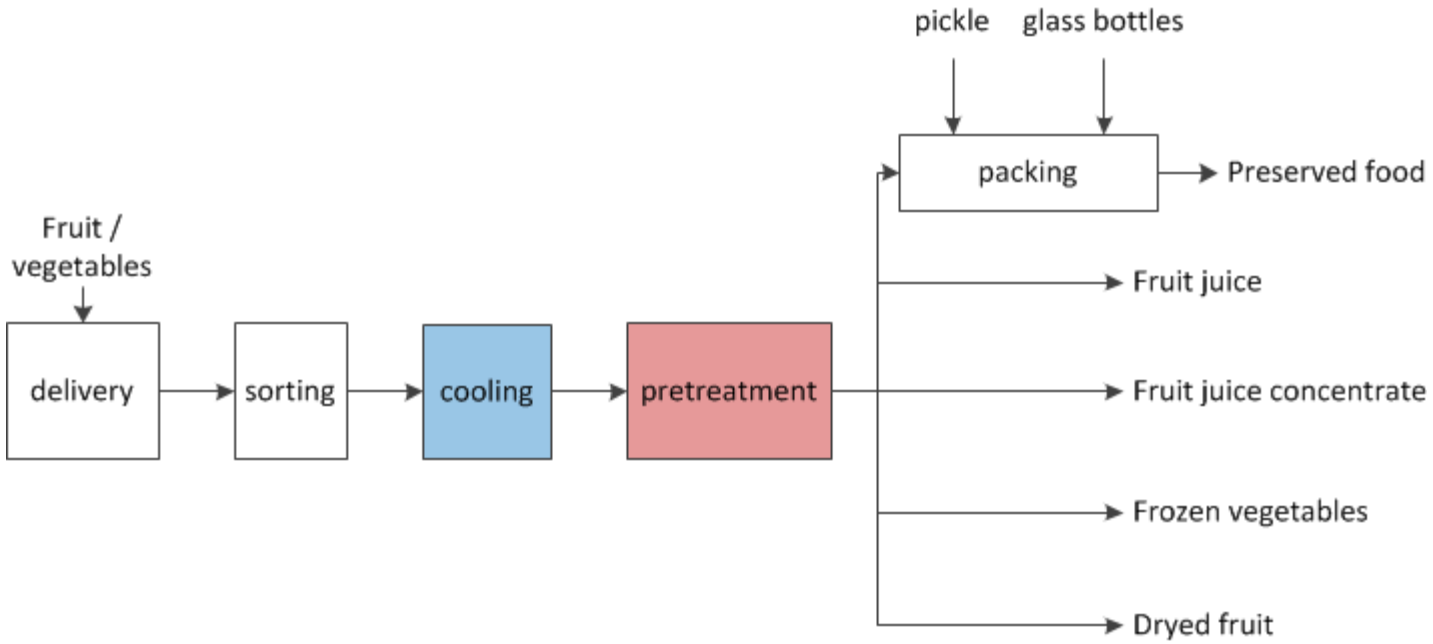


Sub-sector fruit and vegetable processing

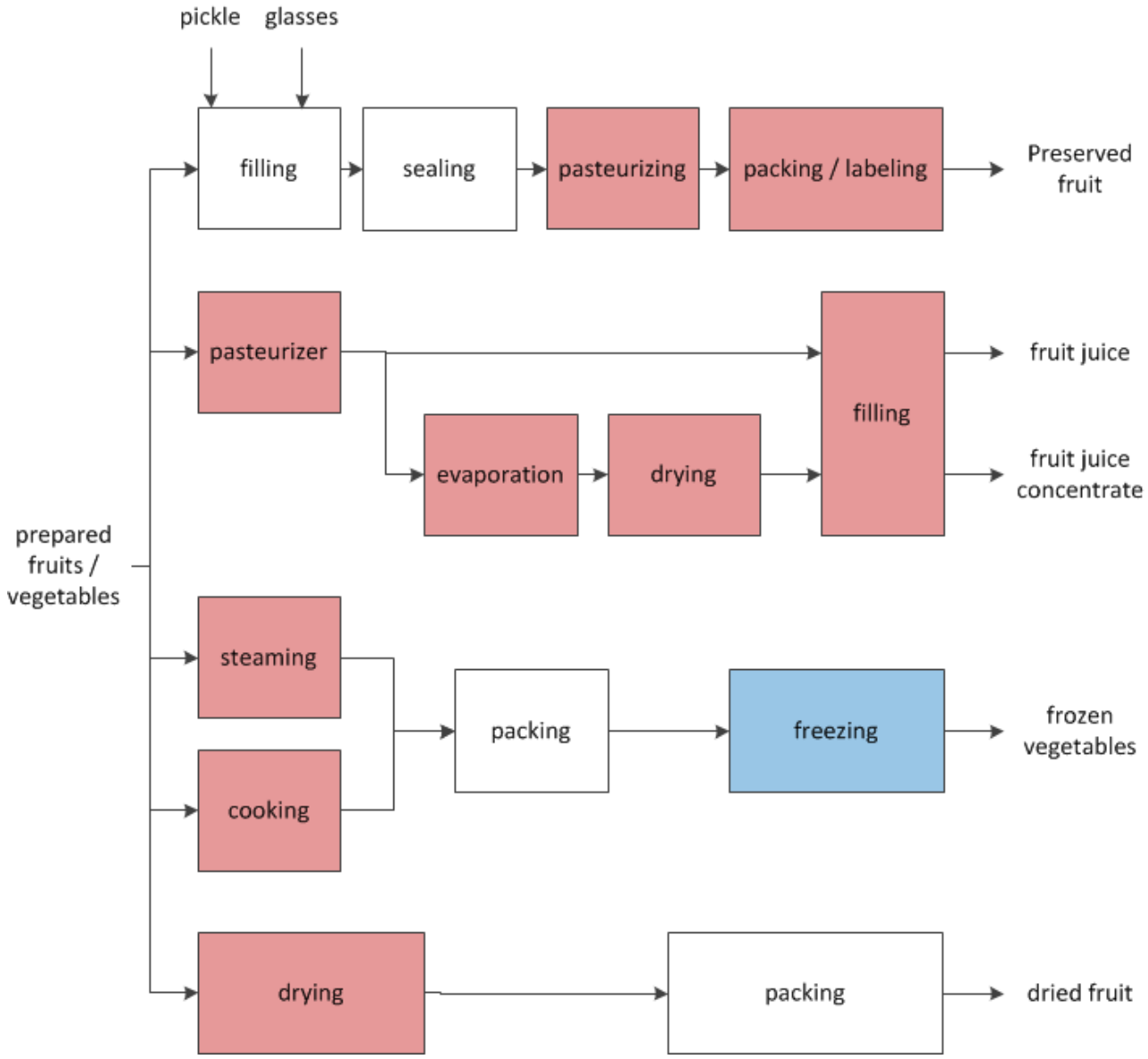
- **The characteristic features of fruit and vegetables are that they are soft edible plant products which, because of their relatively high moisture content, are perishable in their fresh state.**
  - ⇨ Ready meals
  - ⇨ Fruit and vegetable juices
  - ⇨ Heat treated and frozen fruits and vegetables
  - ⇨ Fruit preserves
  - ⇨ Dried fruit and vegetables
  - ⇨ Tomatoes
  - ⇨ Potatoes
  - ⇨ Pickling of vegetables

Flow sheet – unit operations / processes

Flow sheet – unit operations / processes



Flow sheet – unit operations / processes



Supply systems

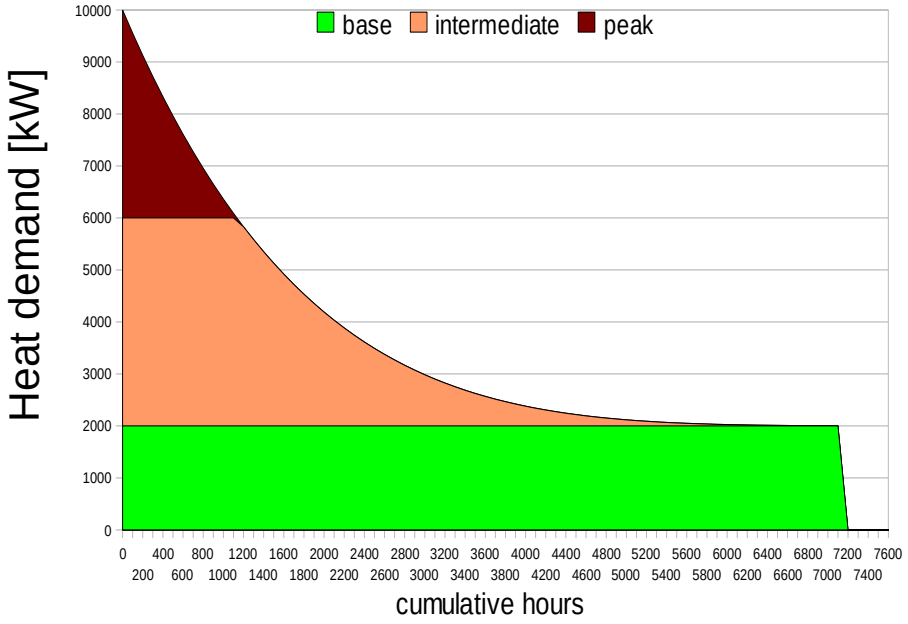
- **Depending on energy demand optimised supply system maximises energy efficiency**
  - ⇨ Supply medium (hot water, steam, cooling medium, etc.)
  - ⇨ Supply temperature (heating rates, process parameters)
  - ⇨ Load profiles
  - ⇨ Etc.
- **Objective**
  - ⇨ Minimization of the primary energy consumption and the environmental impact
- **Next slides give a first idea → details will follow in modules**
  - ⇨ Design, storage, CHP, heat pumps, cooling, solar thermal, biogas, boilers and burners

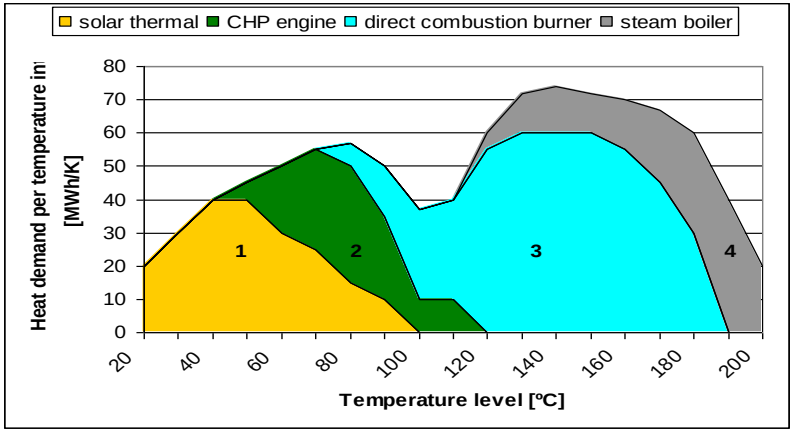
Design of optimised supply system

- **Starting point**
  - ⇨ The analysis of the aggregate energy demand (statistical breakdown) taking into account:
    - **Temperature level of remaining heat and cold demand**
    - **Quantity of demand and waste heat availability**
    - **Temporal distribution of demand and waste heat**
    - **Space availability**
    - **Availability of alternative energy sources and their cost (biomass,…)**
  - ⇨ Heat supply cascade
    - **Suitable equipment selection**
    - **Most efficient equipment covers base load and at low temperature levels (large number operating hours)**
    - **Peak load and at high temperatures is covered by appropriate less efficient equipment**

Supply cascade

- **Dimensioning of equipment for base load, intermediate load and peak load and depending on temperature demand**





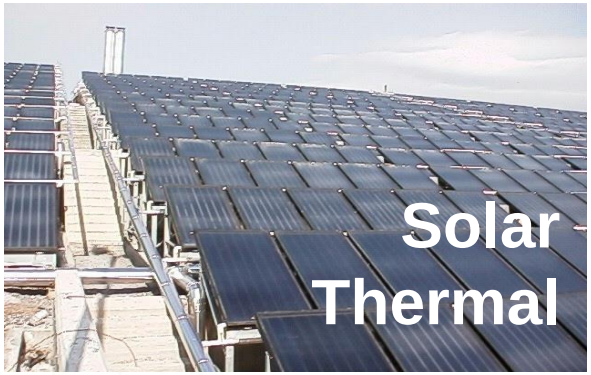
Supply system

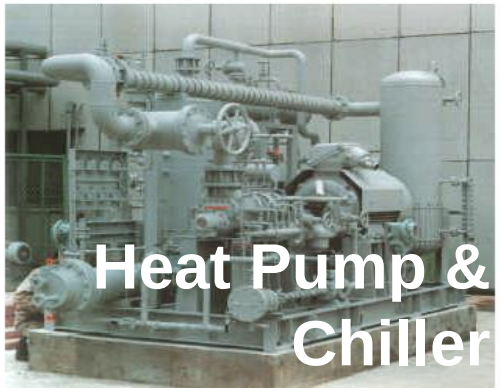
- **Selection of type of equipment to be used and order in the heat cascade**
- **Dimensioning of each type of equipment in the cascade**
- **Selection of the optimum combination of the "whole"**
- **Iterative optimisation of the heat recovery sequence – heat & cold supply**
  - ⇨ As changes in supply system may lead to changes in available waste heat

Additional equipment - storages

- **Heat and cold storage can be used for reducing peak demand**
  - ⇨ Increases the fraction of base load
  - ⇨ Allows higher fraction of the demand to be covered by energy efficient equipment assuring more operating hours
- **Permits covering heat demand with available waste or solar thermal heat**
  - ⇨ When temporal schedules do not overlap
- **Storages**
  - ⇨ Sensible HC storage in form of hot/cold water
  - ⇨ Latent HC storage in saturated steam storage tanks
  - ⇨ Storage with thermal oil
  - ⇨ Solid storages (ceramics, rock beds,…)
  - ⇨ Ice storage and latent storage in other phase-change materials

Supply system





Energy efficient heat & cold distribution

- **In many cases the heat and cold distribution may help to reduce energy consumption**
  - ⇨ Reduction of temperature level
    - **May help to reduce heat losses in pipes and storage**
    - **May be necessary for applying energy efficient technologies (CHP, heat pumps, solar thermal)**
  - ⇨ Direct combustion/cooling
    - **Can increase energy efficiency by eliminating distribution losses and by use of the latent heat of water vapour contained in exhaust gas (e.g. in bath heating)**
    - **Usually possible with rather clean fuels such as natural gas or biogas**

Combined heat and power

- **CHP assures production of heat and electricity from fuel with high efficiency**
  - ⇨ 10 to 25% conversion losses versus at least 45% for electricity-only systems.
- **CHP can also cover cold demand (tri-generation: electricity + heat + cold)**
  - ⇨ Using absorption refrigeration machines
- **For maximizing energy savings**
  - ⇨ CHP should be designed to supply heat to the industrial site where located
  - ⇨ Excess electricity can be exported to public network

Available CHP technologies – overview

CHP Technology	Temperature level	Efficiency (el./thermal)
Gas or fuel oil engine	< 95ºC (cooling water) < 400 ºC (exhaust gas)	(40% / 45%)
Gas turbine	< 400 ºC	(30% / 60%)
Steam turbine	< 250 ºC (partial limit; depending on counter-pressure)	(20-30% / 65%)
Combined cycle (gas turbine + heat recovery steam generator + steam turbine)	< 250 ºC (partial limit; depending on counter-pressure in steam turbine)	(50-55% / 35-40%)
ORC (organic Rankine cycle) turbine	< 250 ºC	(27-50% / 30-55%)
Stirling engine	< 90 ºC	(10-25% / 60-80%)
Fuel cell	< 80 ºC (PEM technology) < 400 ºC (SOFC technology)	(45-60% / 30-50%)

Heat pumps

- **Types of heat pumps**
  - ⇨ Mechanical vapour-compression heat pumps
    - **Usually electrically driven**
  - ⇨ Absorption heat pumps
    - **Using thermal energy**
  - ⇨ Steam jet pumps
    - **Using steam as driving force**
- **Applications**
  - ⇨ Process water heating and cooling
  - ⇨ Drying processes
  - ⇨ Space heating
  - ⇨ Evaporation and distillation processes
  - ⇨ Waste heat recovery

Energy efficient cold generation

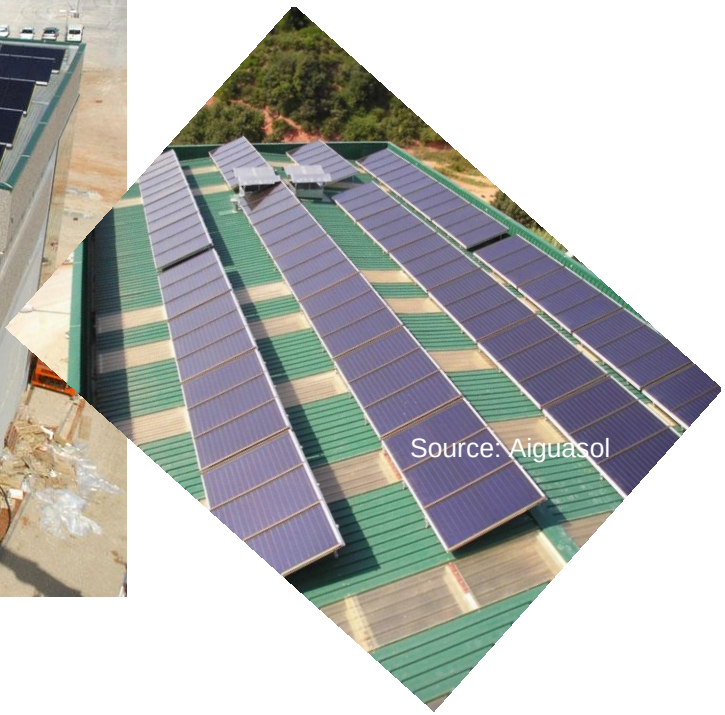
➢ Types of cooling systems

- ⇨ Cooling towers (free cooling)
  - **Open/closed, wet/dry/hybrid cooling**
  - **Electrical power level typically between 10 to 23 kW_{el}/MW_{th}**
- ⇨ Vapour-compression chillers
  - **COP about 4.0 or more in large installations**
- ⇨ Thermal chillers
  - **Absorption and adsorption chillers, jet pumps, etc.**
  - **Integration in CCHP (trigeneration) or solar cooling concepts**
  - **COP (absorption chillers): 0.5 to 0.8 (single effect); 1.0 to 1.3 (double effect)**
  - **Important: -> use primary energy ratio for comparison of thermal and electrical chillers**

Considerations about cooling application

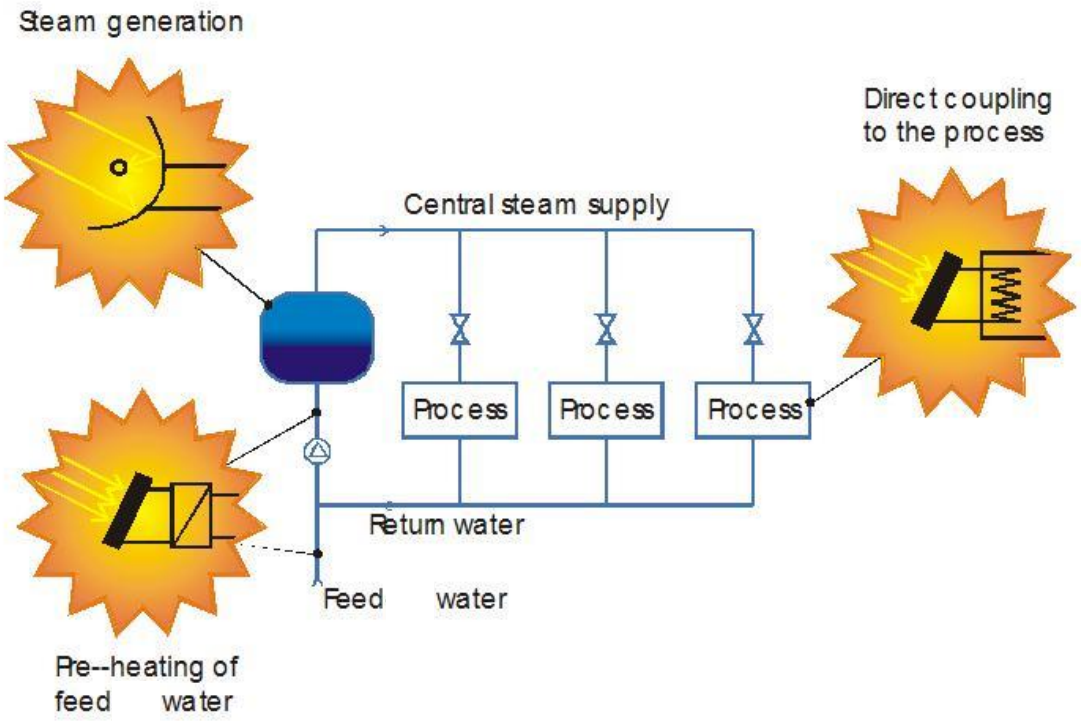
- **Reduction of cooling demand by heat recovery**
- **Use of waste heat from chillers (up to 50ºC possible)**
- **Use of free cooling**
- **Use of chiller cascades where convenient**
- **High temperature of chilled water supply**
- **Low temperature of re-cooling water supply**
- **Reduce part load operation of chillers**

Solar thermal systems



Solar thermal systems

- **Integration of the solar thermal into processes**



Biogas: Different feed-stocks and pre-treatments

Agriculture industry	Slaughter houses	Industry (e.g. food)	Canteen kitchen	commune
•Residues of harvesting •Energy plants •Liquid manure •Solid and liquid dong	•Slaughter house waste water (grease,..) •Slaughter house solid waste (bowels)	•mash •Brewer grains •yeast •Fruit pulp	•Food residues •Kitchen waste •Waste grease	•grass •Biogenic waste •Sewage sludge

Pre-treatment	**examples**
Mechanical/physical	Milling, chaffing, ultra sonic
chemical	Acids, base, wet oxidation
Bio-technological	Enzymes, fungi,
Thermal	Steam explosion, thermal pressure hydrolysis

BOILERS and BURNERS (1)

- **Energy/economic savings criteria for boilers**
  - ⇨ Avoid electrical heating and run boilers fed by lower environmental impact fuels
  - ⇨ NG or LPG allow energy efficient technologies
  - ⇨ Lower steam pressure/ temperature reduce losses and costs
  - ⇨ Avoid low load factor (< 30%)
  - ⇨ Run boilers with higher efficiency for base load/ boilers with lower efficiency for peak load
  - ⇨ Avoid oversized and/or small capacity equipment
  - ⇨ At low temperature run hot water and condensing boilers

BOILERS and BURNERS (2)

- **Energy/economic savings criteria for boilers**
  - ⇨ Optimize the control strategy
  - ⇨ Decrease the off - gas temperature, adjust the excess air ratio and insulate boilers
  - ⇨ Install an economizer and/or an air preheater (recuperator)
  - ⇨ Recover condensate
  - ⇨ Reduce blow-down stream and recover its heat
  - ⇨ If boilers are regularly shut down use dampers

SHIP Egypt

Session 05

Flowsheets
Energy consuming processes of relevant industry sectors

Wolfgang Glatzl | AEE INTEC
Josef Buchinger | ConPlusUltra