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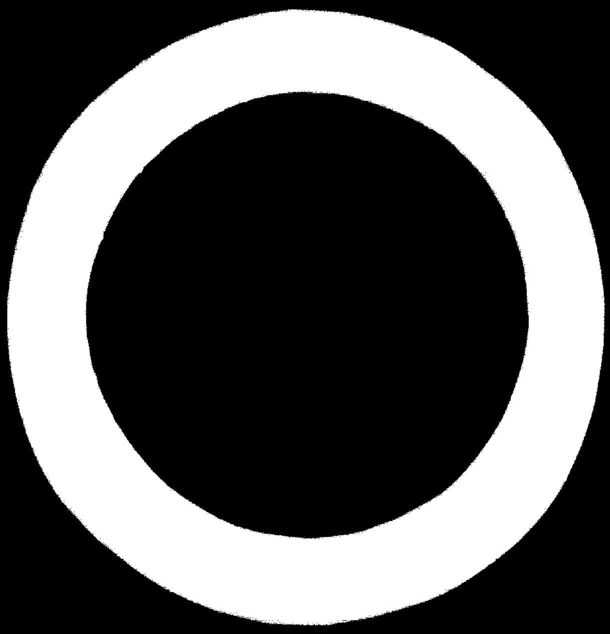
UNITED NATIONS

THE USE OF CENTRI-THERM, EXPANDING-FLOW AND FORCED-CIRCULATION PLATE EVAPORATORS IN THE FOOD AND BIOCHEMICAL INDUSTRIES



UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, VIENNA

FOOD INDUSTRY STUDIES No. 1

THE USE OF CENTRI-THERM, EXPANDING-FLOW AND FORCED-CIRCULATION PLATE EVAPORATORS IN THE FOOD AND BIOCHEMICAL INDUSTRIES

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FOREWORD

With this monograph, UNIDO is initiating a series of studies on recent developments in food processing, to be published for the benefit of the food-processing industries in the developing countries.

The food-processing techniques to be applied, the equipment to be used and the buildings to be erected in developing countries differ greatly from those found in industrialized countries. The raw materials vary from country to country, and differences in capacity of the processing facilities and in the marketing and distribution facilities for processed foods must be borne in mind. In some instances, new processing techniques must be developed for tropical or subtropical raw materials that have not been processed hitherto, even in the developed countries. In such situations it may be necessary to draw upon experience with other products of a more or less similar nature. Special attention must be paid to the rapid deterioration of many food products in tropical climates and to related problems of plant sanitation and the health of the workers.

The requirements of the markets in developing countries are of special importance and will be decisive factors in determining the feasibility of establishing new industries. Special low-cost packaging materials and/or concentrated products may be required.

A special approach is required in order to meet the technical and economic conditions of food processing in developing countries. In many cases, the technical advances already in use in developed countries can be applied economically in underdeveloped countries. Because of technological disadvantages and limited capital and other resources in developing countries, it is evident that the most advanced and successful process must be used in each case in order to obtain the optimum return on the investment of capital and human resources. A developing country should not run the risk of producing processed foods of lower quality or at higher cost than those of a developed country. The process to be applied must be adapted to the special characteristics of the available raw materials, the prevailing working conditions and the special market demands and limitations.

The objective of UNIDO in publishing this series of studies in the food-processing industry is to make information available to the developing countries that will help them to gain good technical insight into selected branches of food processing and to avoid technically obsolescent procedures and processes. It is hoped that this series of studies will disseminate technological information and know-how which will serve as reliable sources of information for governmental authorities as well as for potential investors.

This monograph was prepared by Mr. Bengt Hallström of Sweden as consultant to UNIDO. Thanks are due to Alfa-Laval AB, Lund, Sweden, for their generous co-operation and for permission to use figures from their literature.

The views and opinions expressed in this paper are those of the consultant and do not necessarily reflect the views of the Secretariat of UNIDO.

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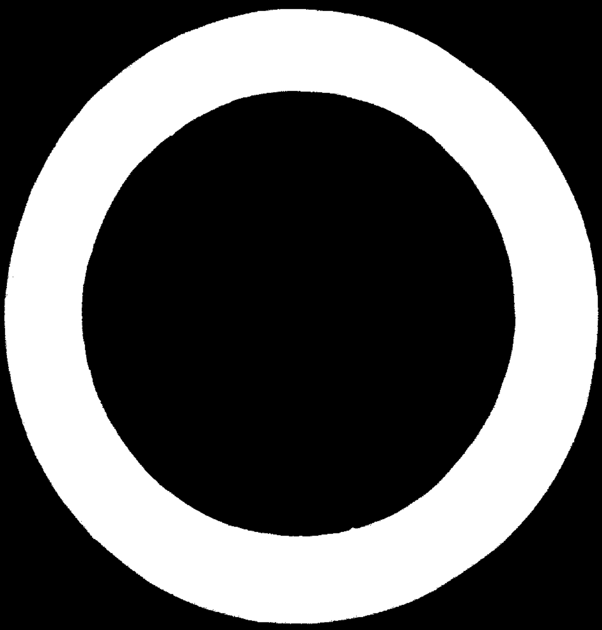

INTRODUCTION

Equipment for concentrating heat-sensitive liquids and especially liquid foods has for the most part been developed since 1900. At the beginning of the century, liquids to be condensed by evaporation were boiled in batches at atmospheric pressure in large open vats. From this stage to the present, very efficient plants have developed that treat the liquids continuously and gently and that operate very economically in terms of fuel. These two lines of development are, of course, opposite. Fuel economy requires multiple-stage plants in which the heating steam is used several times, so that one kilogram of water can be evaporated with but a fraction of a kilogram of heating steam. However, this approach also means that the liquid must pass through all stages ("effects") of the plant. This implies a long in-plant holding time. Reduction of this time to a minimum means that the plant may have but one effect. Such an evaporation process requires a large steam consumption as much as one kilogram of heating steam might be required to evaporate a single kilogram of water.

Since the Second World War evaporation technology has continued to develop logically along these two lines. One approach uses multiple-stage evaporation and has a very economical steam consumption. A relatively long in-plant holding time is accepted although the time figures compare very favourably with those of earlier batch processes. The other approach is based on an extremely rapid evaporation in a plant that performs only one effect. In plants of this type everything has been done to attain a theoretical minimum treatment time, and a high steam consumption is accepted. However, as this process is normally used for high-priced products, the steam cost is of minor importance.

In the present study the development of the multiple-stage evaporation process is considered first. Several interesting designs are observed. One of the first is the conventional long-tube rising- (or climbing-) film evaporator, which is still widely used. The liquid to be evaporated enters the vertical tubes at the lower end and passes upwards while boiling. The tube length may range from four to about seven meters. This design was developed in France and is classic in the sugar industry, for instance. The name of Kestner is very often connected with this design.

Forced-circulation evaporation is used for liquids that tend to precipitate and form deposits on the heating surface. In this system the liquid is repeatedly pumped through a heat-exchanger where it is heated under enough pressure to keep it from boiling on the heating surfaces (either tubes or plates). On leaving the heat-exchanger the liquid is flashed into a vacuum chamber where part of its water is vaporized. A circulation pump brings the remaining liquid back to the heat-exchanger and recirculation continues until the concentration required is reached. This type of evaporator is used in the cellulose industry, for instance.

The next stage of development was invented by an American, Peeble. However, his idea was not used for several years until just before 1950 when Wiegand, in the Federal Republic of Germany, began to build falling-film evaporators in which the liquid to be concentrated enters vertical tubes at their upper ends and boiling takes place while the liquid passes downwards through them. Higher concentrations can be reached in this way than with climbing-film evaporators, and a higher concentration ratio can be obtained in a single passage through one effect. The holding time is thus shortened considerably, which explains why the falling-film principle is so often used in the food industry today. Wiegand has many competitors, among them Holvrieka, Scheffers and van der Ploeg in the Netherlands, Laguilharre in France and Blaw-Knox (on licence from van der Ploeg) and Gulf Engineering in the United States.

At the end of 1957 the Aluminium Plant and Vessel Company, in the United Kingdom, presented its plate evaporator. The operating principle of this device combines climbing- and falling-film evaporation in a very interesting way. The heating surface consists of flat heat-exchanger plates mounted in a frame. While with this equipment the holding time for the treated liquid is about the same as in a corresponding falling-film unit, it has the advantages that the heating surfaces can be opened for inspection or cleaning, that building height is low and that operation is flexible.

A similar plate evaporator is produced by W. Schmidt KG, a plate heat-exchanger manufacturer in the Federal Republic of Germany.

In 1962, Alfa-Laval AB, in Lund, Sweden, presented its compact machine, called the expanding-flow evaporator. This design has approximately the same features as the plate evaporators discussed above, but in-plant holding time has been reduced to about half that for the falling-film process. Furthermore, the cone plates that form the heating surfaces have been surrounded by a stainless steel cover. In this way the risk of leakage into the boiling liquid has been obviated completely. A detailed description of this evaporator is given in a later section of this report.

The development of single-stage evaporation toward the shortest possible holding time has not passed through as many stages. For many years, the best-known design has been the large-diameter falling-film tube with an internal rotating scraper. Many patents have been granted, and many modifications are available, but Luwa AG, in Switzerland, is undoubtedly the best-known manufacturer of this equipment. Some producers of similar machines are Sambay (Samesreuther Müller Schuss GmbH) and Carl Ganzler Apparate- und Maschinenbau in the Federal Republic of Germany; Pfaudler Permutit, Rodney Hunt Co., the Blaw-Knox Co. (Rotovak) and the Kontro Company Inc. in the United States. The last-mentioned device has a conical heating surface.

The rotating conical heating surface was first developed in the United States by Hickman, for sea-water distillation, beginning in 1935. The design was re-discovered and modified by Mautner in Yugoslavia and was presented as a commercial unit by Alfa-Laval in Sweden in 1959. A detailed description of this evaporator is given later in this report.

CENTRI-THERM, EXPANDING-FLOW AND FORCED-CIRCULATION PLATE EVAPORATORS

The Centri-Therm evaporator

The Centri-Therm machine is manufactured in three sizes: CT1B, CT6 and CT9. The CT1B, with a heating surface of 0.1 m^2, is intended primarily for laboratory purposes, but may also be used in small-scale commercial production. The CT6 and CT9 are commercial machines. Their heating surfaces are, respectively, 2.4 m^2 and 7.1 m^2.

The description below is of the CT6 machine but in principle and general design also applies to the other two types.

The principal feature of this type of evaporator is the application of rotating conical evaporating surfaces. In conventional evaporators the liquid film is transported over the evaporating surface by means of the vapour, and the final concentration of the product is therefore limited. The transporting force can be greatly increased with mechanical assistance, which means considerably higher velocity and therefore a large heat-transfer coefficient and the possibility of obtaining a higher final concentration. A higher velocity will also mean shorter holding time on the heated surfaces, and this naturally has a great influence on the final quality of the product, notably on heat-sensitive liquids. In this device the mechanical assistance is centrifugal force, which, at the high rotational speeds now employed, is more than one hundred times as great as the force of gravity.

A cross-section of a Centri-Therm CT6 is shown in figure 1. In the centre there is a rotating bowl with double-walled cones. This bowl or rotor-body is fastened to a tubular shaft. The steam and vapour chambers are separated in the rotor-body by a partition. Steam is piped up through the hollow shaft to the cones, and the condensate is removed by means of a paring device and a special outlet pipe placed inside the shaft. As evaporation normally takes place under vacuum, the vapour chamber must be surrounded by a cover connected to the condenser.

The liquid to be evaporated is sprayed through the injection nozzles onto the rotating cone elements. Because of the centrifugal force, the liquid rapidly moves across the cone surface out to a channel, whence it passes through axial holes in the rim of the cone element up to a concentrate-paring channel. From here it is taken out of the evaporator by means of a stationary paring device. The evaporation process is usually completed in a single passage over the heating surface.

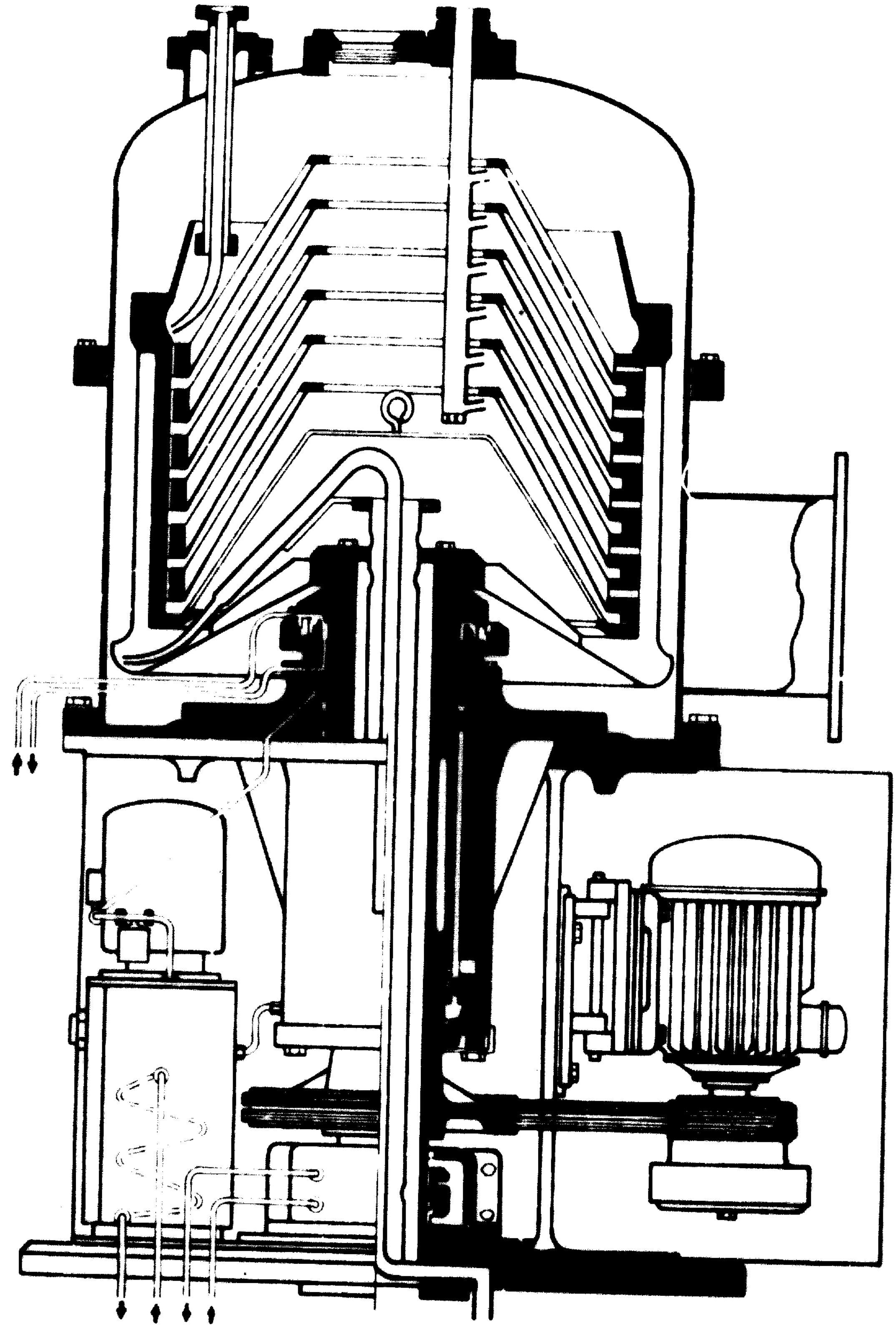

Figure 1. Cross-section of a Centri-Therm CT6 evaporator

Figure 2 shows a standard cone element, consisting of two stainless-steel cones placed one inside the other and welded together at their tops and to a ring at their bottoms. This ring has radial holes for steam and condensate and vertical holes through which the concentrate passes. When the saturated steam enters the space between the inner and outer cone it condenses on the wall of the inner cone which is cooled by the concentrate. The water formed by condensation is thrown by centrifugal force against the wall of the outer cone and flows along it and out through the steam holes. Consequently the steam side is continuously kept free from water and carries no water layer to hinder condensation. We obtain thus dropwise condensation resulting in a very high α-value.[1]

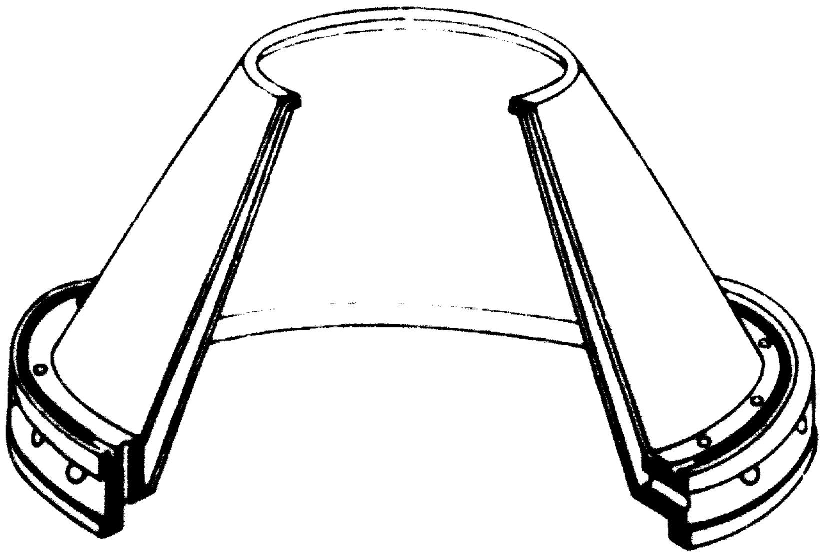

Figure 2. Cut-away diagram of a standard cone element in the Centri-Therm CT6 evaporator

The cone elements are stacked upon each other in the rotor body and can easily be lifted out of the machine for inspection or cleaning.

The distributor is shown in figure 3 and consists of a main pipe with a number of short branches fitted with nozzles. The liquid to be condensed is fed through the main pipe from the top of the evaporator and is sprayed onto the rotating heating surface in the direction in which the cone is moving. The flow velocity of the incoming liquid is equal to the speed of the rotating surface so as to prevent drop formation and splashing.

As noted above, the concentrate is collected in the paring channel. From here it is removed from the evaporator through the paring device, consisting of a knife-edge at the inlet hole and the removal tube. It is important that this device be correctly adjusted. The level is set by means of adjustment washers. The centre position is set by turning a large flange, which has an eccentric movement (figure 4). The angle position is adjusted by turning the removal tube in such a way that the outer edge of the scraping blade is 5 to 6 mm from the outlet channel and so that there is a relief angle between the paring device and the outlet channel (figure 5).

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[1] The α-value may be defined as the amount of heat (in kilocalories) received from steam per square metre of surface per hour at a temperature difference of 1°C.

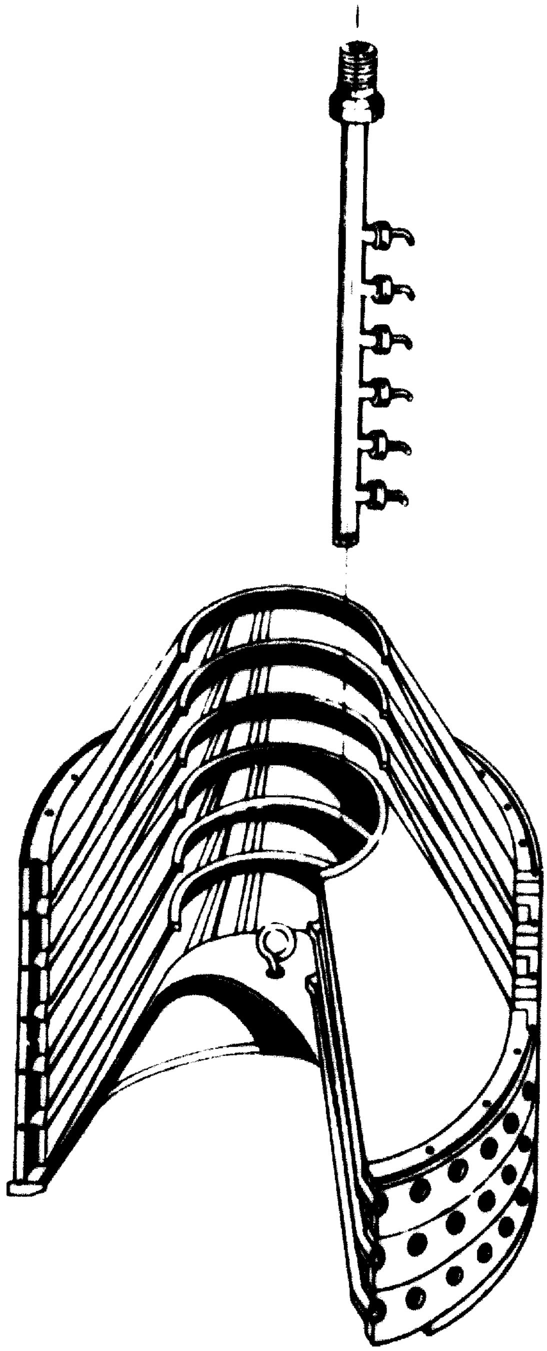

Figure 3. The distributor (top) removed from the rotating surfaces of the Centri-Therm CT6 evaporator

Inlet holes of different diameters are available and may be chosen according to the volume and viscosity of the liquid to be processed.

Seals and packings are naturally important in any system that operates under vacuum. Stationary seals consist of O-rings, and the rotating part is sealed with carbon seals.

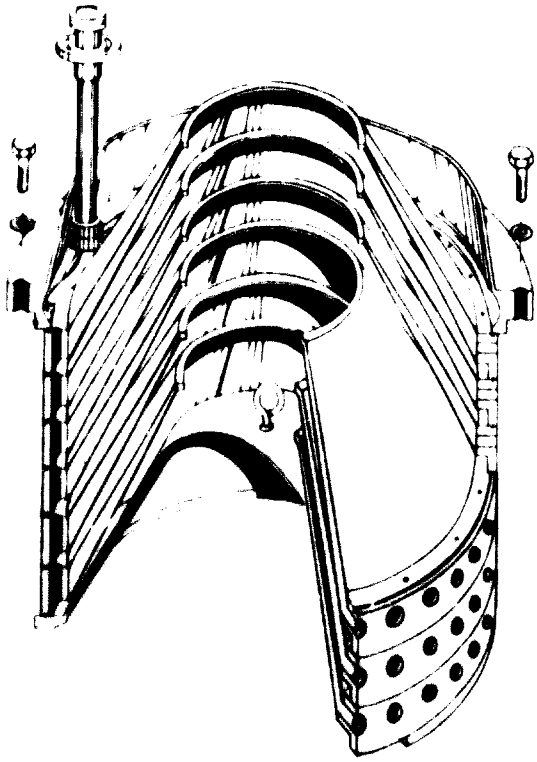

Figure 4. Positioning of the paring device in the channel for the concentrate, Centri-Therm CT6 evaporator

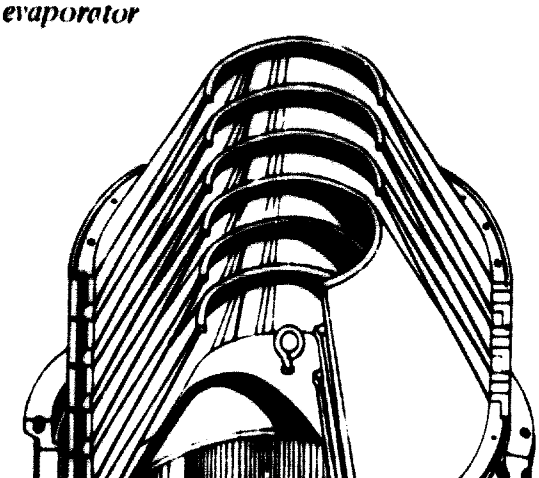

Figure 5. Adjustment of the paring device for the removal of the concentrate, Centri-Therm CT6 evaporator

Ball-bearings are used for the rotating shaft. These may become hot as steam is piped through the shaft. To cool them as well as to ensure efficient lubrication, the machine is fitted with an automatic oil circulating system. This system consists of a stainless steel tank with an oil pump and a cooler, plus an oil filter, a pressure gauge and a relief valve. The pump motor is connected with the Centri-Therm motor in such a way that the evaporator cannot be put in operation until the oil pump has been run for a while, in order to ensure that the bearings will be properly lubricated and cooled from the outset.

The material used in all components coming into contact with the product is 18/10/2.5 stainless steel (acid-proof steel). Packings and O-rings are normally of oil- and heat-resistant nitrile rubber, but for application in the chemical and pharmaceutical fields Viton rubber has been used. Several of these machines have also been supplied with explosion-proof motors.

The Centri-Therm evaporator is also manufactured in a slightly modified version. This modification is only available in size CT6 and is denominated CT6C. The operating principles of this modification are shown in figure 6. The liquid enters the distributor at (1), the steam outlet is at (2), the outlet for the water from condensation is at (3). The outlet for the concentrate (4) is radial, and the concentrate is collected on a rotating transport cone (5) and passed by centrifugal force to the upper end of the cone and from there to a collecting channel, as in the standard machine. The steam inlet is at (6). This modified version permits higher concentrations.

A standard one-stage Centri-Therm plant for the condensation of fruit juice is shown in figure 7. Its principal components are numbered and explained below.

(1) *Strainer.* The liquid is strained through a perforated disc in order to prevent the larger particles from reaching the injection nozzles, which they might plug. A standard plant has only one strainer, but for products that contain pulp (e.g. citrus juice) a set-up with two strainers and two-way cocks is obtainable that permits one filter to be cleaned while the other is in use.

(2) *Balance tank, with two float-operated valves.* The product to be condensed is connected to the upper valve and water to the lower one. The tank will consequently act as a safety device, as the lower valve will admit water if the inflow of the product should cease; the risk of running the evaporator dry is thus eliminated. When lye or other cleaning fluids are circulating through the balance tank during cleaning, the water valve will also automatically compensate for the water loss due to evaporation.

(3) *Positive feed-pump, with variable-speed drive.* The product is pumped from the balance tank to the evaporator by a single-stage pump (Mono H-30 on a standard CT6 and Mono H-40 on a CT9) fitted with a variable-speed drive. The use of a positive pump with variable speed ensures complete control of the feed and also of the degree of concentration.

(4) *Flow-meter.* A flow-meter of the rotameter type is inserted in the line between the feed-pump and the evaporator.

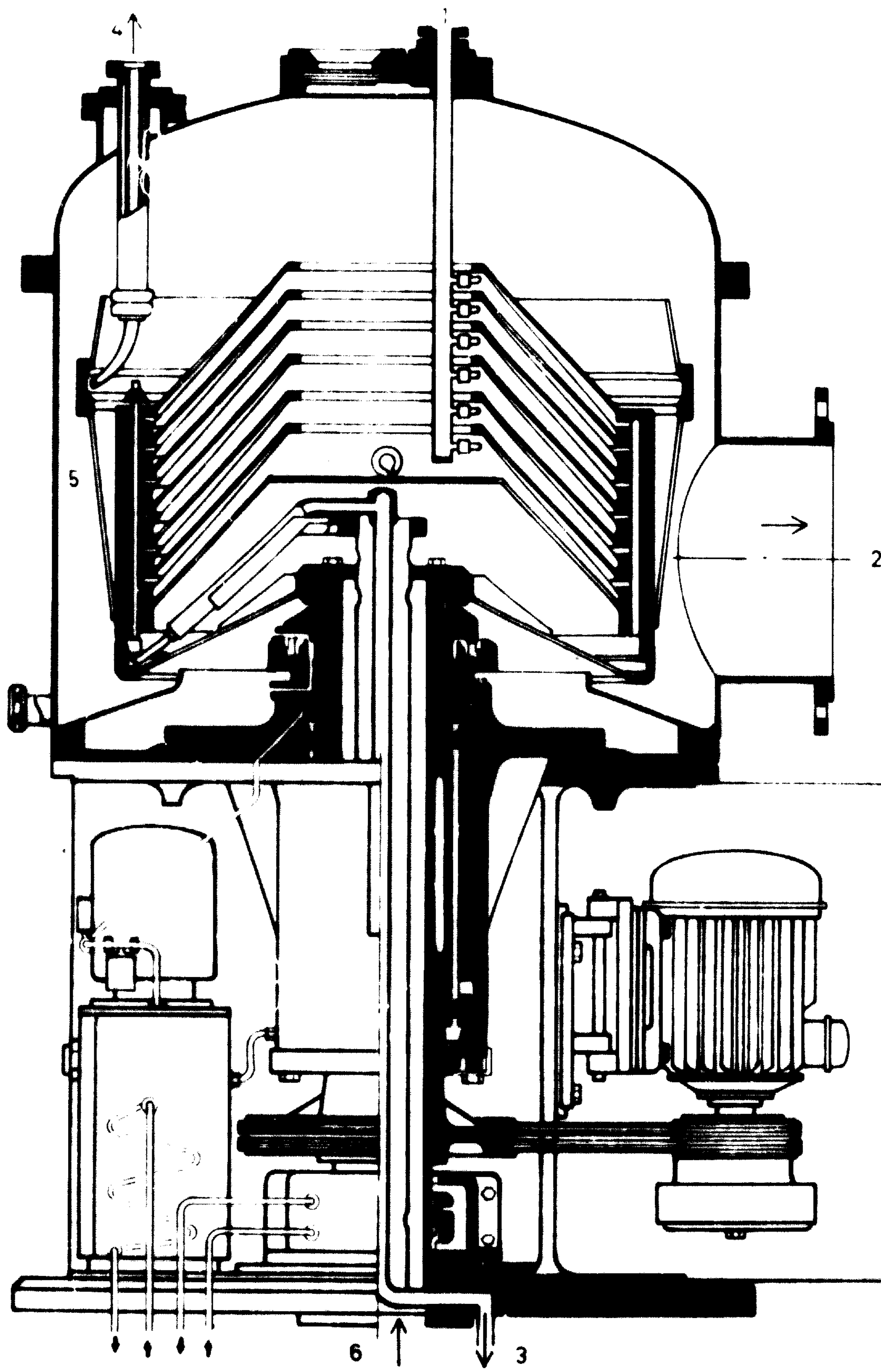

***Figure 6.** Modified Centri-Therm CT6 evaporator (CT6C) for higher concentrations (see text for explanation of numbering)*

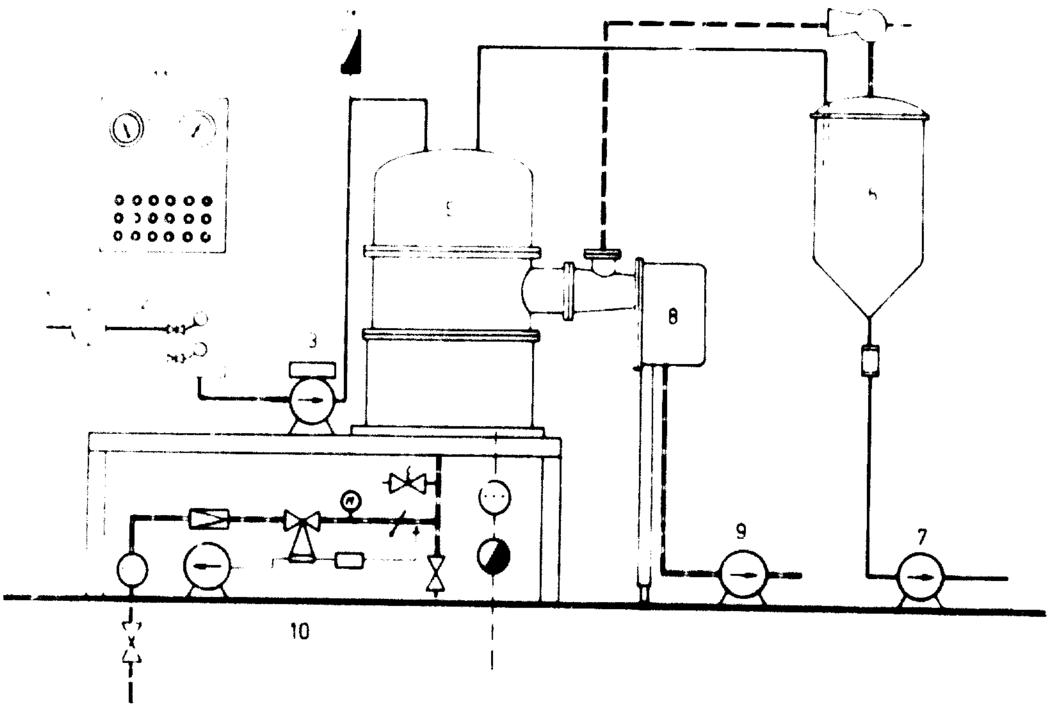

Figure 7. Standard one-stage Centri-Therm evaporator for the condensation of fruit juice (see text for explanation of numbering)

(5) *Modified Centri-Therm.* This element of the plant has been discussed in detail above.

(6) *Expansion cooler with thermo-compressor.* From the evaporator the concentrate is drawn into a vacuum chamber. As the vacuum here is much higher than in the evaporator, some water will immediately flash off and vaporize. As the latent heat of vapour is high (586 kcal/kg at 20°C) much heat is consumed in the process and consequently the temperature of the concentrate instantly drops to a value corresponding to the saturation temperature of vapour at the prevailing vacuum in the cooler. (The gas drawn off is normally water vapour, but it can of course also be solvent, alcohol, or the like.) The vacuum in the expansion chamber is created by a thermo-compressor, the outlet of which is connected to the condenser.

In many cases the viscosity of the product will not permit cooling to the lowest range, as it may be impossible to pump the concentrate out of the cooler. An alternative is to use a swept-surface cooler.

For cooling down to 8°C and 5°C, two-stage compressors are used. Steam consumption naturally increases considerably when cooling to low temperatures, partly because more water must be drawn off, but principally because far more energy is consumed to attain the high vacuum required.

Great care must be taken when designing the vapour pipes from the cooler. Owing to the low pressures, even minute quantities of vapour will have considerable volume, and it is recommended that the compressor be fitted as close to the expansion chamber as possible in order to avoid an undue pressure-drop on the suction side. Under no circumstances should the vapour velocity be allowed to exceed 80 meters per second without careful calculation of the subsequent pressure-drop.

(7) *Concentrate-extraction pump.* Normally a two-stage Mono H-32 (on CT6) or H-42 (on the CT9 model Centri-Therm) is used.

(8) *Condenser.* A fluid may exist in the form of a vapour (gas) or as liquid. The change from the vapour to the liquid state is called condensation. For a simple fluid, such as water, the change from liquid to vapour and from vapour to liquid will take place at a certain temperature at a given pressure. This temperature is the saturation temperature. Thus the pressure at which the evaporation is carried out corresponds directly to the temperature of the vapour drawn off from the evaporator, and the pressure in the vapour pipe will consequently govern the evaporation temperature. A condenser is required to reduce this pressure and maintain a partial vacuum. Condensers are of two minds: surface condensers and barometric condensers, commonly of the spray type.

Surface condensers include such well-known designs as the tubular condenser and the plate heat-exchanger. If the condensate is to be used in a steam boiler or for other purposes (condensate is excellent for cleaning the plant after operation) a surface condenser must be used.

Also shown in figure 7 are (9) a liquid-ring air-pump to draw off the non-condensative gases from the condenser; (10) automatic steam-regulating valve, safety valve, steam filter, steam trap, thermometers and related devices; and (11) the control panel, with push-buttons, contactors and fuses. Accessory equipment for

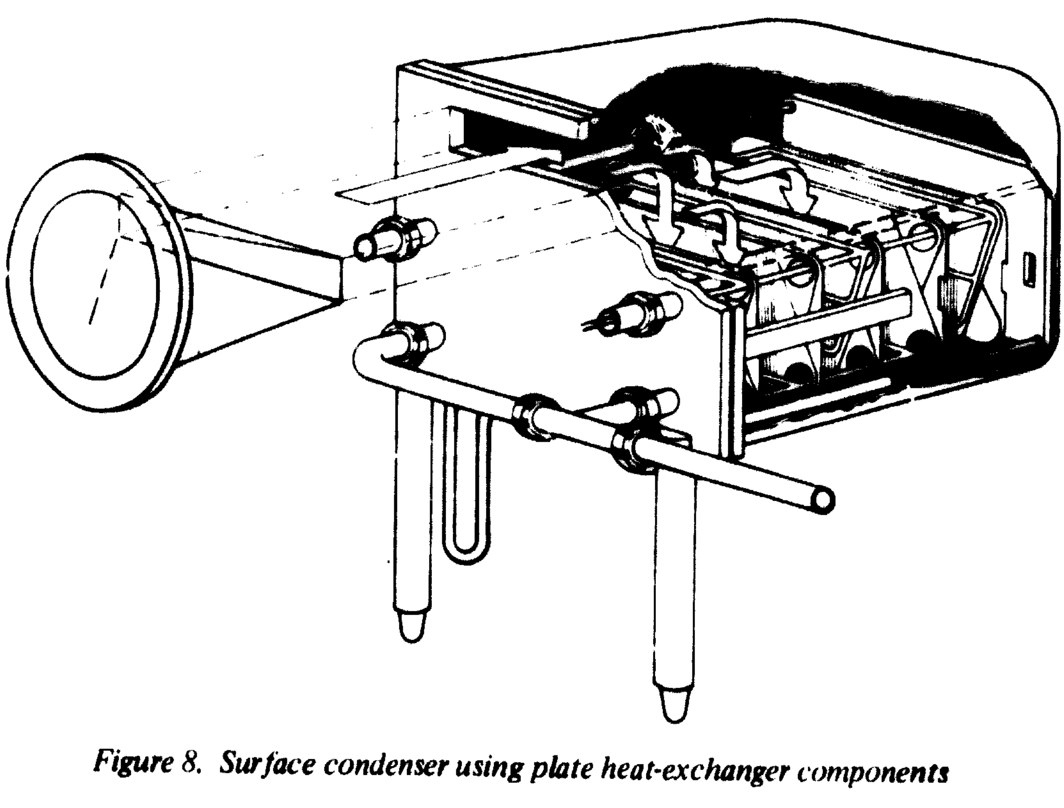

Figure 8. Surface condenser using plate heat-exchanger components

de-aerating and pre-heating can be added, as may the aroma-recovery system that is discussed at the end of this section.

A new surface condenser has been developed that uses plate heat-exchanger components (figure 8). It is called the Alfa-Laval box condenser. Ordinary heat-exchanger plates are used on the cooling medium side. This equipment is suitable for pre-heating milk, juices and other foods, since sanitary connexions and surfaces are ensured.

Figure 9 shows a typical barometric condenser of the spray type. It operates as follows: water is pumped in through the top connexion (1) and is distributed uniformly over a toothed weir. A curtain of water falls down to a baffle plate, and the vapour entering through the side inlet (2) is mixed thoroughly with water, ensuring efficient condensation. The condenser must be accurately levelled when erected if an unbroken curtain of water is to be formed. Air and non-condensative gases are drawn off from the top (3) to a vacuum pump, and water is drawn off through the tailpipe (4).

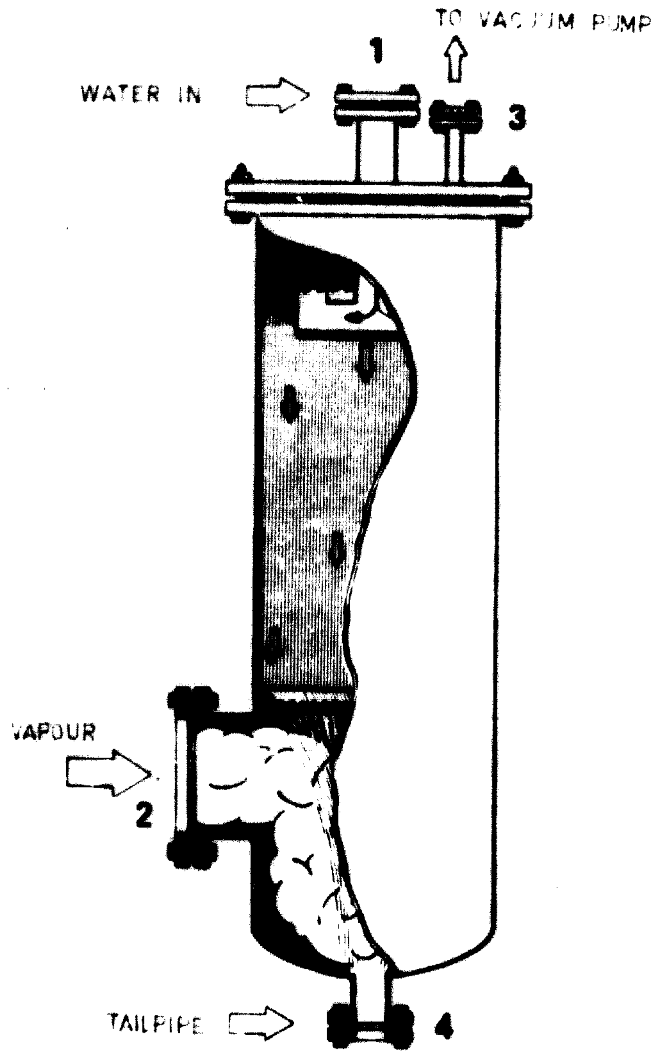

Figure 9. Typical barometric condenser of the spray type (see text for explanation of numbering)

On the steam side the plate is open all along its upper edge (see figure 8). This arrangement provides a large opening through which the high-volume vapours can pass. The plates and cover as well as the frame and other components are of stainless steel therefore aggressive media may also be handled. The device can be arranged to suit the amount of cooling water available, and the water consumption can be kept low. Its dimensions are quite small.

The platage can be arranged either in parallel or in series. When the pre-heating section is used, both water and product sides must be parallel, as is also the case when a very small pressure drop is required. Utilizing the condenser as a pre-heater will reduce cooling-water consumption, especially when the product to be treated is cool, as is normally the case with milk, for example.

If there is no pre-heating section, the platage will usually be in series, thus permitting the cooling-water to leave the condenser at 1°C or 2°C below vapour temperature. If clean water is being used for cooling, the hot water may then be collected in a tank to be used for washing and the like.

Spray condensers are widely used because of their simple design and low cost. However, they must either be provided with powerful pumps to remove the water from the tailpipe and some kind of level regulator or be mounted sufficiently high to allow the water to be drawn off through the tailpipe by gravity. The long pipes and the erection work required naturally add to their cost.

The expanding-flow evaporator

Although the expanding-flow (EF) evaporator bears a superficial resemblance to the Centri-Therm machine the fundamental principles of these two devices are completely different. Instead of using double-walled rotating cones, the EF device operates with single-walled stationary conical surfaces. The incoming liquid is forced over the surface by means of the vapour in the same way as in the climbing-film evaporator. Since the cones are stacked upon each other, the heating surface can easily be adapted to various capacities by using appropriate numbers of cones. The design also permits low height, and the heating surfaces are accessible for cleaning and inspection. The cone stack is surrounded by an inner hood, which separates possible drops of liquid from the vapour, and an outer cover. All components are of stainless steel, standard 18/8 or, for some fruit juices and chemical purposes, 18/10/2.5. Each unit of the EF evaporator described here has a maximum heating surface of 35 m^2.

The operation of the EF evaporator is diagrammed in figure 10. The liquid to be heated enters at the bottom through the hollow spindle in the centre and is ejected through holes in the spindle into the space between two cones. As the liquid is normally pre-heated to a temperature above evaporation temperature in the evaporator, some water will immediately flash off, and the mixture of vapour and liquid will begin to move upwards in the space between the cones. At the end of the passage the vapour will be separated from the liquid and pass through the hole in the intermediate hood and over to the next effect or to the condenser. The concentrated liquid drops down to the bottom of the evaporator and is drawn out by the concentrate-extraction pump.

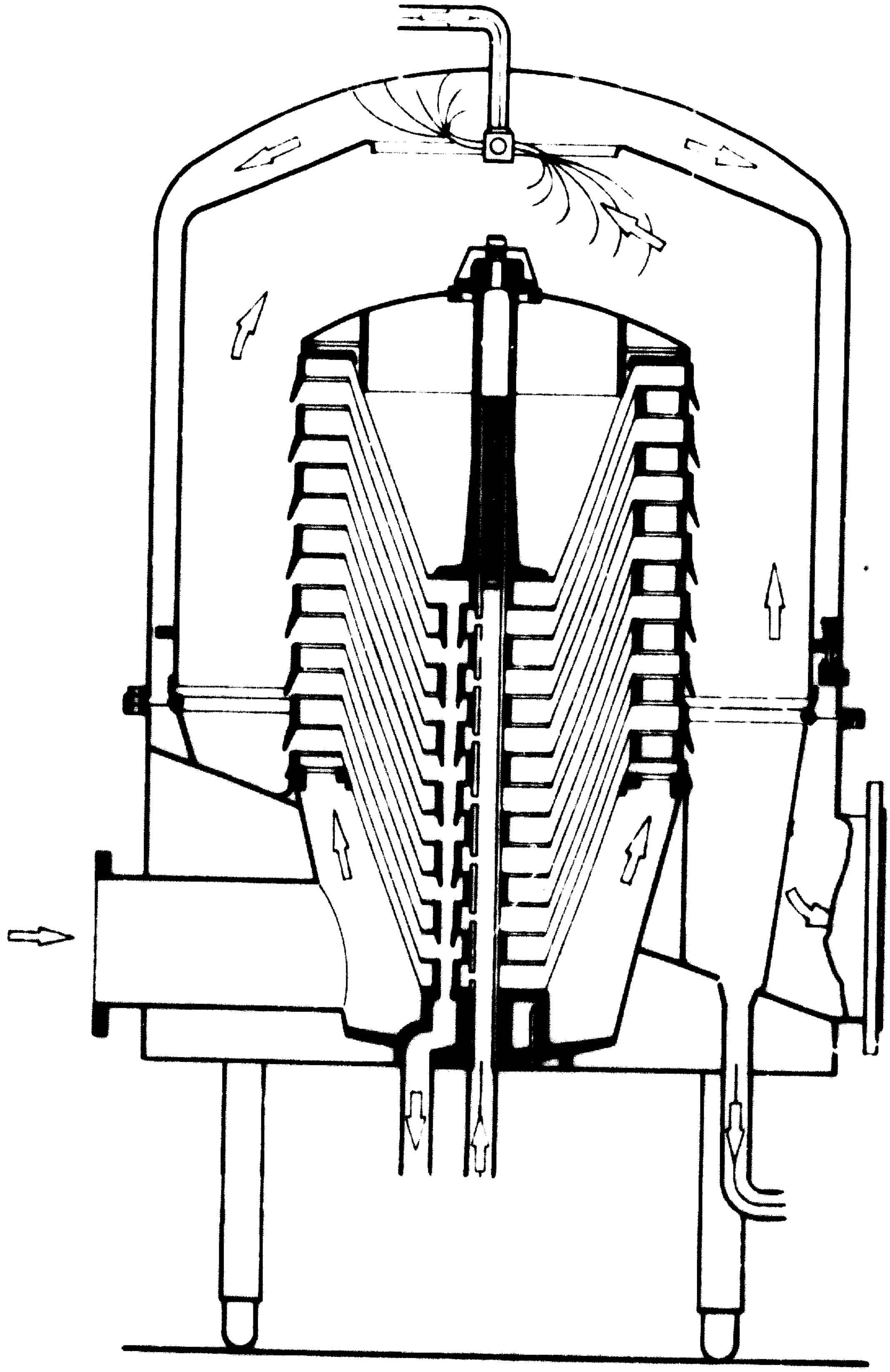

Figure 10. Cross-section diagram of an expanding-flow (EF) evaporator, showing direction of flow

The steam enters the evaporator through the side inlet, moves upwards through holes in the cone brims and in between every other passage. In this way there is always steam on one side of the cone and liquid on the other. The steam will begin to condense as the steam-condensate mixture moves downwards in the steam passages. At the end of the passage the condensate is collected in an outlet connected to the condensate pump and withdrawn.

An individual EF cone is diagrammed in figure 11. This component is made from a single stainless-steel sheet, forming a light but rigid element. Only one disc is shown in this figure, but steam and condensate will not, of course, travel in the same passage as the product, as has been explained in the discussion of figure 10.

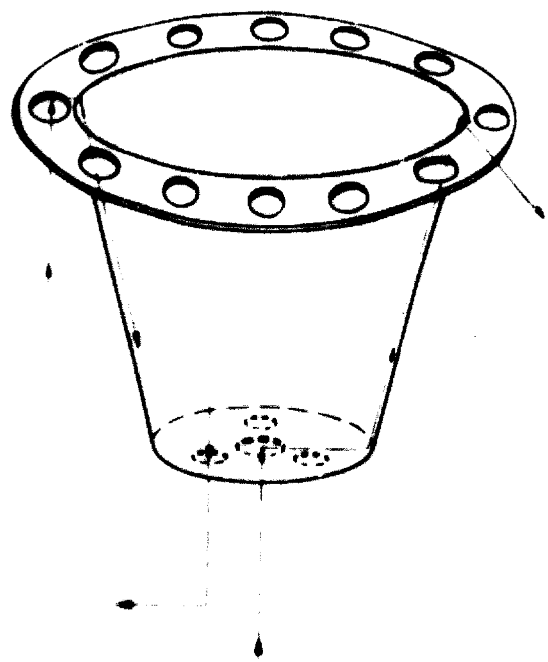

Figure 11. Diagram of an individual cone element of the expanding-flow evaporator

A flow diagram of a typical two-stage expanding-flow milk evaporating plant is presented in figure 12. In principle, this layout will be the same for several other products. There are also one- and three-stage plants, as well as combinations with the Centri-Therm, aroma recovery plants, etc. These combinations are dealt with later in a separate section.

The function of the plant is as follows: From a balance tank (1) the milk is pumped by the feed pump (2) through a regulating valve to the condenser, where some of the vapour from the second effect is used to pre-heat the milk. From the condenser the milk goes to a plate heat-exchanger (4), passing a flow-meter (3) of the rotameter type. In the plate heat-exchanger the milk is first heated by the condensate from both effects, whereupon the temperature is increased in the heating section by means of vacuum steam.

From the plate heat-exchanger the heated milk enters the first-effect EF evaporator (5) where evaporation takes place. The concentrate is then pumped to the second-effect evaporator (6), and finally the finished product is removed through regulating valve (7).

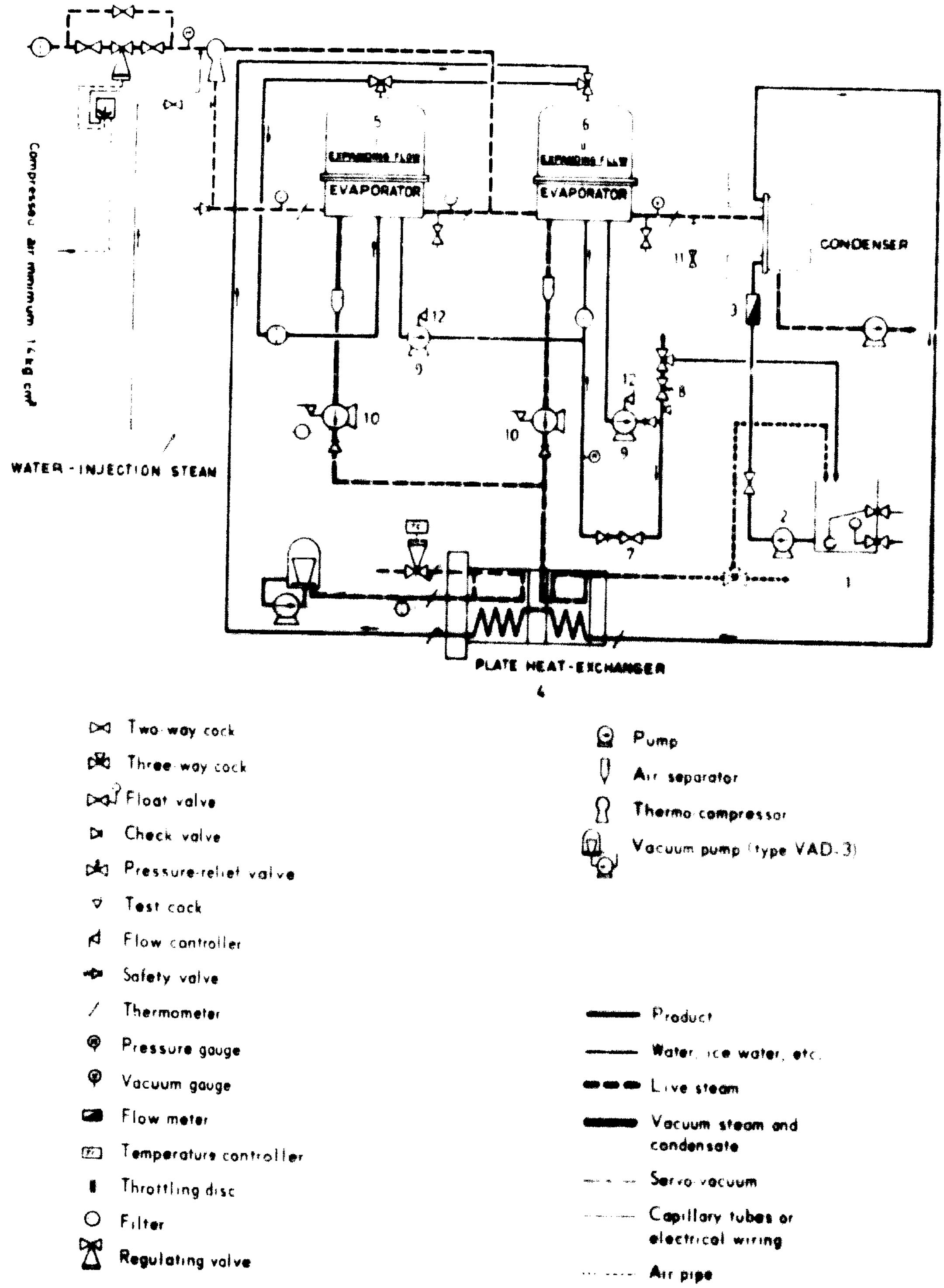

Figure 12. Flow diagram of a typical two-stage milk evaporating plant (see text for explanation of numbering)

If evaporation is carried far, re-circulation will be required in the last effect. The pipe from the concentrate pump back to the evaporator serves this purpose. Component 8 is a pressure-regulating valve by which the amount of re-circulation is set. This valve will also even out possible fluctuations in pressure.

To feed the product into the evaporator from the balance tank, a sanitary centrifugal pump is used. Centrifugal pumps are also used as concentrate (9) and condensate (10) pumps. Some products such as skim milk can contain considerable quantities of air. As the EF evaporator will practically always be equipped with a thermo-compressor, some of the air released in the first effect during operation will be drawn with the vapour through the compressor and into the first effect steam side. If not removed it will block part of the heating surfaces and reduce heat transfer. To assist the condensate pump and also in order to prevent air from passing with the condensate, where it may be collected in the plate heat exchanger, there is a special air trap in the suction line between evaporator and condensate pump. Air will be drawn off through the 25-mm pipe on the side and onto the condenser. In this air-line there is also a regulating valve (11) by which the suction is throttled in such a way that only air and no water, or at least only very little of it, will pass in this direction.

The concentrate pumps are equipped with water-cooled double seals so that there will be a small feed of cooling and sealing water to them (12).

The same type and size of vacuum pump is used for the EF evaporator as for the Centri-Therm device. Since this element has already been described in the discussion of the latter, it need be added only that it might be desired to clean the plant with acid under vacuum, although such cleaning is done normally only with lye. The use of acid may cause damage to the vacuum pump by excessive corrosion, as this pump is constructed mainly of cast iron and bronze. However, stainless steel vacuum pumps will be available to meet such conditions.

The condensers used in EF systems are the same as those used in Centri-Therm evaporators and are considered at length above in the section that deals with them.

In EF evaporating systems thermo-compressors are used to save steam, and the small temperature differences usually present (around 14°C) permit the compressor to operate with 50 per cent live steam and 50 per cent vapour, assuming a steam pressure of 8-10 kg/cm^2.

The economies are thus considerable. As previously noted, the compressor must work within narrow limits regarding pressure and capacity if the highest possible efficiency is to be attained. Should it be necessary to alter pressure or capacity slightly, it might be possible to maintain efficiency by merely changing the compressor nozzle.

The noise created by thermo-compressors is always troublesome. Adequate insulation is very helpful, however. Also, insulation of the bend after the compressor with a layer of mineral- or glass-wool, and over this a layer of foam plastic at least 50 mm thick is recommended. This insulation should be protected with a cover of aluminium or stainless steel.

The steam is highly superheated as it leaves the thermo-compressor, since it is under great pressure (usually from 8 to 12 atmospheres). This pressure drops sharply at the nozzle. However, before the steam can condense on the surfaces of the cone stack it must be cooled to the saturation point. Since the latent heat of steam is released only during condensation, a portion of the heat-transfer process must take place beforehand. The superheated steam is therefore saturated by water-injection; hot water from the condensate pump is forced through a spray nozzle against the steam flow and is instantly converted into steam, a process that consumes large amounts of heat.

A disadvantage of the use of superheated steam is the risk of formation of dry films of the product on the cone surfaces ("burning on") when heat-sensitive liquids are treated.

The forced-circulation plate evaporator

In principle, this type of evaporation plant consists of a heat-exchanger, a vacuum chamber and a circulation pump. The liquid to be evaporated is circulated at high velocity through the heat-exchanger and is heated under pressure. The heated liquid leaving the heat-exchanger is subjected to vacuum when entering the expansion vessel. Part of the water content of the liquid is thus vaporized and drawn to a condenser. The partly concentrated liquid enters the circulation pump and is returned to the heat-exchanger for further heating and expansion. Circulation continues until the required concentration is reached. Fresh liquid is continuously added to the circulating volume, and concentrated liquid is pumped out of the system.

The size of plants of this type is limited only by the size of the heat-exchangers available for use in them. Quite large capacities can be attained with plate-type heat-exchangers. Arrangements in two or three effects are possible, depending on the temperature differences that can be used with the liquid to be treated.

The forced-circulation plate evaporator has the advantage that it produces no deposits even with liquids that are normally difficult to treat or those that contain particles such as pulp. It can also be used with liquids of high viscosity. On the other hand, the in-plant holding time of the product is rather long, and the electrical consumption of the circulation pumps is high.

Comparison of the characteristics of the three types of evaporator

To facilitate comparisons among them, the characteristics of the three evaporating systems that have been discussed here are set out in table 1.

Accessory aroma-recovery equipment

As noted, various kinds of accessory equipment can be used with the evaporator systems described above. Among the most interesting of these accessories is the aroma-recovery plant, designed for use with an expanding-flow evaporator, which is described in detail below.[2]

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[2]The temperatures and evaporation ratios used in this example apply to the recovery of apple-juice aroma.

Table 1. *Comparison of the characteristics of three evaporator systems*

	Centri-Therm	Expanding-flow	Forced-circulation
Principle	Rotating conical heating surface	Stationary conical heating surface	Circulation pump plate heat exchanger vacuum chamber
Process	Single-stage – finisher	Single or multiple-stage pre-evaporator	Single or multiple stage
Retention time	Less than 10 seconds	Less than 30 seconds per stage	Less than 15 minutes per stage
Dimensions	Compact, low building height, plug-in unit	Compact, low building height	Compact
Flexibility	None	Good	Good
Ease of dismantling for inspection and cleaning	Good	Good	Very good
Applicability for use with liquids of these characteristics			
Viscosity			
Low	Yes	Yes	Yes
Medium	Yes	No	Yes
High	Yes	No	No
Tendency to form deposits			
None	Yes	Yes	Yes
Medium	Yes	Yes	Yes
Severe	No	No	Yes
Particle content			
None	Yes	Yes	Yes
Small (slurries)	To some extent	To some extent	Yes
Larger (e.g. pulp)	No	No	Yes

The aroma-recovery plant has three principal sections: the pre-heating section, the aroma-recovery section and the aroma-condensing section. As shown in the flow sheet (figure 13) the plant, taken as a whole, consists not only of equipment for recovery of aroma from evaporated vapours but also of an evaporator to extract the aroma from the juice. Normally speaking, however, the term "aroma-recovery plant" refers only to the section concerned with the recovery and concentration of the evaporated aroma.

The raw juice enters the plant through a balance tank that ensures a regular rate of feed through a float-controlled inlet valve. The juice is then moved by a centrifugal pump to a plate heat exchanger (1) where it is pre-heated by regeneration to approximately 70°C. Here the de-aromatized juice from the evaporator is utilized as heating medium. The capacity is adjusted by means of the valve on the outlet of the feed pump and a flow-meter.

The pre-heated juice is then fed into an EF evaporator (2) where 10 per cent of the incoming juice is evaporated at atmospheric pressure at 100°C. The quantity of water evaporated can be checked by means of a flow-meter mounted in the pipeline to the next evaporator effect.

The tenth part of the liquid that contains most of the volatile flavours is then condensed and super-cooled in the condensing section of a plate heat-exchanger (3). The condensate and non-condensable gases, which are saturated with aroma vapours, are piped to an ice-water-cooled section for the recovery of as much as possible of the aroma substances. This section consists of a special evaporation-condensation unit (4), described below, a laboratory glass cooler (5) and an ice-water-cooled blocking condenser for the vent gases (6) that derives its cooling water from an ice-water generation plant (7). Operating conditions and the quantity of evaporated vapours may be checked by means of a flow-meter and a sight glass.

The evaporation-condensation unit (4) is of a special type, with two sections mounted under the same hood. The lower one operates as an evaporator in which one tenth of the flow is vaporized by live steam; in the upper section these vapours are condensed directly by the cooling-water.

Finally, the aroma substances, which by now have been concentrated to a one-hundredth part of the raw juice volume, pass by gravity through the laboratory glass cooler (5). This aroma concentrate can be filled into light-proof demijohns and stored at ordinary cellar temperatures for future use.

Before leaving the plant, the vent gases from the two evaporating stages pass through the ice-water-cooled blocking condenser (6). Here they are cooled and most of the aroma substances are condensed. This condensate runs back to join the aroma concentrate from the condenser.

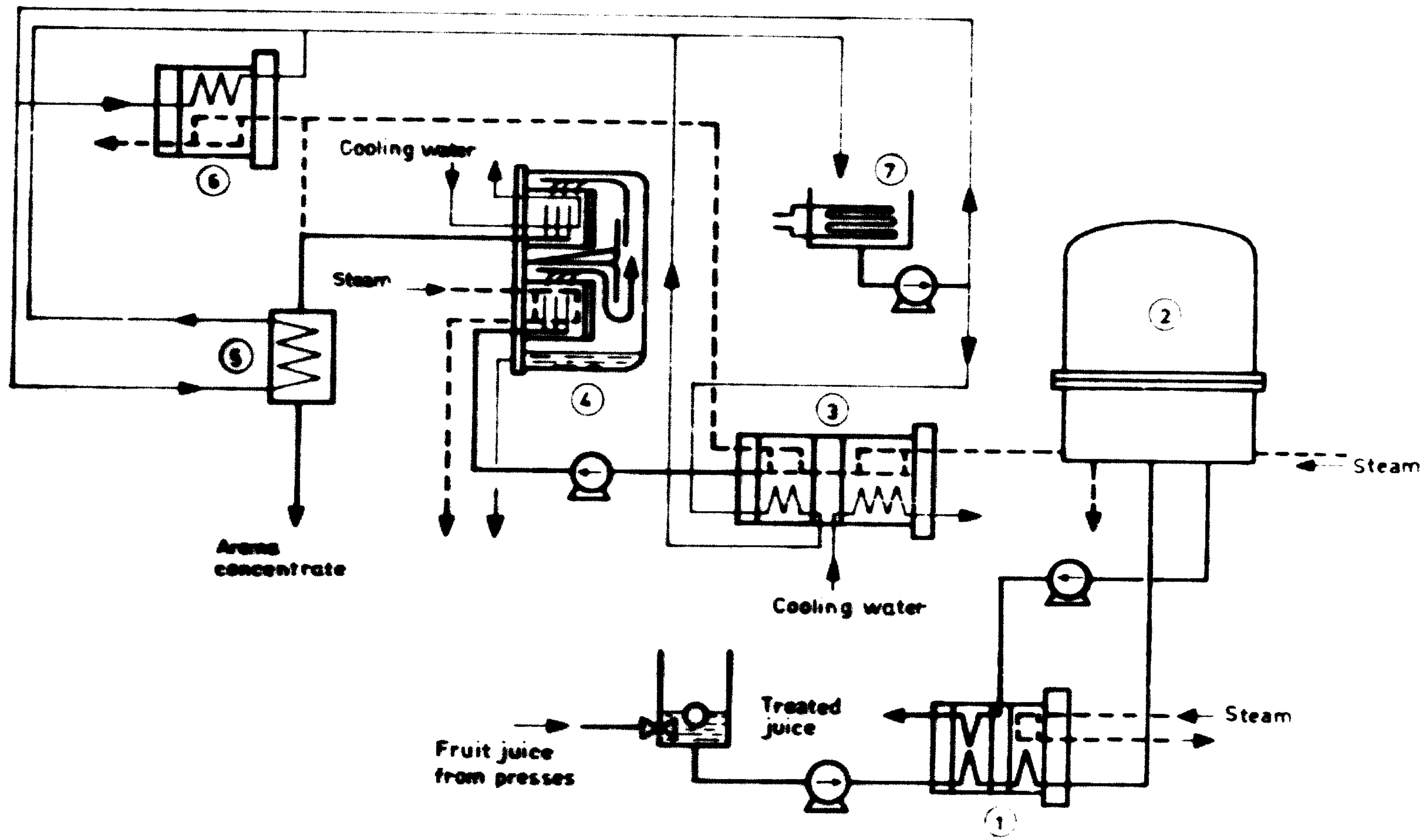

Figure 13. Flow-sheet of an aroma-recovery plant (see text for explanation of numbering)

APPLICATIONS IN THE FOOD AND BIOCHEMICAL INDUSTRIES

Three types of modern evaporators have been described. They operate in different ways and have different characteristics. Together they form a complete line of machines that can, singly or in combination, perform almost any concentration of fluid that might be required in the food and biochemical industries.

Almost all organic substances are very sensitive to heat. Temperature and treatment time are therefore of utmost importance. Thus, increasing the treatment temperature of such material by 10°C approximately doubles the rapidity with which it will deteriorate. This means, for example, that a processing temperature of 70°C for 10 seconds is comparable to 60°C for 20 seconds, 50°C for 40 seconds, 40°C for 80 seconds, 30°C for 160 seconds, and so on. Thus, using modern evaporators with relatively brief product-holding time, the same results can be achieved at a relatively high temperature as were obtained in older equipment that operated at a lower temperature and higher vacuum for a longer time. The new condensing and vacuum equipment is therefore simpler, easier, and more economical to use. At the same time, there is less deterioration and higher quality of the final product when using the same temperature as before. This is illustrated in the products discussed below.

This list is not exhaustive; only examples taken from different industries have been selected. Some of these product lines are discussed in greater detail than others in the hope that they might serve as typical examples of how complete processing lines can be arranged.

Dairy products

Milk products are today the greatest source of protein for human consumption. However, production centres are away from the large population centres, and it is one characteristic of a microbiological product such as milk that the untreated product is very perishable, and transportation of it for considerable distances is consequently impossible. Various processes are available for overcoming these difficulties, and the most important of these to date is the transformation of liquid milk into a powder. This is achieved by drying the liquid in either of two ways: spray drying and roller drying. As the drying process is relatively expensive, the liquid is first concentrated in an evaporator, as this pre-treatment is less costly than drying. Steam consumption (in kilograms) per kilogram of water removed by evaporation is approximately as follows:

	(kg)
Spray drying	3.0
Roller drying	1.5
Single-stage evaporation	1.1
Three-stage evaporation	0.3

Spray drying or roller drying can be done either at the milk-collecting centre (alternative A) or away from it (alternative B). These two alternatives are diagrammed in figure 14.

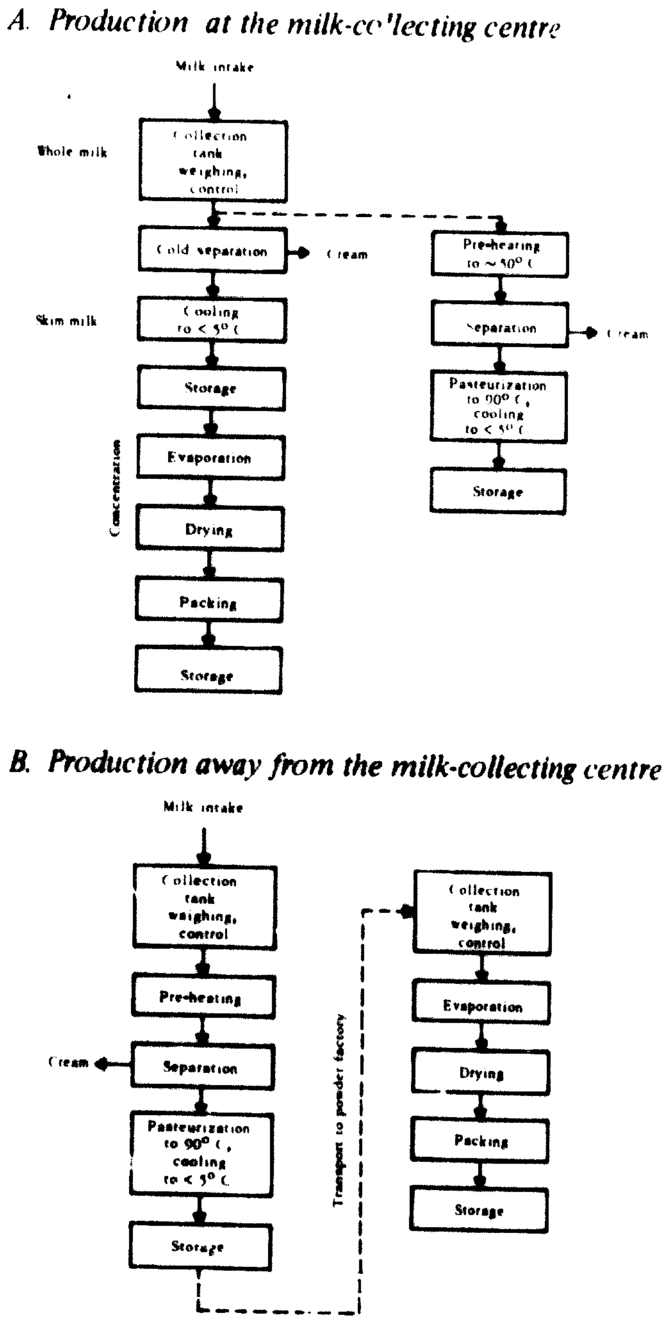

Figure 14. Two alternative methods of milk powder production

Figure 15 shows a principal flow sheet of a double-effect evaporation plant and a normal spray dryer. This arrangement can be used for skim milk, whole milk, fat-enriched milk and whey. In the latter case, however, some minor modifications might be needed as described below.

For spray-drying purposes skim milk is normally concentrated in the evaporation plant from 9 to 45-48% DS.[3] When roller drying is used, the concentration ratio is normally lower due to difficulties in roller-drying higher content of DS. Normal figures are 30 to 35-38% DS but some types of roller dryers can treat up to 43% DS.

In the evaporating and drying of skim milk, cost is a prime consideration. This means that the most economical plant must be chosen in each case, and the total amount of powder to be produced per year and the expected number of operating hours per year are of great importance. Among others, the questions in Diagram A should be considered.

When planning an evaporation plant, it should be recognized that the inclusion of many stages raises primary cost but reduces operating cost. If skim milk for treatment is available for only a short season, only a few stages are generally used. On the other hand, if the milk supply is fairly even over the year, the use of relatively many stages is generally more economical. However, many local conditions, such as the costs of heating steam, cooling water and labour must be considered. A complete cost evaluation should be made.

However, even in an existing plant, the operator can do much to increase production economy and efficiency. Operating conditions are very sensitive to milk quality, and everything should be done to transport and store the milk at the lowest possible temperature before concentration and drying. Better microbiological quality of the milk means fewer interruptions in operation and longer operating times between cleaning cycles. These circumstances are of particular importance in countries with warm climates.

Milk characteristics to be avoided are high bacteria content and high acidity. Measures that can be taken to prevent them include shortening of pre-treatment storage time; cooling as much and as rapidly as possible; reduction of evaporation temperature; and reduction of the temperature difference between steam and milk in the evaporator.

Roughly the same general rule as for skim milk can be applied to whole milk. Very often a plant is laid out for both products; in this case the evaporation capacity is lower when treating whole milk than when treating skim milk (difference is 10 to 15 per cent). Whole milk is generally concentrated to about 48% DS before spray drying. Inlet concentration is 12% DS.

Surplus whey from cheese factories is generally removed in order to produce cattle feed and to avoid drainage problems. Evaporation is normally followed by roller drying. As with skim milk, it is most important to treat the whey when it is as fresh as possible. Longer storage or transportation time must take place at a low temperature (less than 5°C).

[3] Percentage of dry substance content. See definition in Annex.

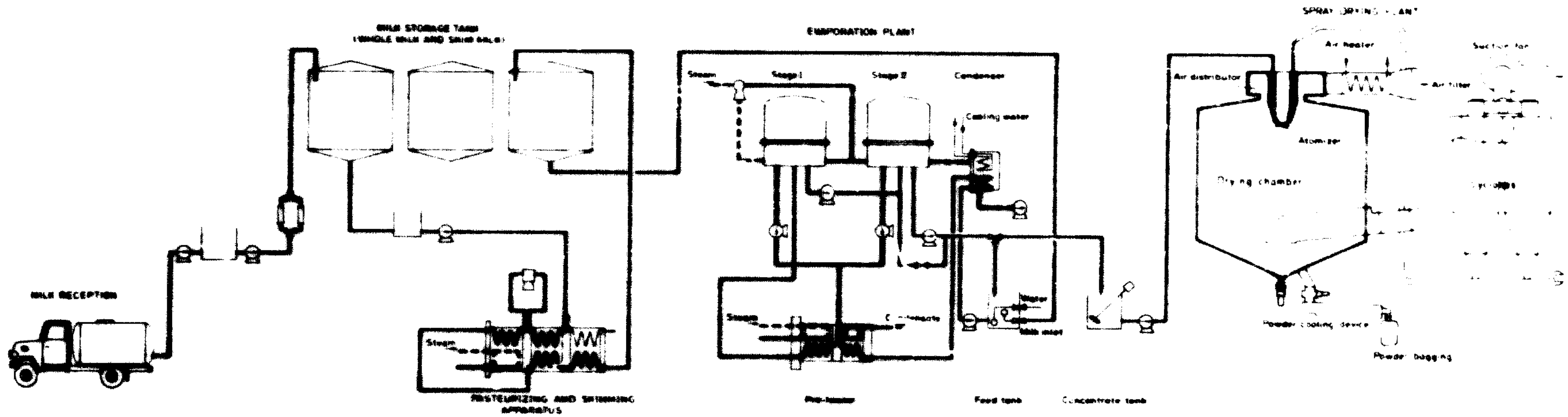

Figure 15. *Process diagram of the production of dried skim milk powder*

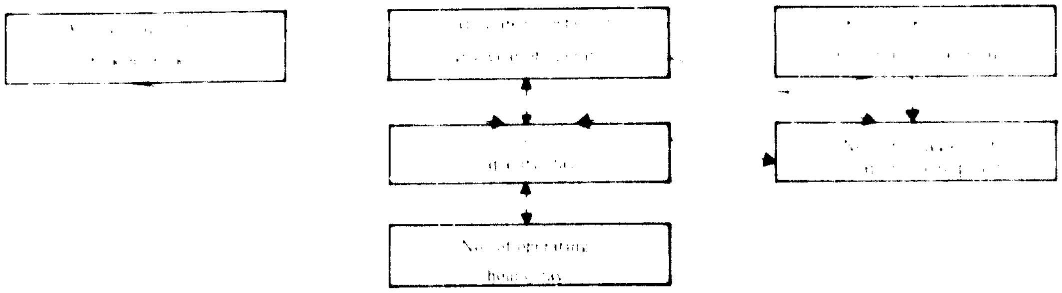

Diagram A. Evaporation and drying of skim milk

The problems involved in the evaporation of whey are very much dependent on the type of cheese from which it originates. This is also a determining factor for the maximum outlet concentration from the evaporator. Inlet concentration is approximately 6% DS. Outlet concentration may vary from 30 to approximately 55% DS.

If a higher concentration is required this can be reached by mounting a single-stage "finisher" after the pre-evaporator. The forced-circulation type of evaporator can be used, and a concentration of approximately 70% DS is then the maximum. However, when Centri-Therm evaporator is used instead, a maximum concentration of approximately 80% DS can be reached.

When producing roller-dried powder, the concentration reaches 30-45% DS. For the spray process a higher concentration can be used, 45-55% DS. In this case special action must be taken to avoid clogging of the powder in the outlet from the drying chamber and the cyclones. The powder is very hygroscopic; however, it will be less so if some of the sugar in the concentrate is crystallized prior to drying. This can be done by cooling the concentrate below 10°C after it leaves the evaporator and keeping it at that temperature for about 24 hours. The concentrate will then have a sandy consistency and will yield a less hygroscopic powder when spray dried. The crystallization process in the concentrate may be accelerated by seeding with whey powder or lactose.

The production of sweetened condensed milk presents special problems. A plant for this purpose is diagrammed in figure 16 and discussed below. After pre-heating, the milk is stored in a tank, where sugar is added. The pre-heating temperature is of importance for the final thickening. Low-temperature heating (60-65°C) tends to yield a final product that thickens rapidly, but higher pre-heating temperatures reduce thickening. The best results are usually achieved by pre-heating the milk to about 77-80°C. By adding one kilogram of water per kilogram of sugar, a syrup is obtained that is added to the pre-heated milk.

Concentration takes place in a two-stage forced-circulation evaporator. This type of machine provides a sufficient holding time and the most convenient treatment for forming sugar crystals of the optimum size. The concentrate is filled into a jacketed tank with a scraper. After holding for about one hour (agitator running) at the concentrate temperature (normally about 50°C), the batch is cooled to about 20°C by water or even ice-water in the tank jacket. The product is then ready to be filled into its containers.

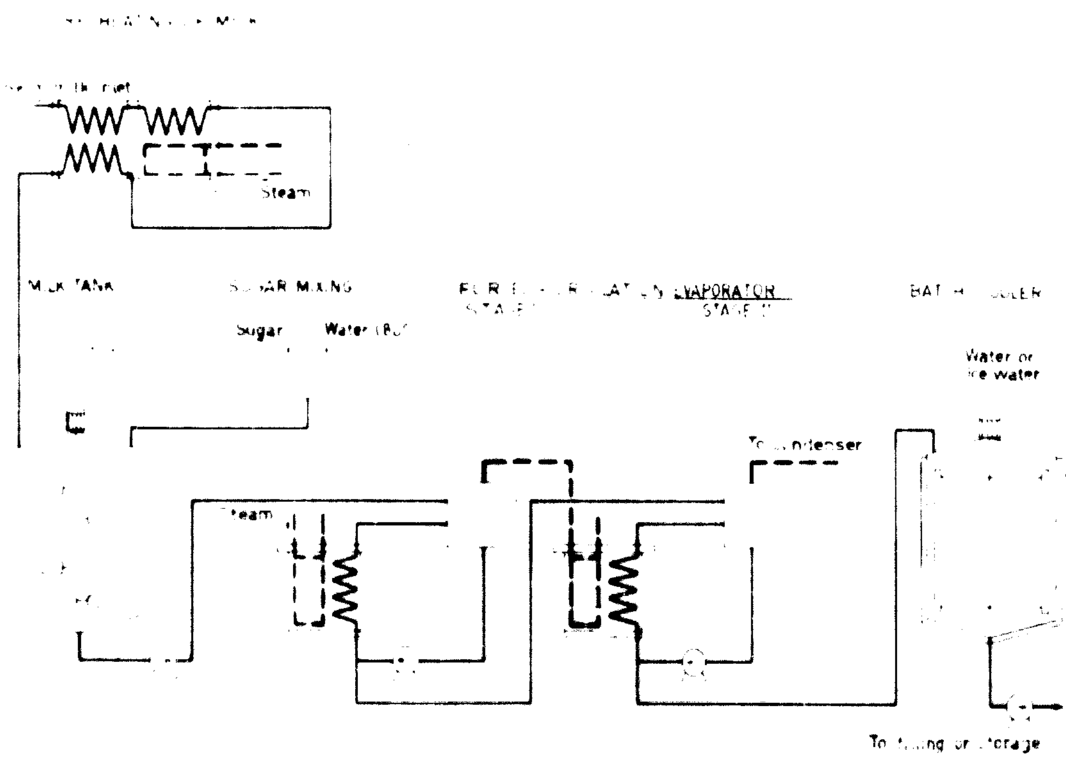

Figure 16. Suggested flow diagram for the manufacture of sweetened condensed milk

A typical temperature programme for the production of sweetened condensed milk in a plant such as that shown in figure 15 is the following:

milk tank	50°C
evaporator	
(stage I)	75-50°C
(stage II)	45-50°C
finished product	
(after cooling)	ca. 20°C

Two typical recipes for the production of sweetened condensed milk are the following: *(a)* 1000 kg skim milk plus 163.5 kg sugar (with some water), to yield a product that will contain 47.5 per cent sugar, 25.2 per cent non-fat substances (such as casein) and 27.3 per cent water; and *(b)* 1000 kg whole milk (2.85 per cent fat), 207 kg sugar (with some water), to yield a product that will contain 46.4 per cent sugar, 20.2 per cent non-fat substances, 6.4 per cent fat and 27.0 per cent water.

Evaporators have many other uses in the dairy industry, among them the manufacture of ice-cream and yoghurt, the concentration of buttermilk, and the production of fat-enriched milk. These are more specialized processes, and descriptions of them are not within the limits of this paper.

Fruit juices

In all fruit-juice concentration, as well as in aroma-recovery, it is essential to keep the time-temperature relationship at a minimum. The evaporators of the Centri-Therm and expanding-flow types described above are therefore extremely well suited for this purpose, as the in-plant retention time is very short. To obtain optimum quality of the concentrate the Centri-Therm is always used as a "finisher". The size of the Centri-Therm unit is determined by the capacity of the plant and if an even higher capacity or better economy are required (multiple-stage evaporation) the expanding-flow evaporator is used for pre-evaporation before the finishing stage.

The aroma-recovery problem for orange juice has not yet been completely solved commercially. In Europe this problem is not even taken into consideration, and the juice is concentrated in the most gentle and economical way from the initial concentration of about 10-11°Brix to 72°Brix. Older production plants often use tubular convection-circulation calandrias in which the holding time for the product is very long, as much as 30 minutes in some cases. However, it has been found that a single passage and short evaporation time are of utmost importance for the quality of the concentrate. The type of evaporation performed by the Centri-Therm machine is especially gentle to vitamin C (losses less than 2 to 6 per cent), colour (deterioration of carotenoids less than to 3.6 per cent) and amino-acids (deterioration less than 0.8 to 6 per cent).

It has also been found that retention time is most important in the loss of aroma substances. The longer the concentrate is retained in the evaporator, the smaller the quantity of aroma substances that remains in it after the evaporation process. It has been found that concentrate produced in the Centri-Therm evaporator loses little aroma; in this respect, this machine is presently the best for concentrating orange juice.

European processors normally work with relatively small plants in which one or two Centri-Therm evaporators are sufficient. This means that they obtain high quality without special arrangements regarding aroma-recovery. For higher capacities, pre-evaporation with the expanding-flow machine takes place before the Centri-Therm evaporator is used.

In the United States normal capacities for orange processers are much higher than in Europe. This means that Centri-Therm plants are quite insufficient and much care must be taken regarding aroma. Usually the "cut-back" method is used. This means that only a part of the fresh aroma-containing juice is concentrated but this is done to a higher degree than is required in the final product. The remaining part of the fresh juice is added to this concentrate so that the desired concentration is attained. In this way the final product contains a certain amount of fresh aroma which gives the necessary appearance. The process is illustrated in Diagram B, in which the normal concentration figures are also shown.

The pulp content of the fresh juice is a limiting factor as regards concentration. Too high a pulp content causes the formation of precipitates on the heating surfaces of the evaporator and thereby lowers its capacity. The machine must be stopped for cleaning after a certain time. The following figures show the maximum pulp content in the fresh juice that can be treated without difficulty:

Centri-Therm, when concentrating to 72°Brix, 5 per cent pulp

Centri-Therm, modified design, when concentrating to 72°Brix, 10 per cent pulp

Expanding-flow, when concentrating to 40°Brix, 10 per cent pulp

(The pulp-content figures refer to measurements according to the centrifugal method.)

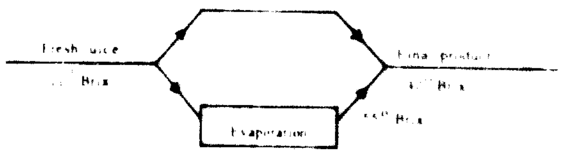

Diagram B. The "cut-back" evaporation process

Figure 17 shows a principal-flow diagram for a normal European complete orange juice processing plant. Lemon juice is similarly evaporated to a content of 40-45 per cent dry substance. Grape-fruit juice is concentrated in the same way.

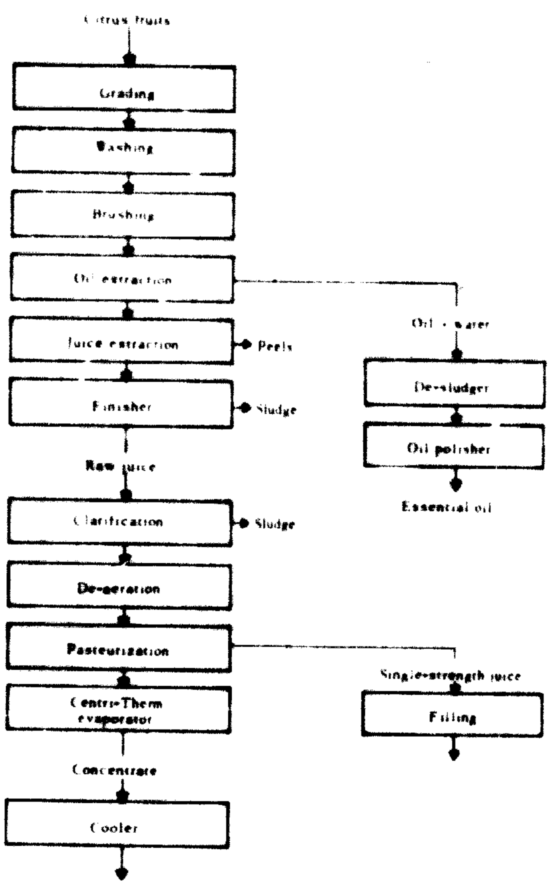

Figure 17. Principal-flow diagram of normal complete orange-juice processing plant of the European type

Apple and pear juices. The system for aroma recovery described in the previous section is also utilized for apple juice. The complete process is illustrated in figure 18. After grading and washing the fruit is fed into a press to extract the juice. From this point it is most important to protect the juice from oxidation and aroma loss. Contact with air must thus be minimized. The juice is pumped to a centrifuge for clarification. Next comes the aroma-recovery procedure, and about one tenth of water content is evaporated, the juice volume being reduced by that amount. The aroma-recovery plant described above is used, and the aroma concentrate leaves it concentrated 100 to 150 times, according to requirements.

Gelatine and preparations for depectinization (in order to facilitate the precipitation and to make the sediment more compact) are added to the remaining juice (90 per cent of the original volume). The process is completed in storage tanks for a certain time, the length of which depends upon temperature and type of additive. After settling, the juice is filtered to produce a brilliantly clear light-amber colour. The amount of additive to be used and the temperature/time relationship are recommended by the manufacturers of these preparations.

After depectinization the juice is treated in an evaporation plant for final concentration. For plants of lower capacities only the Centri-Therm is used, but for higher juice capacities the pre-evaporator (expanding flow) is also used. Normally the juice is concentrated to 70-72°Brix, at which concentration the juice is normally self-preserving. Evaporation must take place within the briefest possible retention time so that quality, and especially colour, can be maintained. After cooling, the concentrate is stored in tanks. Juice should be stored at 0-5°C and the aroma concentrate at not more than room temperature. For consumption, the concentrate is diluted and the aroma concentrate added. Pasteurization and filling are done afterwards.

This system has several important advantages over the older one in which the fresh juice is stored without aroma-recovery and concentration. For example, fewer storage tanks and less building space are required. Also, the quality and aroma of fresh juice vary considerably during the season. With the system described, this variation can be compensated for by dilution and addition of aroma concentrate, permitting a uniform and high product quality. Furthermore, transportation and handling costs can be reduced if dilution and filling are performed at a distance from the point of production.

Figure 18 diagrams a medium size of production plant in which one expanding-flow evaporator and one Centri-Therm CT6 are combined to form a two-stage plant. In this way high concentrate quality (short retention time) is combined with low steam consumption.

For more delicate juices, such as those of berries, aroma recovery cannot be carried out in the same way as for apple juice. The reasons for this are that such juices and their aroma substances are more sensitive to heat, and that a larger part of the juice than 10 per cent (as for apple) must be evaporated in order to obtain sufficient yield of the aroma recovery. The plant layout diagrammed in figure 19 is suggested for use with juices of this kind.

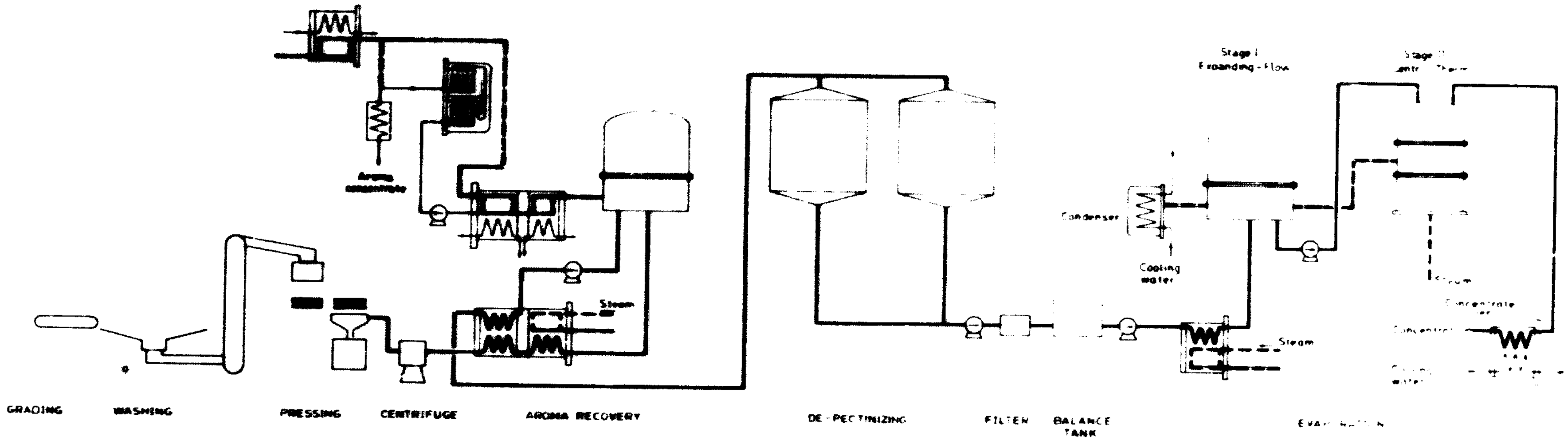

Figure 18. ***Diagram*** *of a plant for the complete* ***processing*** *of* ***apple*** *juice, including* ***aroma*** *recovery*

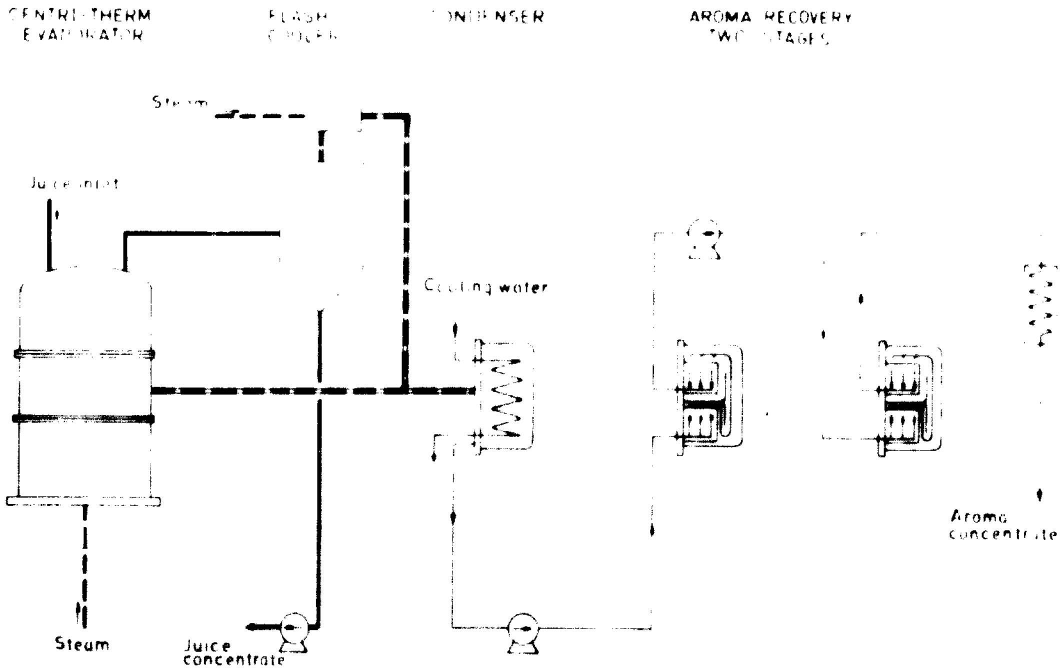

Figure 19. Suggested plant for evaporation and aroma recovery with delicate juices such as those of berries

Instead of heating the juice to 100°C and recovering the aroma in the first stage of evaporation, the complete concentration takes place in a Centri-Therm device. Here concentration is completed in single passage to the dry substance content required. In this way the juice and concentrate temperature will never exceed evaporation temperature in the Centri-Therm machine (about 50°C). All vapours formed (containing the aroma) are condensed in the usual way in a surface condenser in this case the box condenser. The condensate (containing the aroma) is heated to 100°C and treated twice in the special vaporizer-condenser described earlier. Among the advantages are low-temperature treatment, recovery of aroma from all the vapour and comparatively inexpensive equipment.

In the processing of pineapple juice, the extracted juice is centrifuged to remove heavy solids and is heated to 75°C to inactivate enzymes. Either the aroma-recovery process or the "cut-back" procedure is applied, as described above in the discussion of citrus juices. After centrifuging, the juice may be 9-10°Brix, while in a modern centrifuge 20-25% DS in the pulp phase can be reached. Aroma recovery takes place according to the previously described two-stage condensation process. In order to attain a yield of aroma in the aroma concentrate of more than 60 per cent, the water evaporation must be increased to 20-25 per cent of incoming juice in the aroma-recovery evaporator. The de-aromatized juice is normally concentrated to 45-60°Brix. Evaporation takes place in the expanding-flow machine as pre-evaporator and, if required, is completed in the Centri-Therm machine.

Grape juice is either concentrated 1:3, yielding a product that keeps well under very good storage conditions, or 1:4 to 1:5, in which case the concentrate is self-preserving. The volatile flavouring elements may be recovered in an aroma-recovering evaporator such as the one that has been discussed. The expanding-flow evaporator should be used to produce the 1:3 concentrate; for the higher concentrations the Centri-Therm device should be used.

In the concentration of grape juice, special precautions must be taken against the precipitation of wine-stone (tartaric acid) on the heating surfaces. Shortness of holding time on the heating surfaces is of great importance, and all parts of the plant through which the raw juice or the concentrate will pass – tube bends, valves, pumps, pre-heater and evaporator – should be designed to minimize flow resistance.

Some processing methods that can be used to counter this precipitation problem may be mentioned: *(a)* cold storage of the fresh juice at −3°C for one week; de-sulphurization of the juice before concentration (the lower its acidity, the less the tendency of juice to form deposits); and stabilization of the juice by neutralization, if this is permitted in the country concerned. Sodium bicarbonate is a possible additive.

Another important problem in connexion with the concentration of grape juice is that many processers wish to store their fresh juice in order to concentrate it over a longer period after the rush time of grape-harvest is over. Sulphur dioxide (SO_2) is added in order to preserve the fresh juice. At the time of evaporation it is necessary to remove it and restore the normal content of less than 0.2 per cent. To achieve this it is necessary to observe certain evaporation conditions closely: holding time should not be too short, evaporation may be increased, and flash-cooling of the concentrate may be used in order to increase the sulphur dioxide removal still further. It can also be removed by means of special vacuum treatment prior to evaporation.

Apricot, peach, apple and pear purées are concentrated for less expensive canning or for shipment to consuming centres where they may be combined with syrups for the preparation of nectars. Such products are treated only in the modified Centri-Therm with radial outlets from the bowl. The degreee of concentration depends on the type and kind of fruit and on the pre-treatment. The treatment sequence is diagrammed in figure 20.

Concentrated tomato juice is normally referred to as tomato paste or tomato purée. The usual way to concentrate tomato juice is by means of some kind of forced-circulation evaporator. This type of process involves long holding time and thus endangers the product quality. In practice the high viscosity of the concentrate also causes fouling of heating surfaces and slows evaporation.

A few years ago a better method was suggested by several different people. This process involves the following treatment: after washing and sorting, the tomatoes are broken and pulped. The juice obtained is centrifugally separated into pulp and almost pulp-free serum. Only the serum is concentrated, and the concentrate is re-mixed with the pulp to give the final product. Figure 21 shows the principal flow diagram.

The kind of fruit, pre-treatment and the type of centrifugal separator used are the determining factors for pulp content in the serum phase and for moisture content in the pulp phase. It is of course intended to maintain not too low a pulp content in

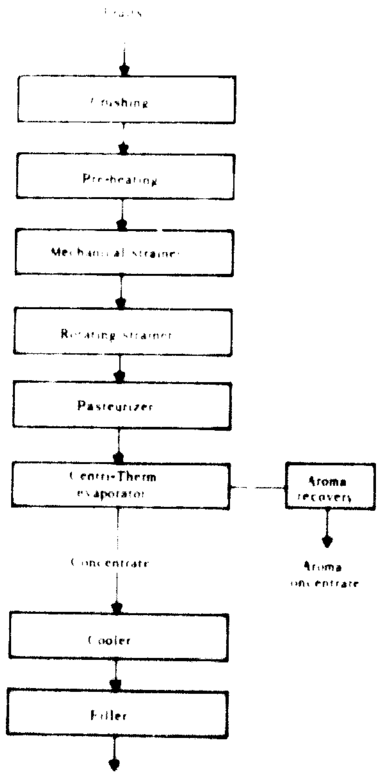

Figure 20 Treatment sequence in the processing of nectars and other pulpy juices

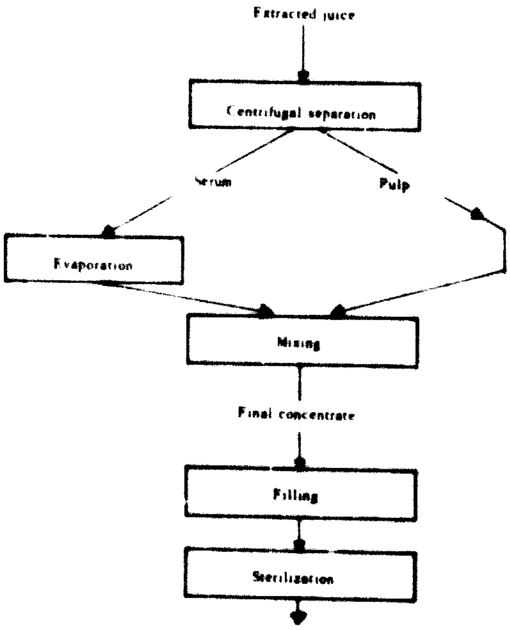

Figure 21. Principal-flow diagram of tomato-juice processing (separation method)

the serum but still reach acceptable evaporating characteristics. Of course, the dry substance content, which is roughly the same as the pulp content of the pulp phase, should be as high as possible. In this way the concentration ratio and evaporation capacity for the serum may be kept lower. An example from the field is shown in Diagram C.

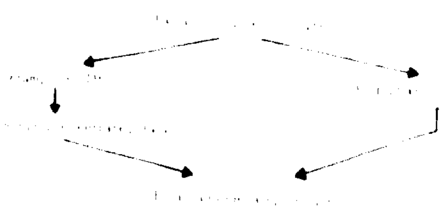

Diagram C. Serum and pulp concentrations in evaporation of tomato juice

The degree of concentration of course depends on how much pulp is left in the serum. If an almost clear serum juice is obtained it may be concentrated in the same manner as apple juice, and a concentration of 70-80°Brix may be reached. If these precautions are combined with efficient centrifugal separation (high content of pulp in pulp phase) a final product of 32-35% DS concentration may be reached.

The type of evaporator to be chosen also depends on the remaining content of pulp in the serum. With clear serum juice the expanding-flow evaporator is used first for pre-concentration, and then the Centri-Therm machine is used as the finisher. This combination offers high product quality (minimum deterioration from heat) and good heat economy.

If the remaining pulp content in the serum exceeds a certain limit all serum concentration should be done with the Centri-Therm evaporator. This limit depends on the kind of fruit and pre-treatment. It might be necessary to use the modified Centri-Therm with radial outlets from the bowl. This modification offers certain advantages for pulpy products.

Brewery products

In this industry evaporation is achieving ever wider use. For instance, it is expensive to transport hops over long distances. Processes whereby an extract is produced have therefore been introduced, and the extract is later concentrated by evaporation. In this way much smaller volumes need be transported.

Concentration of wort and malt takes place as the result of rationalizing production. In this way malt or wort are produced at large centres, where they are concentrated. The concentrate is transported to filling plants, where only brewing, fermenting and filling take place. Transport may also take place in order to use a certain type of beer produced at a certain place. Evaporation of beer is done in order to decrease the alcohol content to a specified limit or to lower storage and transport costs. Before discussing these concentration processes a complete flow diagram of brewing is given in figure 22. This shows where in the total process evaporation may be of interest.

In the concentration of wort, whether hopped or not, the raw wort is fed to the evaporator at a concentration of approximately 12% DS. Concentration ratio is about 1:7, which means a concentrate of 80-84% DS. At this concentration wort is self-preserving. Concentration takes place in the expanding-flow evaporator to about 60% DS and in the Centri-Therm machine to the final concentration. This procedure gives the most gentle treatment and avoids recirculation in any of the evaporator stages.

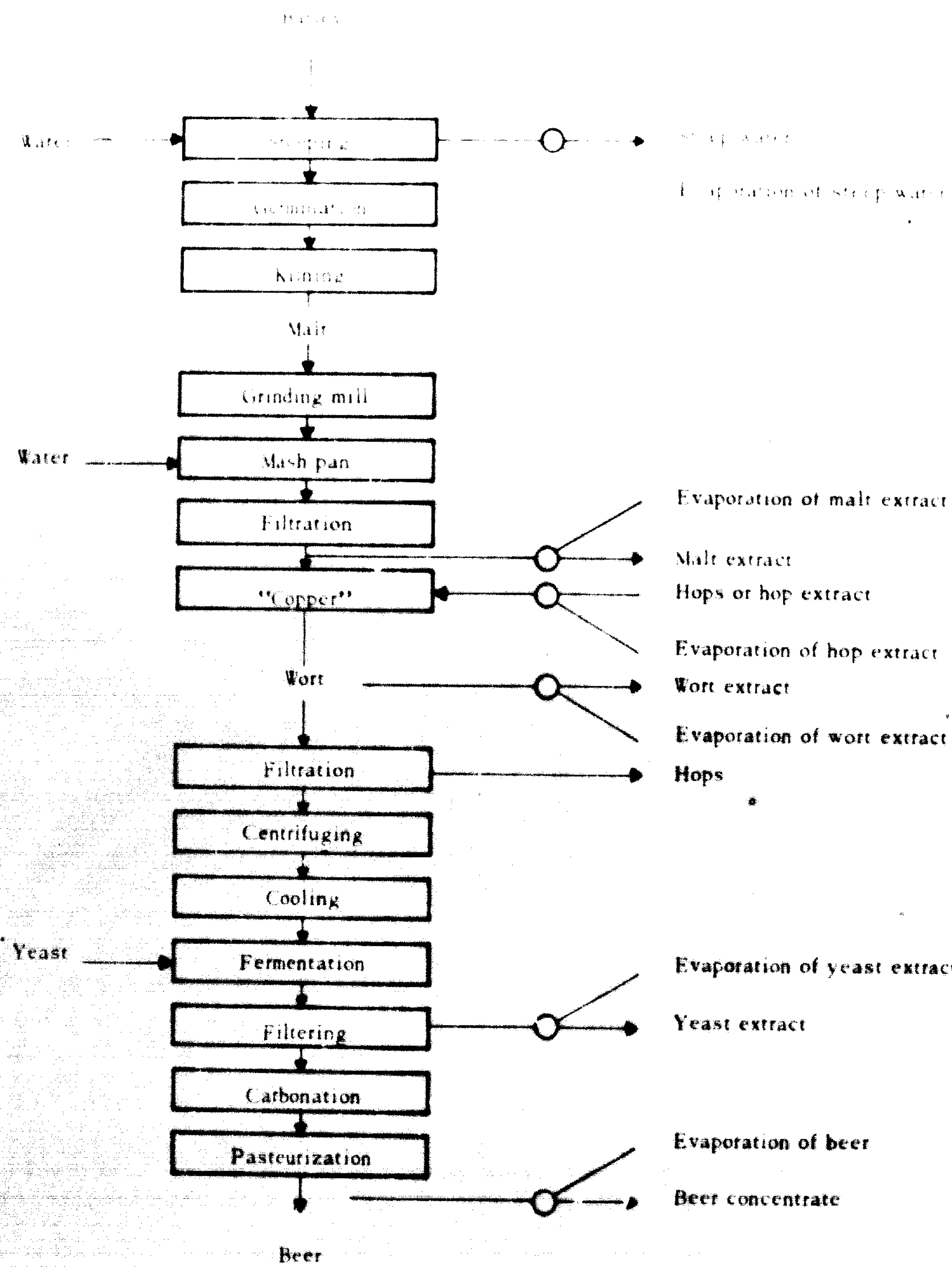

Figure 22. Some possible applications of concentration by evaporation in the brewing industry

The wort concentrate may be transported for reconstitution, fermentation and bottling elsewhere. Plants for these purposes may be small and can be supplied with wort concentrate from a central brewing plant. As noted above, it is also possible to concentrate the hopped wort by evaporation; tests of this possibility have been carried out. However, in this process the aroma is partly lost, and at this time the addition of an aroma-recovery unit is not a practical solution. Concentration of malt extract is carried out in the same way as for wort.

Beer may be concentrated either in order to produce a fully fermented beer with low alcohol content or to make a beer concentrate for export and therefore with small volume (low transport costs) and/or low alcohol content (no customs duty). With such a process it is possible, for example, to reduce the alcohol content from 6 per cent to under 0.5 per cent while increasing the dry substance content from 8% DS to approximately 20% DS. No change in taste or colour occurred when this process was performed in a Centri-Therm evaporator. The vapours leaving the evaporator were piped to a rectification column for recovery of alcohol and aroma ingredients.

Evaporators can be used in the production of hop extract. The hops are extracted in a solvent such as methylene chloride. The intention of the evaporation process is to recover as much of the solvent as possible and to reduce the methylene chloride content in the concentrate. The concentrate is very viscous (about 4000 cp at 40°C) and sensitive to heat. Evaporation is carried out in the Centri-Therm machine at low temperature in two stages.

Large-scale production of yeast extract is made possible by the fact that little more than 20 per cent of the yeast produced by batch fermentation methods in the brewery industry is required for seeding subsequent batches. The production of yeast extract is shown in Diagram D.

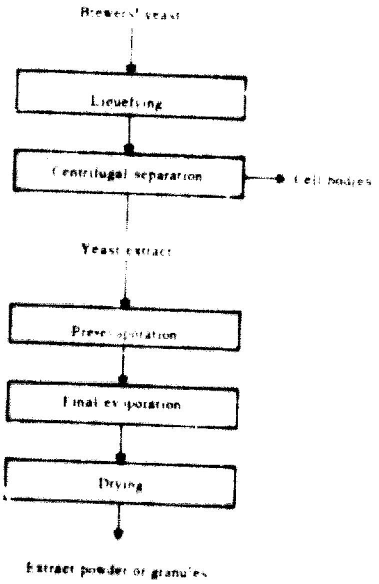

Diagram D. Production of yeast extract

Liquefaction is carried out by either autolysis (careful application of heat), plasmolysis (rapidly instituting autolysis) or hydrolysis (action of hydrochloric acid under various conditions). After removal of the cell bodies etc. the DS content of the extract is in the range of 5 to 8 per cent.

Evaporation can be completed either in two processes as shown in the diagram (pre-evaporation and final evaporation) or in one single operation. The alternative to be chosen depends on how the concentrated extract will be used. The gentler way is of course a single passage through a Centri-Therm evaporator. In either case the extract is very sensitive to heat. Methods involving relatively high temperatures may cause precipitation of insoluble matter and development of unpleasant burnt-bitter flavours. The product becomes more and more sensitive to heat as the DS content of the extract increases.

Starch derivatives, glucose and sugar solutions

All starch derivates and sugar solutions are well suited to treatment by the Centri-Therm evaporator. They are usually very viscous and very sensitive to heat treatment. The colour, especially for clear solutions, changes very quickly at increased temperatures. It is therefore important to treat these products with the shortest possible retention time. For a high concentration ratio, better economy and high capacity the Centri-Therm is combined with the expanding-flow machine in one or more effects.

Diagram F presents a principal process diagram for starch conversion, carried out either with maize or from potatoes. This scheme gives only a rough explanation of the process; modifications may be needed if the raw material is maize starch or potato starch. Alterations may also depend upon which final product is required.

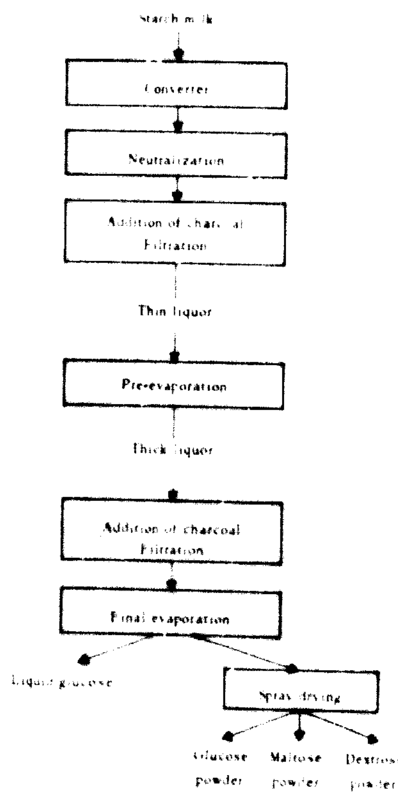

Diagram E. A principal process for starch conversion using maize or potatoes

The concentration of the thin liquor depends on which conversion system is used. Variations are within the range 30-43°Brix corresponding to starch-milk concentrations of 16-23° Baumé prior to the converter. Pre-evaporation increases the concentration to around 60°Brix. This evaporator may be of the expanding flow type and, in order to lower the steam cost, multiple-stage evaporation may be used.

The final evaporation is carried out in a Centri-Therm evaporator and produces a glucose concentration of 80-83% DS according to need. It is especially important to operate this stage at the lowest possible heat to avoid deterioration. The colour of the product is very sensitive to heat, but it has been proved that the colour does not change at all during the passage through the Centri-Therm evaporator.

Another possibility is to complete both evaporation cycles in one evaporation plant. If this is done in a two-stage Centri-Therm plant, concentrating from 43-82°Brix is so gentle that the intermediate decolorization process can be excluded, thus permitting savings in labour and charcoal costs.

Sugar solutions are usually easy to concentrate to a high DS content. Among the reasons for these good results are that these solutions form no deposits on the heating surfaces, as in most cases they are clear, they do not foam and their viscosity is not high at increased concentration. In the expanding-flow evaporator the maximum obtainable concentration is 65-70% DS; in the Centri-Therm machine 80-90% may be reached. Sugar concentrators are used in the candy processing and pharmaceutical industries.

It is also possible to use the Centri-Therm in the manufacture of beet sugar. In the traditional process the final cooking is carried out in a tubular evaporator called a "pan" in which concentration and crystallization are simultaneous, resulting in a rather long holding time and superheating of the sugar crystals. Furthermore, after the crystals have been formed they are submitted to a decreasing temperature in the tubes of the pan. The crystals are therefore partly dissolved, and during this process cavities in the crystals are filled with the fresh, contaminated thick liquor. When the crystals grow again these cavities still contain foreign matter that lowers the quality of the final product. In a modified process the thick liquor is first concentrated to 82-83% in a Centri-Therm and the concentrate is then crystallized by means of chilling in a separate vessel. This yields a final product of much higher quality.

Coffee and tea extracts

Every coffee concentrate manufacturer uses its own extraction process; thus the concentrations preferred for feed and concentrate by different processers vary also. In the coffee-concentrate industry firms are reluctant to give information about their processes. Consequently, even if many concentration plants are in operation in this industry, the manufacturer of the evaporators can know very little about concentration ratios and the like.

The Centri-Therm is especially suitable for coffee extraction because of the short in-plant holding time that it makes possible. Recent years have seen an increasing demand for coffee extract evaporation because of the larger market for coffee powder of the instant type. Freeze-drying is becoming ever more common, but this process is expensive, thus any water that is removed beforehand is a gain. Here the Centri-Therm offers an excellent solution and increases the capacity of the drying plant as well as reducing the operating costs. Moreover, this is done without adverse effect on the high quality of the product of the freeze-drying process. No other type of evaporator is sufficiently rapid and gentle to pretreat the concentrate for freeze-drying without loss in quality of the final product.

Evaporation also forms an essential part of instant tea processing. The extract is concentrated up to 35-40% DS or even higher. Precipitation may occur due to "creaming", but this effect can normally be overcome by adjustment of the evaporation temperatures. As in coffee processing, the producers of tea concentrates are unwilling to disclose any technical data.

Thickeners, glue, pectin

This heading includes many different products of which only a selected few are dealt with here. All of these products are characterized by the facts that they have a very high viscosity even at low concentration and that they are very sensitive to heat, since their protein content is high. After concentration, drying completes the production process. It is therefore most economical to reach as high a concentration as possible before drying. Viscosity drops with increase in temperature and, if the holding time can be kept short enough, a relatively high evaporation temperature can be accepted. A good approach to the concentration of most of these products is therefore a relatively high evaporation temperature and a low temperature difference.

Gelatine is made from hides (of first-class quality) or of bones. After extraction the usual maximum dry substance content is 6% DS. To reduce drying costs, evaporation should be carried out to as high a concentration as possible.

The quality of gelatine is defined in terms of viscosity at a certain temperature and measured according to a special method. The viscosity is measured in degrees Bloom. Gelatine is most sensitive to heat, and the deterioration is observed in loss of viscosity, which means a lower value in the Bloom scale.

Pre-evaporation normally involves some minor problems. For example, flow speed must be kept high to maintain sufficient wetting of the heating surface. Capacity is relatively low as calculated in the amount of evaporation per square meter of heating surface. Maximum concentration after pre-evaporation is about 10% DS.

Final evaporation is completed in a Centri-Therm plant. Quality losses from this type of evaporation are very low; the viscosity value in the Bloom scale decreases only about 5 per cent. Maximum obtainable concentration depends on the viscosity, that is, the quality and Bloom-value of the gelatine fed into the plant. For first-quality products such as those for use in the photographic industry, a maximum of 30-35% DS can be reached. Comparing this to conventional evaporation systems such as the forced circulation machine, a considerable gain in quality and drying costs is obtainable.

Evaporation of glue involves about the same problems as for gelatin. However, the viscosity of glue at a given concentration is much lower than for gelatin, and this of course means that a higher final concentration may be reached. Quality and viscosity deterioration are also of less importance than for gelatin. Pre-evaporation may be carried out in an expanding-flow plant and final evaporation in a forced-circulation plate evaporator or in a Centri-Therm device. Concentrations of 50-55% DS are obtainable.

The major value of seaweeds lies in their relatively large content of easily accessible, strongly hydrophilic colloidal polysaccharides such as agar, algin and carragheenin. These hydrocolloids can be used in aqueous systems as thickeners, gelling agents, emulsion stabilizers, suspending agents, emollients, demulcents and for less easily defined functions covered by the general term "stabilizer".

Seaweed extracts are very viscous and must be diluted with water to facilitate handling. This water must later be removed. For this purpose the expanding-flow evaporator is recommended. It is important that a high flow speed be maintained on the heating surface. Recommendations regarding concentration ratio cannot be given here as the composition of these products varies from one manufacturer to another.

Pectin factories very often combine processes for producing apple-juice concentrate during the season. During off-season, machinery and operators are used for the production of pectin. It must be remembered, however, that the evaporator capacity is much lower when treating a pectin solution than when treating apple juice. Normally, only about one third of the water-evaporation capacity for apples may be calculated for pectin. This figure is approximate, degrees of concentration etc. are of course the determining factors.

The optimum throughput for pectin production requires a far larger quantity of raw material than for apple juice. Consequently, if the plant is to be fully utilized, fruit must be obtained from other apple-juice processors as well as from the producer's own sources.

Pectin is extracted at a reduced pH. Factors such as the type of acid, time, temperature and pH value are of importance to the quality of the pectin produced and also affect the evaporation process.

The concentration of pectin is normally calculated in pectin units or grades. The grade of pectin may be defined as the number of grams of sucrose that one gram of pectin can jellify in a standard jelly that contains 65 per cent soluble solids.

The normal evaporation process is carried out by means of a two-stage plant. (The use of three effects lowers the temperature in the third effect so much that the viscosity becomes too high.) In both effects a high degree of forced circulation is maintained. Expanding-flow or forced-circulation plate evaporators may be used. A higher concentration can be reached in the latter alternative, and it is also possible to combine the expanding-flow device as pre-evaporator and the forced-circulation plate evaporator as finisher. The maximum obtainable concentration is about 5 pectin units.

APPLICATIONS IN THE PHARMACEUTICAL INDUSTRY

The field of pharmaceuticals is so wide and includes products of so many different kinds that it is impossible to cover it in the limited space available here. The classification that follows is therefore both incomplete and unsystematic; only a few examples can be given.

Most of the pharmaceutical products are heat sensitive, often to such a degree that even a fast-acting evaporator must be operated at a very low temperature. Therefore this field is likely to be that in which most Centri-Therm plants will find use.

Gentleness of treatment is not the sole consideration. This type of industry also works frequently with small batches of very expensive products. Minimum holding volume in the plant is then of importance, and evaporation should be completed without any losses; the evaporator should be able to be emptied completely. When small batch sizes are frequent, in many cases the laboratory size Centri-Therm may be used in production.

Antibiotics

Since the First World War many substances have been discovered that act as selective bactericides. Notable among these agents are the sulphonamides and the antibiotics. Evaporation is involved in the manufacturing of most of these substances. Only one example, that of the antibiotic streptomycin, is given here.

Streptomycin is grown in a liquid culture medium. After filtering (for example in a rotating vacuum filter) the pH of the filtrate is adjusted. The streptomycin is recovered in large ion-exchange columns which are eluted by means of hydrochloric acid. The eluate consists of streptomycin in a clear water solution. The viscosity is low, and the concentration may be around 50,000 streptomycin units per cubic centimetre. The solution is evaporated at low temperature to about fourfold concentration. After precipitation and filtering a second evaporation is carried out, possibly after the addition of a solvent in order to decrease the water content further. Final precipitation and crystallization are performed and the product is then dried under vacuum.

Both concentration processes are fulfilled in the Centri-Therm evaporator. Evaporation temperature is kept below 40°C. Among the advantages of this evaporation process over earlier ones are: continuous operation, higher yield and better colour (less deterioration).

Hormones

Several substances in this group such as adrenalin, thyroxin and insulin require evaporation in their manufacturing. As an example, the method of insulin processing is given below.

Insulin, a hormone produced in the pancreas, is specific in the treatment of diabetes. Frozen pancreas glands of the ox or pig are minced and their insulin content is extracted with hydrochloric acid and alcohol. This extract is then filtered and stored (at various stages of the process) and adjusted. The water and alcohol are removed from the extract by evaporation in a Centri-Therm device, and the resulting concentrate is re-filtered and stored. The insulin is finally removed by precipitation. Some processors require as low an alcohol percentage as possible after evaporation, while others permit a higher percentage, and remove the alcohol after crystallization. The fat content of the extract affects the maximum alcohol percentage that can be attained.

Enzymes

Several Centri-Therm plants are presently being used in the preparation of various enzymes. Unfortunately, however, very little knowledge is available about these processes.

Dextran

Dextran is a fermentation product of sugar and molasses. It is extracted by means of alcohol that must be removed afterwards. This is done when the dextran solution is being concentrated prior to spray drying. Pre-evaporation takes place in an expanding-flow plant which is balanced so that the distillate has a suitable alcohol/water composition for re-use in the extraction process. The alcohol/yield in this stage is of great importance for the economy in the complete process. Final evaporation is carried out in a Centri-Therm evaporator.

PRE-INVESTMENT DATA

Some of the economic factors that should be taken into consideration prior to the installation of an evaporation plant are discussed below. In order to make the calculations more realistic, two examples have been chosen and actual figures are given. Equipment prices are approximate export prices from Sweden. All prices and costs are referred to in Swedish currency. While conditions and cost prices vary considerably from one country to another, and any exemplified condition may not hold true for all readers, the figures given below make it possible to calculate the actual costs taking local circumstances into consideration.

Flow diagrams

The two examples selected are both fruit-juice evaporation plants. Alternative A is a low-capacity plant that comprises an aroma-recovery unit, a Centri-Therm CT6 evaporator and a flash cooler; alternative B is a large-capacity plant that comprises an aroma-recovery unit, a two-stage expanding-flow evaporator, a thermo-compressor, a Centri-Therm evaporator and a flash cooler. These two alternative plants are diagrammed in figure 23 and compared below.

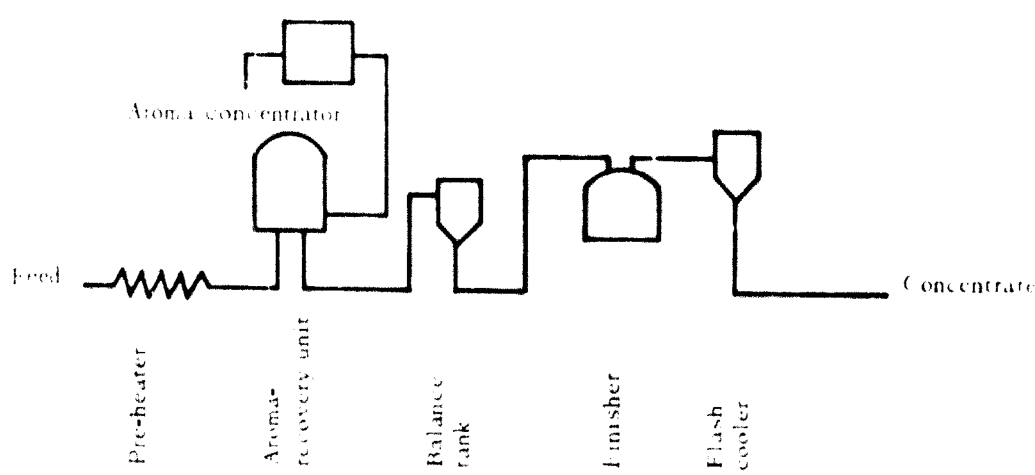

Figure 23. Flow chart for one of two alternative fruit-juice evaporation plants: Alternative A

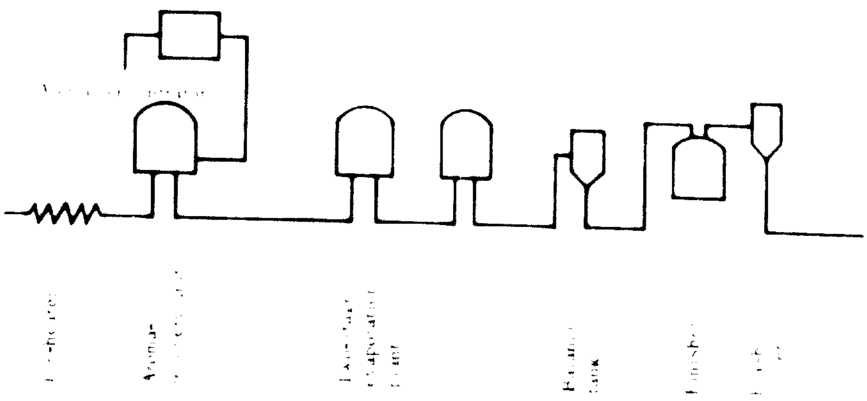

Figure 23. Flow chart for one of two alternative fruit-juice evaporation plants Alternative B

Capacities

Alternative	*A*	*B*
Feed (kg/h)	1,050	7,000
Feed concentration (%DS)	11	11
Concentrate (kg/h)	165	1100
Concentrate (%DS)	70	70
Aroma concentrate (kg/h)	10.5	70
Aroma concentrate, concentration	1:100	1:100

Technical data

Alternative	*A*	*B*
Feed temperature (°C)	20	20
Evaporation temperature, aroma recovery unit (°C)	100	100
Evaporation temperature, pre-evaporator		
stage I (°C)	–	70
stage II (°C)	–	49
Evaporation temperature, finisher (°C)	50	53
Concentrate temperature after flash cooler (°C)	20	20

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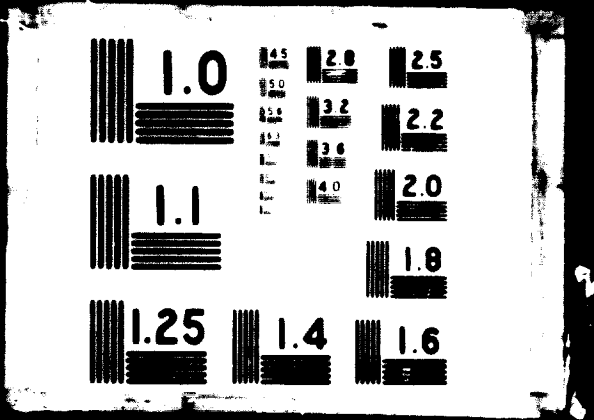


Steam, cooling water and electricity requirements

Alternative	*A*	*B*
Steam:		
pre-heater to aroma-recovery unit (kg/h)	20	130
aroma-recovery unit (kg/h)	130	840
pre-heater (kg/h)		60
pre-evaporator (kg/h)		1,645
finishing evaporator (kg/h)	850	550
flash cooler (kg/h)	30	230
total steam consumption (kg/h)	1,030	3,455

Steam pressure for thermo-compressor of pre-evaporator and flash cooler, 10 kg/cm^2, for other items 3 kg/cm^2.

Alternative	*A*	*B*
Cooling water (20°C):		
aroma-recovery unit (m^3/h)	1.8	11.5
pre-evaporator (m^3/h)		34.5
finisher (m^3/h)	16.5	15
additional cooling water etc. (m^3/h)	0.7	1.5
total water consumption (m^3/h)	19.0	62.5
Ice-water (2°C):		
aroma-recovery unit (kcal/h)	300	1,800
Electricity, effect installed (kWh):	11.8	25.6
average consumption	8	18

Working capital (in Swedish Kronor = S. KR)

The plants are built as plug-in units and are pre-erected at the factory. This means minimum on-site installation costs. However, the installation costs, shown below, hold true only when the locality is sufficiently prepared and steam and water piping are close to the place where the evaporator is to be situated.

Alternative	*A*	*B*
Equipment price from manufacturer (S. KR)	195,000	440,000
Installation costs (S. KR)	5,000-10,000	10,000-20,000

Processing costs (in Swedish Kronor)

Capital and maintenance costs

Presumptions:	15-year amortization interest 8 per cent maintenance 6 per cent	
Alternative	*A*	*B*
Capital costs per year (S. KR)	28,300	63,600

Steam, water and electricity per year (1,400 production hours)

Presumptions:	steam cost	S. KR 17:–/ton
	water cost	S. KR 0.10/m³
	electricity	S. KR 0.07/kWh

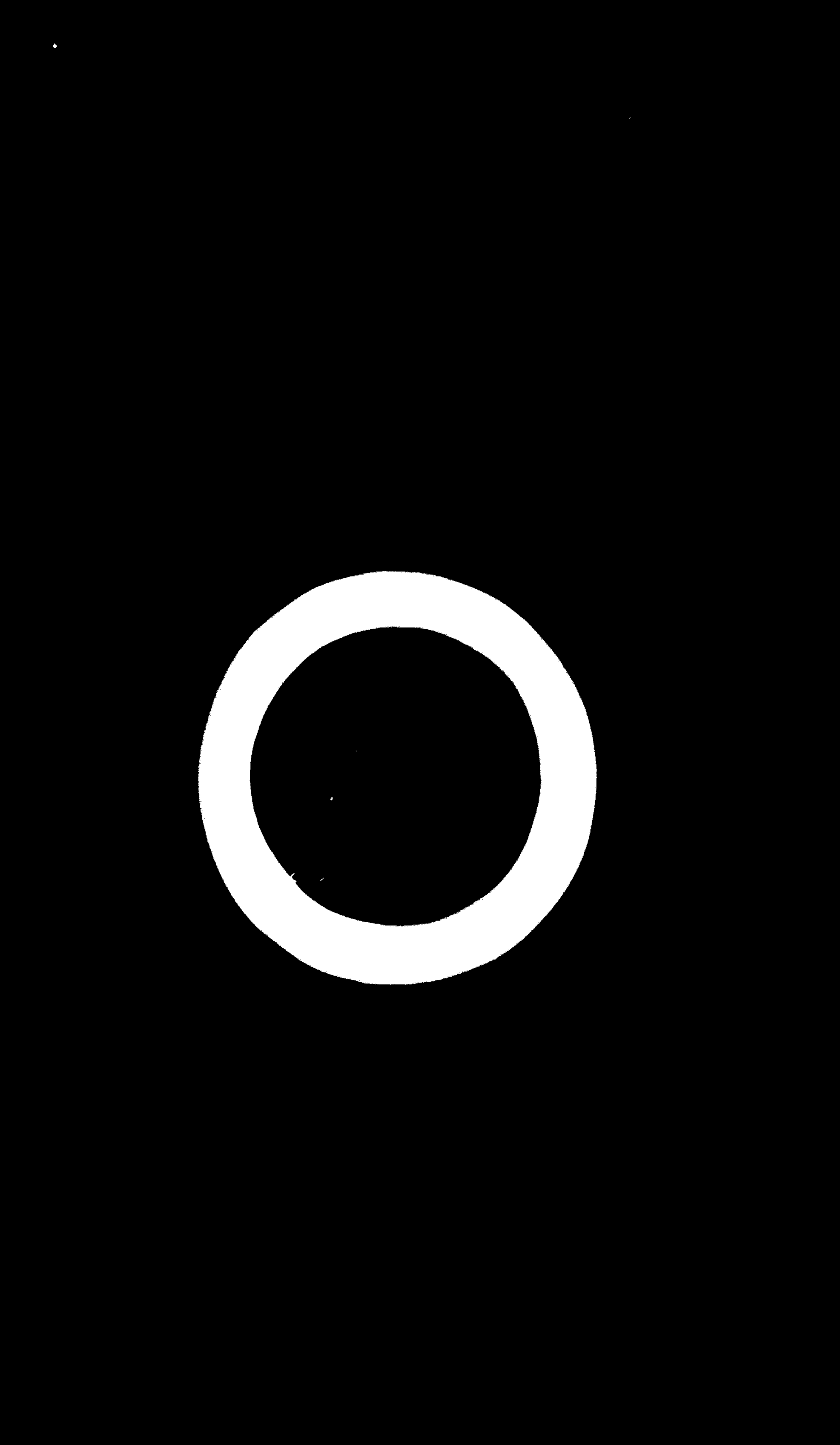
Alternative	*A*	*B*
Steam costs	24,510	82,230
Water costs	2,660	8,750
Electricity costs	780	1,760
Total	27,950	92,740

Staff

One skilled man can operate either plant. This labour cost varies within wide limits; only as an example, the yearly cost in Sweden would be S. KR 25,000, including taxes and costs for social benefits.

Total costs (in Swedish Kronor)

Alternative	*A*	*B*
Capital and maintenance costs	28,270	63,600
Steam, water and electricity costs	27,950	92,740
Staff costs	25,000	25,000
Total yearly cost	81,220	181,340
Total cost per hour	58.01	129.53
Total cost per kilogram of concentrate	0.33	0.11



SOME DEFINITIONS

Evaporation is a process for the concentration of a solution by means of boiling away the solvent, which is often just water. In evaporation the valuable component is the concentrated liquid that remains after the solvent has been boiled away.

Distillation is an evaporation process in which the condensed vapour contains the valuable product.

Rectification means that the condensed vapour from the distillation process (called the distillate) is again distilled. By repeating this process several times the final distillate will have a very high percentage content of the light solvent. Repeated distillation may be performed in the same unit or column.

Stripping means a complete as possible removal of an unwanted component from a solution. Usually this component has a low content of water or a solvent.

Degree of evaporation may be defined in terms of the concentration ratio, or, to put it another way, the ratio of feed to concentrate quantity.

Formulas:

Feed $$F = C + E = \frac{e}{e-1} \cdot E = e \cdot C$$

Concentrate $$C = F - E = \frac{1}{e} \cdot F = \frac{1}{e-1} \cdot E$$

Evaporation $$E = F - C = \frac{e-1}{e} \cdot F = (e-1) \cdot C$$

e represents concentration ratio (evaporation ratio).

Dry substance content (DS) is the amount of dissolved substance in a solution. This amount can be determined by the careful drying and weighing of a sample. For many solutions there is a known correlation between the percentage of dry substance content (% DS) and the density; this means that the density can be measured by means of an aerometer and then the percentage of dry substance (% DS) can be read in a table. Another method is to determne the refractometer mdex and from a table obtain the % DS. Other density scales also exist: e.g. °Baume and °Brix.

Single-stage evaporation. Live steam is applied to the heating surface of the evaporator. The vapour leaving the evaporator is condensed in a separate condenser either a mixing condenser or a surface condenser. In the former the vapours are mixed with the cooling water: in the latter the vapours are brought to a water-cooled surface for condensation.

Multiple-stage evaporation. Two or more evaporators may be arranged in series. In the first, the liquid boils at higher absolute pressure and temperature than in the second. The vapour from the first evaporator heats the second. This is double-stage evaporation, and in this way 2 kg of vapour can be boiled off from liquid by the use of only 1 kg of steam. Three or more evaporators may be used in series in the same way.

Thermo-compression. A thermo-compressor is a steam-jet ejector, in which the heat of high-pressure steam is converted into kinetic energy that draws off the vapour and recompresses the mixture to a pressure higher than that of the vapour, The diagram shows a single-stage evaporator with a thermo-compressor.

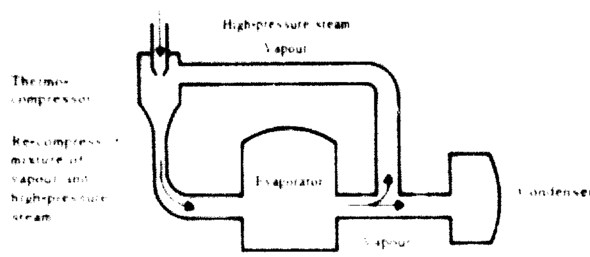


Diagram. Single-stage evaporator with single compressor

Heat economy. The normal temperature difference between heating steam and vapour in a stage of a liquid food pre-evaporator is 12-15°C. If a thermo-compressor is applied to such an evaporator stage about 1 kg of high-pressure steam can compress 1 kg of vapour and thus form 2 kg of compressed vapour. If the temperature difference is higher more steam is needed to compress 1 kg of vapour, and vice versa. At the temperature difference mentioned (12-15°C) this means that evaporation of 1 kg of water requires only 0.5 kg of steam. This represents a saving of 50 per cent, as compared to a single-stage plant without a thermo-compressor. In a two-stage plant the saving is 33 per cent, and in a three-stage plant it is 25 per cent. The above-mentioned figures are approximate; real figures are slightly lower because of heat losses etc. For rough calculations the figures in the table may be used.

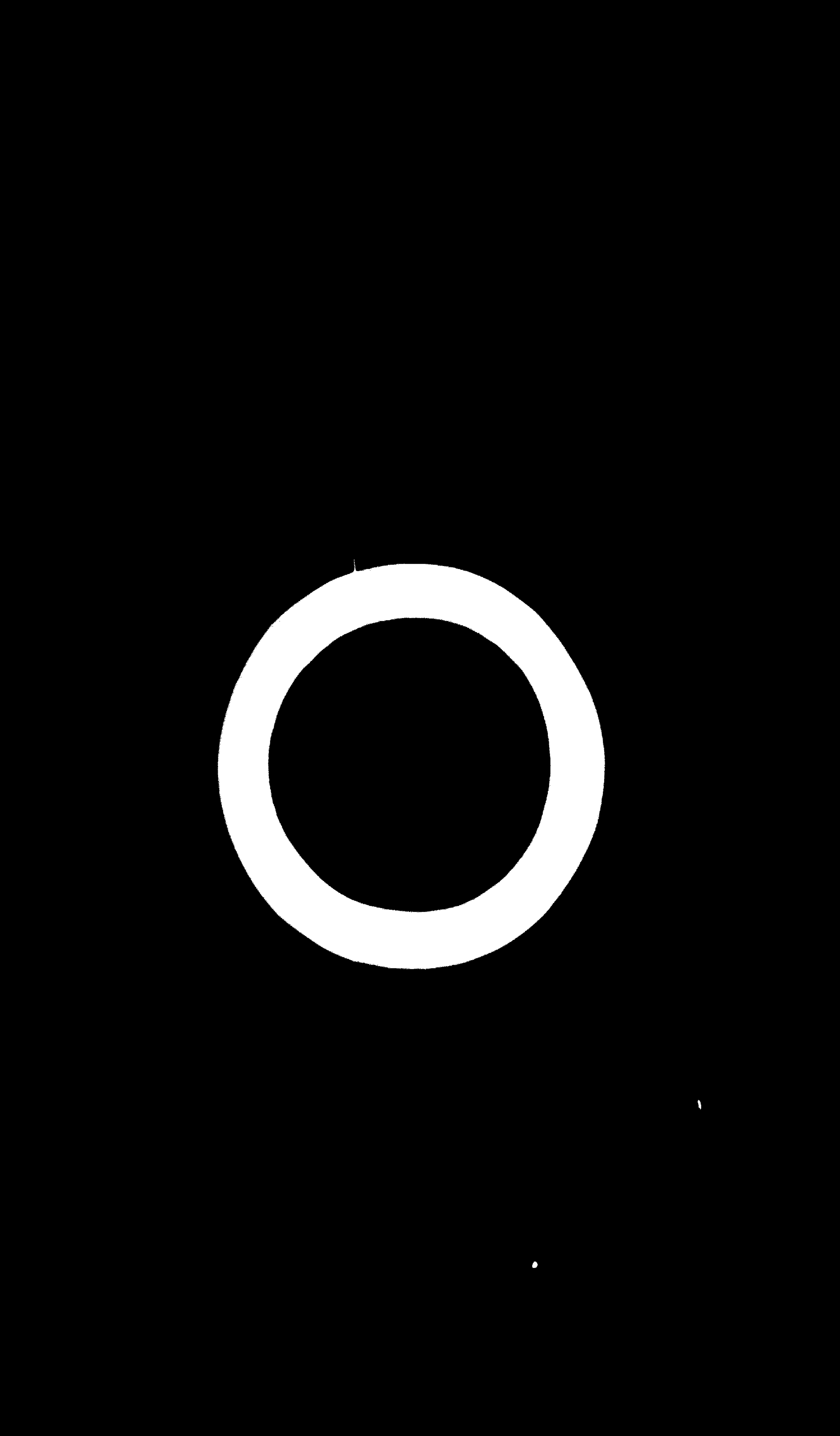
Heat economy of different evaporation plants

Type of plant	*Amount of steam needed to evaporate one Kilogram of water* (kg)
Single-stage, without thermo-compressor	About 0.6
Single-stage, with thermo-compressor	About 0.6
Double-stage, without thermo-compressor	0.3-0.4
Double-stage, with thermo-compressor	0.3-0.4
Triple-stage, without thermo-compressor	0.3-0.4
Triple-stage, with thermo-compressor	0.25-0.3

In the condensers of either the surface or the mixing type the full amount of vapour must be condensed by means of cooling water. Multiple-stage evaporation therefore also requires less cooling water than does single-stage operation. Consequently, thermo-compression lowers the cooling water demand still further.

Heating surface. This is the internal metal surface in the evaporator; steam is condensed on one side and the heat formed is transferred through the metal wall to the other side where the liquid to be evaporated flows. The heat passes into this liquid, and in most cases part of the liquid is immediately vaporized. However, in the case of forced circulation, the liquid pressure is such that no boiling takes place. In this case the liquid temperature is increased and evaporation takes place in a separate vessel. Heating surfaces may be of different shapes in different types of evaporator designs. Tubes, cylinders, cones and plates can be mentioned.

Boiling point elevation. The temperature of the boiling liquid and that of the vapour are the same. If a dissolved substance is present in the liquid, the boiling point of the solution is slightly increased and correspondingly the vapours formed are superheated to a degree equal to that of the elevation of the boiling point. This results in a correspondingly smaller temperature difference over the heating surface. This elevation of the boiling point is proportional to the concentration, molecular weight and degree of dissociation of the dissolved substance. Usually the elevation is so slight that it can be ignored in technical calculations. Only when very highly concentrated solutions or strongly dissociated molecules such as sodium hydroxide (NaOH) are concerned should the elevation of the boiling point be noted.



FOOD INDUSTRY STUDIES

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ID/SER.I/1 The use of centri therm, expanding-flow and forced-circulation plate evaporators in the food and biochemical industries
by Bengt Halström, Alfa-Laval AB, Sweden

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