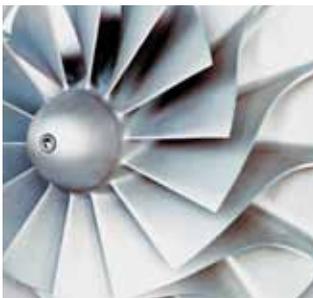


Evaporation technology using mechanical vapor recompression

Technology and applications



Evaporation technology using mechanical vapour recompression



Thermal separation processes such as evaporation and distillation are energy intensive. In the course of their development, the aim of efficiently using this energy and of reducing costs first led to single-effect plants heated by live steam, then to multiple-effect plants, then to thermal vapour recompression, and finally, to the use of mechanical vapour recompression systems.

In conventional evaporators, the energy content of the vapour stream produced is lost to a large extent or is only partially used. In comparison, mechanical vapour recompression permits the continuous recycling of this energy stream by recompressing the vapour to a higher pressure and therefore, a higher energy content. Instead of live steam, electric energy is used indirectly to heat the plant.

Mechanical vapour recompression reduces the energy costs and the CO₂ footprint and, consequently the environmental load.

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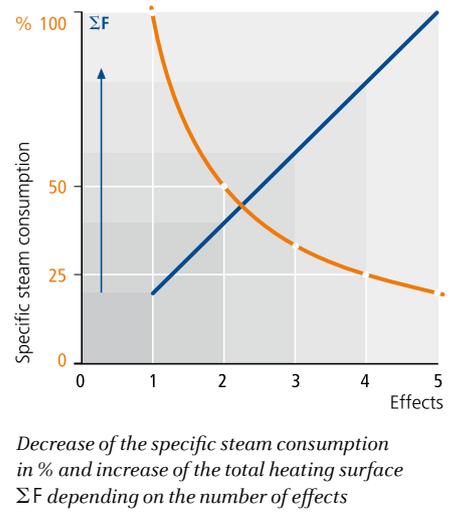
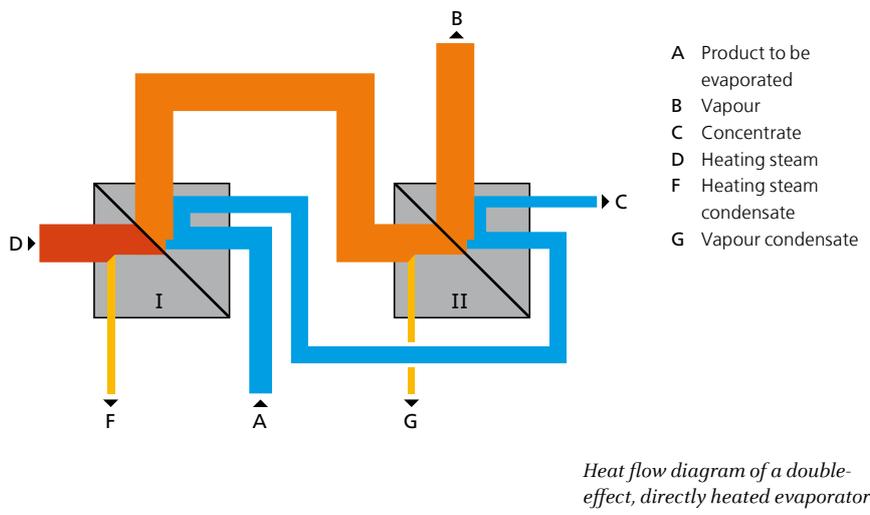
Processes designed to save energy in evaporation plants

When evaporating fluids, heat is transferred to the fluid to be evaporated. In industrial-scale applications, this process indirectly takes place via an evaporator that is used as a heat exchanger. This heat is used to heat the fluid and finally to evaporate the solvent (in most cases water).

In this way, the concentration of the non-volatile substances in the fluid is increased. The evaporated solvent is referred to as vapour. Thus, the produced vapour contains approximately the same thermal energy as the used heating steam, however, at a lower pressure and temperature level. During condensation, this thermal energy has to be dissipated again.

Different heat carriers can be used to heat the evaporator. Apart from hot water or thermo-oil, water steam is used in most of the cases which condenses on the heating side of the evaporator and which dissipates its condensation heat on the evaporation side.

Multiple-effect arrangement



The heat flow of a single-effect evaporator shows that the thermal energy included in the vapour (enthalpy) must be about the same as that of the thermal input on the heating side. For the normal case of water evaporation, you can produce 1 kg/h of vapour with 1 kg/h of live steam since the specific evaporation heat is about the same on the product side as on the heating side.

By using the vapour produced as heating steam in a second effect, the energy requirement of the overall system will nearly halve. This principle can be continued over several effects in order to further improve the energy saving.

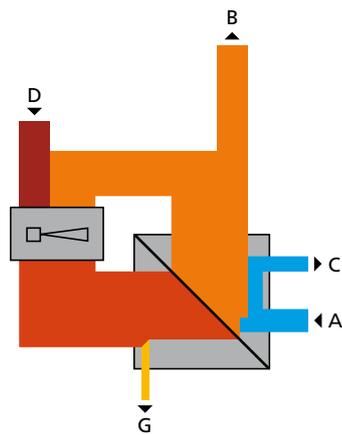
The max. permissible heating temperature of the first effect and the lowest boiling temperature of the last effect result

in a total temperature difference which can be distributed to the individual effects. The total heating surface to be used for all effects thus increases proportionally with the number of effects so that investment costs increase whereas energy saving decreases.

Processes designed to save energy in evaporation plants

Thermal vapour recompression

- A Product to be evaporated
- B Vapour
- C Concentrate
- D Heating/motive steam
- G Vapour condensate



Heat flow diagram of an evaporator with steam jet vapour recompression



Three-effect falling film forced circulation evaporation plant with thermal vapour recompressor for waste water from monosodium glutamate production. Evaporation rate: 50 t/h

In thermal vapour recompression, motive steam is used to compress part of the vapour produced in an evaporation effect from a lower evaporation pressure and temperature level to the heating pressure of the first evaporation effect.

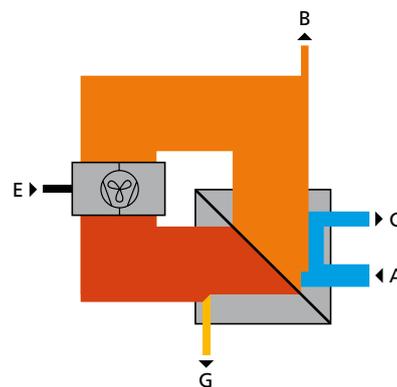
In this way, the heat energy included in this first effect can be used again for heating. The required heating steam will reduce to the motive steam quantity. For this purpose, steam jet vapour recompressors are used (thermo-compressors). They have no moving parts, ensuring a simple and effective design that provides the highest possible operational

reliability. The use of a thermal vapour recompressor has the same steam/energy saving effect as an additional evaporation effect. However, the steam jet vapour recompressor is incomparably more cost-effective.

Mechanical vapour recompression



Mechanical vapour recompressor (centrifugal fan) of a single-effect falling film evaporation plant in food production



- A Product to be evaporated
- B Vapour
- C Concentrate
- E Electrical energy
- G Vapour condensate

Heat flow diagram of an evaporator with mechanical vapour recompressor

Using mechanical vapour recompression, a mechanically operated compressor recompresses practically the complete vapour of an evaporation effect from a lower evaporation pressure and temperature level to the heating pressure of the same evaporation effect. In this way, its heat energy is re-used for heating and does not have to be condensed without being used.

Contrary to thermal vapour recompression, no motive steam is required, and practically only the drive energy which in most cases is electrical and which is necessary for the mechanical recompressor, will be required. The costs for energy requirements often are considerably lower than for thermally heated plants. A low additional thermal energy is needed to balance the overall heat requirement and to start-up the plant.

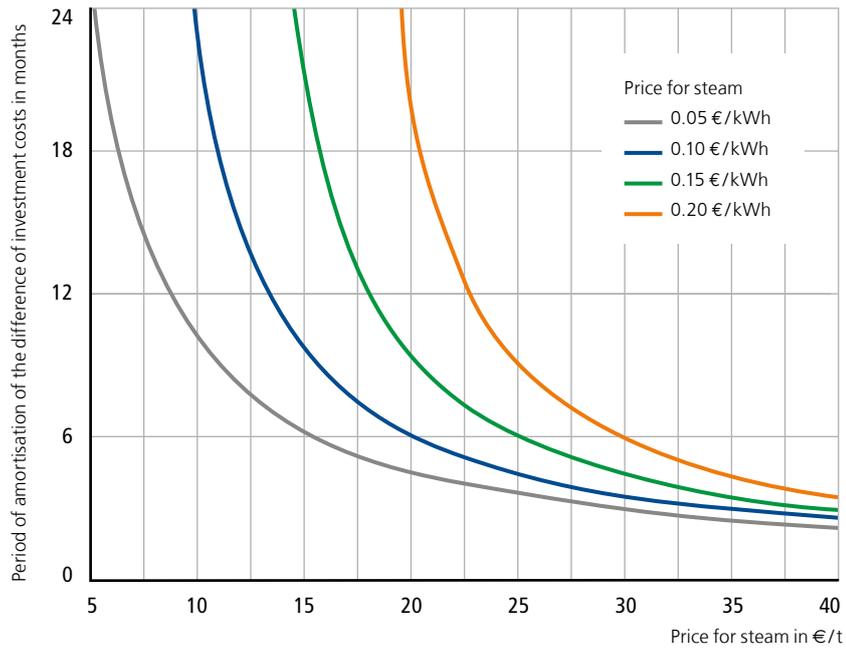
In thermally heated plants, more or less all of the heating and/or motive steam energy has to be dissipated in the condenser to cooling water. In mechanically heated plants only a small portion has to

be dissipated. This considerably reduces the energy requirement and also the residual heat to be dissipated.

The required power input of the mechanical vapour recompressor is nearly proportional to the pressure and temperature difference that has to be overcome so that it directly depends on the installed heat exchanger surface. With increasing surface, the required power input will decrease. Pressure drops and, in particular a potential product-specific boiling point increase determine the compressor capacity to be installed and thus the specific energy requirement of an evaporation plant.

Processes designed to save energy in evaporation plants

Mechanical vapour recompression – an investment that pays off



Period of amortisation of the difference in investment cost of two plant types, depending on the prices for energy.

In many cases, the investment costs of an evaporation plant with mechanical vapour recompression are somewhat higher than for a comparable thermally heated plant. This difference, however, is amortised in a relatively short term thanks to the low energy costs during operation.

The diagram above shows an example for the period in which this investment cost difference can be amortised depending on the price for steam and electrical power. The representation is based on an evaporation plant for an evaporation capacity of 20 t/h for a product with moderate boiling point elevation of 3.5 K and a boiling temperature of 90°C. The comparison shows a four-effect



Single-effect falling film evaporation plant with mechanical vapour recompression for wheat starch effluent, evaporation rate: 17,000 kg/h

falling film evaporation plant with thermal vapour recompression and a single-effect falling film evaporator with an individual vapour recompressor (centrifugal fan). The investment costs only include the evaporation plant, without any additional expenditures required for civil works, for example for buildings and infrastructure.

Types of construction of mechanical vapour recompressors

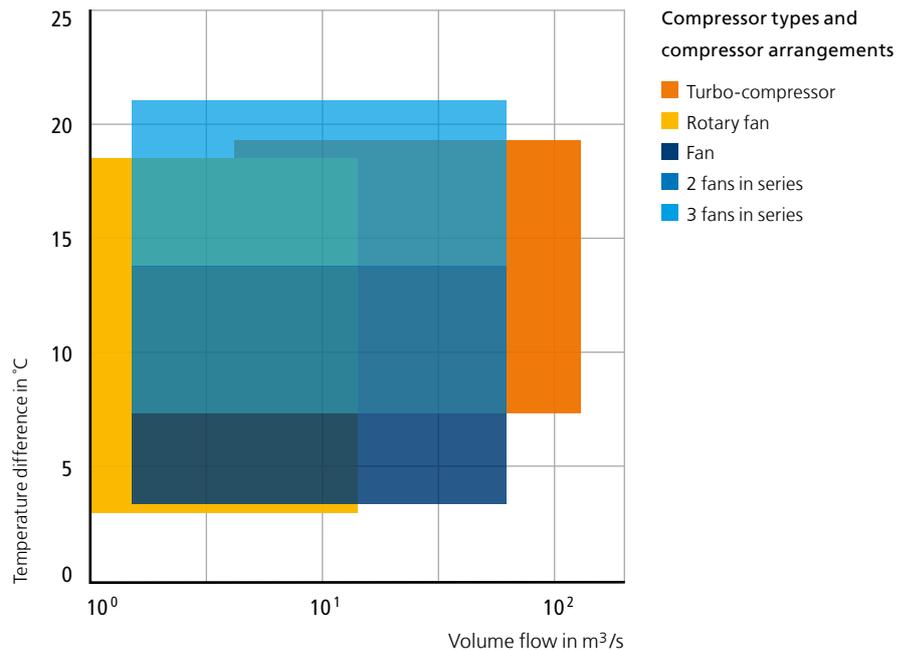
Centrifugal fans, centrifugal compressors, rotary blowers

A temperature difference on the heating surface is required to heat an evaporation plant. This means that temperature and pressure of the heating steam are higher than boiling temperature and pressure of the product to be evaporated. In plants with mechanical vapour recompression, this temperature difference is achieved by compressing the evaporated vapour in a corresponding recompressor.

In principle, all common compressor types are suitable as mechanical vapour recompressor, i. e. any machine operating according to the principle of positive displacement and dynamically operating continuous-flow machines. In evaporation plants, however, the following three types are actually used:

- Centrifugal fans
- Centrifugal (turbo) compressors
- Rotary (roots) blowers

For medium and high capacities, the centrifugal fan is the most commonly used type. Today, two or more fans arranged



Applications of compressor types and arrangements depending on temperature difference and volume flow

in series are preferred to the turbo-compressors which, however, still can be found in special applications. The field of application of rotary blowers is restricted to small evaporation rates.

The respective application with its operating conditions determines which compressor type is suitable. The required pressure increase and the volume flow of

the vapour to be compressed are decisive parameters. The pressure ratio between outlet pressure and suction pressure is referred to as the compression ratio. The saturated steam temperature difference results from the pressure ratio.

Types of construction of mechanical vapour recompressors

Centrifugal fans

Centrifugal fans are continuous-flow machines consisting of a spiral-type housing which accommodates a rotating impeller with radially ending blades or with backward-bent blades.

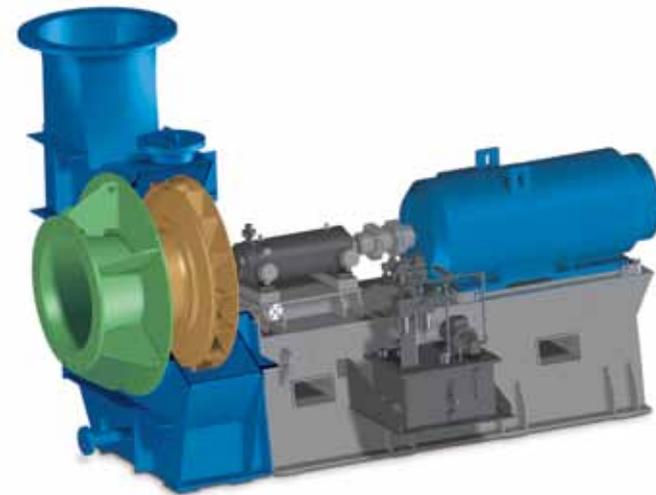
The vapour enters the machine in axial direction through the suction nozzle. In the rotating impeller, the vapour is conveyed radially to the outside. With increasing centrifugal speed and deflection of the flow, energy is transferred to the vapour corresponding to the blade



shape. After having passed the impeller, the vapour is conveyed in the spiral housing to the discharge nozzle where it is discharged from the machine at a higher pressure and temperature level.

In a centrifugal fan, both the housing and the impeller are welded structures. Reinforcement ribs stiffen the housing depending on the relevant design conditions. Fan bearing, coupling with coupling guard and drive motor are accommodated on the base behind the fan housing.

Usually, the speed of centrifugal fans ranges between 2,000 and 5,000 rpm so that the fan shaft is directly coupled with the drive motor. A frequency converter adjusts an operating point differing from synchronous speed. A laterally arranged oil system lubricates the fan bearing. At volume flows from 1 to 140 m³/h, state-of-the-art high-performance fans achieve compression ratios from 1.2 to 1.4.

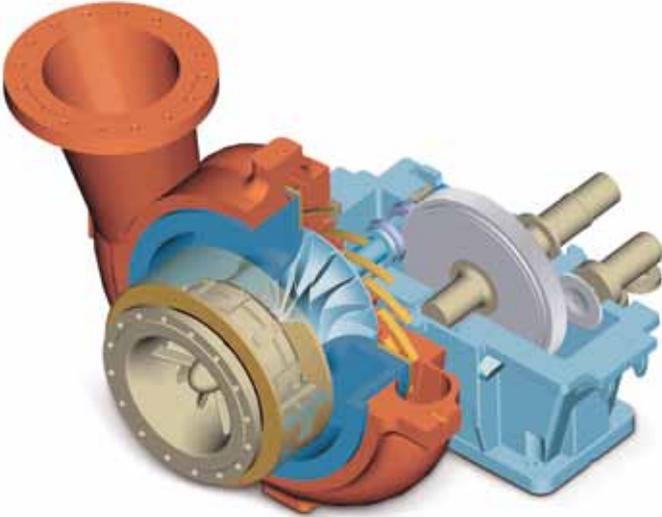


Centrifugal fan (Source: Piller)

Centrifugal (turbo) compressor

Centrifugal compressors are also continuous-flow machines in radial construction with an energy transfer comparable to that of a centrifugal fan. Centrifugal compressors also consist of a spiral-type housing with axial suction nozzle, accommodating a rotating, usually semi-open impeller.

The speed of these machines, however, is considerably higher and ranges between 12,000 and 18,000 rpm so that a gearbox is needed between the fan shaft and the motor.



Centrifugal compressor (Source: Atlas Copco)



Piston blower (Source: Kaeser)

The high rotating speeds and the resulting centrifugal forces result in special requirements to shape and stability of the impellers which therefore are made of high-quality materials (stainless steel or titanium alloys), in most cases integrally milled from a cast blank. Cast housings are frequently used. The gear ratio of this machine type causes higher requirements to bearing and lubrication system and to machine monitoring. For this machine type, in most cases an adjustable inlet guide vane installed at the suction socket regulates the capacity. At a comparable volume flow range between 1 and 140 m³/s, with a single-stage turbo-compressor a compression ratio of more than 2 can be achieved.

Rotary blower

In a rotary blower, also called roots blower, two, two- or three-blade rotary pistons rotate in opposite directions. In a simple design, a rotary piston has a symmetrical, octagonal shape. Together with the circumferential housing, it builds a so-called conveying chamber in which the vapour is conveyed from the suction side to the pressure side of the machine.

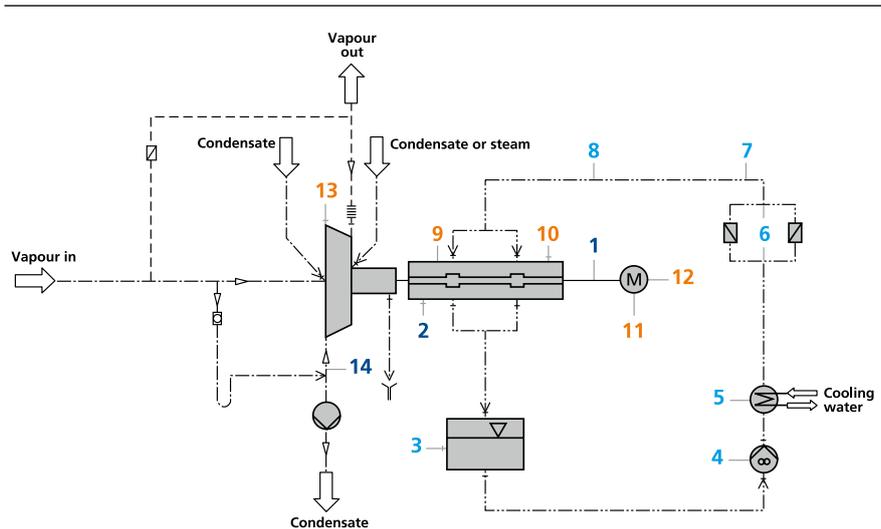
Due to the shape of the rotating pistons, the housing and the relatively tight gaps it is ensured that the conveying chamber follows the rotation and transfers the vapour from the suction to the pressure side and it is suitably sealed to limit leak flows back to the suction side. Since the size of the conveying chamber does not change with the movement, there is no internal sealing in this special positive displacement compressor. The compressor discharges the already compressed vapour. The vapour in the conveying chamber is compressed to counter-pressure only via partial return flow. Since the tight gap has to be maintained and since thermal expansion can cause problems, these machines are limited to applications in smaller performance ranges. Nonetheless, for volume flows of 0.05 to 15 m³/s a compression ratio of up to 2 is possible.

Principles of function and design features

Monitoring and safety equipment

Optimum operation of an evaporation plant requires safe and sufficient heating. In plants with mechanical vapour recompression, the permanently reliable operation of the compressor is vital.

In order to immediately recognize irregularities or beginning wear and tear and in order to prevent mechanical damage, these machines are provided with a number of monitoring and safety devices.



Monitoring and safety devices using the example of a centrifugal fan:

- Impeller speed (1)
- Shaft vibrations (2)
- Bearing temperature (9, 10)
- Housing temperature (13)
- Fluid in the housing (14)
- Oil pump (4)
- Oil level and oil temperature in the tank (3)
- Oil pressure and oil flow (6, 7, 8)
- Oil cooler (5)
- Motor bearing temperature (12)
- Motor winding temperature (11)

Compressor drives

Several types of motors are suitable as drive of a vapour recompressor. The selection of the drive depends on its efficiency and availability of the drive energy in each individual case.

Drives with three-phase current asynchronous motors are the most common used. Their standard sizes and types of protection, their low weight-to-power ratio and volume, min. maintenance requirements and a good price-performance ratio offer remarkable advantages.

In some few cases, direct-current motors and gas motors are used, sometimes, also steam turbines are used.

Three-phase current asynchronous motor

The three-phase current asynchronous motor runs according to the number of its pole pairs at speeds of 3,000, 1,500, 1,000 or 750 rpm – in synchronism with the mains frequency – or – if a frequency converter is used – at infinitely variable speed. A distinction is made between high-voltage and low-voltage motors. The motor capacity in the low-voltage range is up to 630 kW at a mains voltage of 400 V, and up to 1,250 kW at a mains voltage of 690 V. High-voltage motors and converters are suitable up to approx.

6,000 kW. The efficiency level of asynchronous motors is constantly high over a wide load range.



Steam turbine

The use of a speed-controlled steam turbine as drive engine will be recommendable if the produced waste steam is available and can be used.

Regulating the capacity of mechanical vapour recompression systems

There is one fact that applies to all industrial evaporation plants and, for this reason, also to evaporation plants with mechanical vapour recompression: the required evaporation rate of a plant might vary during the operating period. Therefore, the possibility of adjusting the capacity has to be taken into consideration in the design.

Short-term capacity fluctuations are possible, e. g. in cases in which the evaporation plant has to follow fluctuating operating conditions of an upstream process. Long-term operation of the plant at

reduced capacity is another scenario to be taken into account.

In principle, any modification of mass flow, product temperature or other product parameters results in a modification of the so-called plant characteristic and in the requirement to adjust the thermal flow to be transferred in the plant. This can be done by correspondingly adjusting the pressure and/or increase in saturated temperature produced by the compressor.

Regulation conceptions

Apart from an adjusted dimensioning of the plant components, the required variance of the operating points also influences the selection of the optimum regulation design for the vapour recompressor.

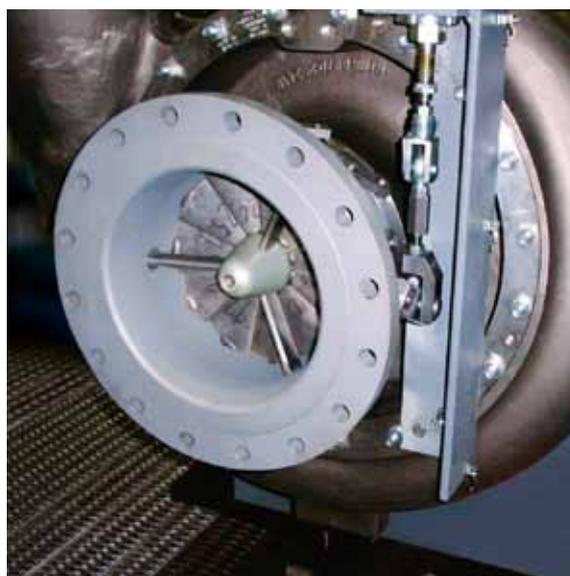
Different regulation mechanisms can be used to influence the compressor curve that indicates the correlation between the conveyed volume flow and the corresponding pressure or increase in saturated steam temperature, in most of the conventional continuous-flow machines. The resulting characteristic diagrams should be optimized to ensure that the designed, different plant operating points can be achieved at best possible efficiency levels.

The most important regulation variants for centrifugal fans and turbo-compressors are:

-
- Speed control
 - Pre-rotation control
 - Suction pressure control
 - Bypass control
-



Frequency converter cabinet



Inlet guide vane

Energy optimization of existing multiple-effect plants by means of mechanical vapour recompression

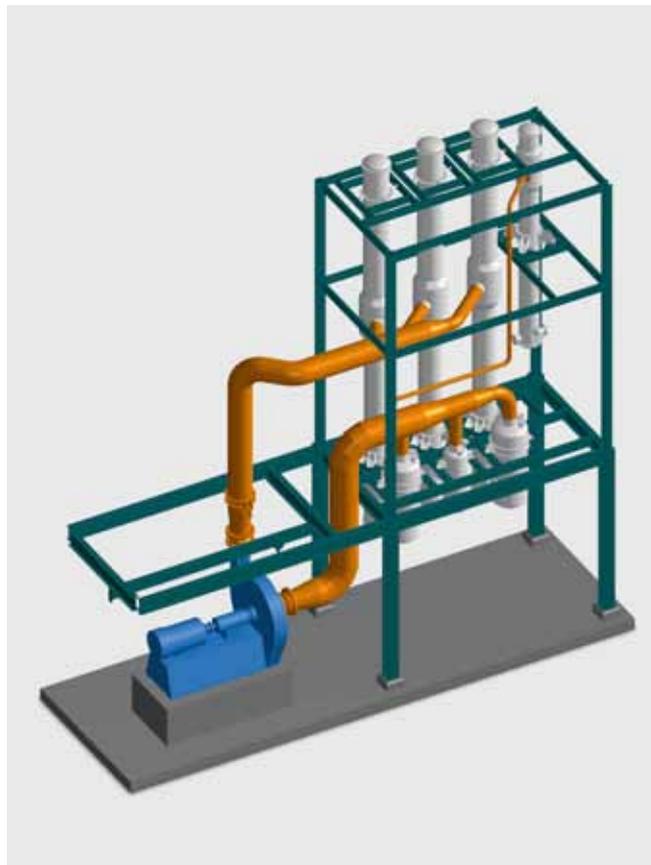
Thousands of multiple-effect evaporation plants have been installed all over the world during the past decades. They were either heated only directly with live steam or were equipped in addition with a thermal vapour recompressor.

Over the years, steam costs increased considerably in most regions. The optimum plant arrangement of the past in many cases is no longer efficient today, compared to state-of-the-art plants heated by means of electrically operated mechanical vapour recompressors. In such a case, the question is how to compensate for this operating cost disadvantage.

Increasing energy costs are to be expected also in the future. An increase of the number of effects to reduce the specific energy requirement often is not feasible. Therefore, a retrofitting to heating by means of mechanical vapour recompression should be evaluated.



Before: Three-effect falling film evaporation plant, directly heated



After: Plant retrofitted to heating by means of mechanical vapour recompression

Retrofitting

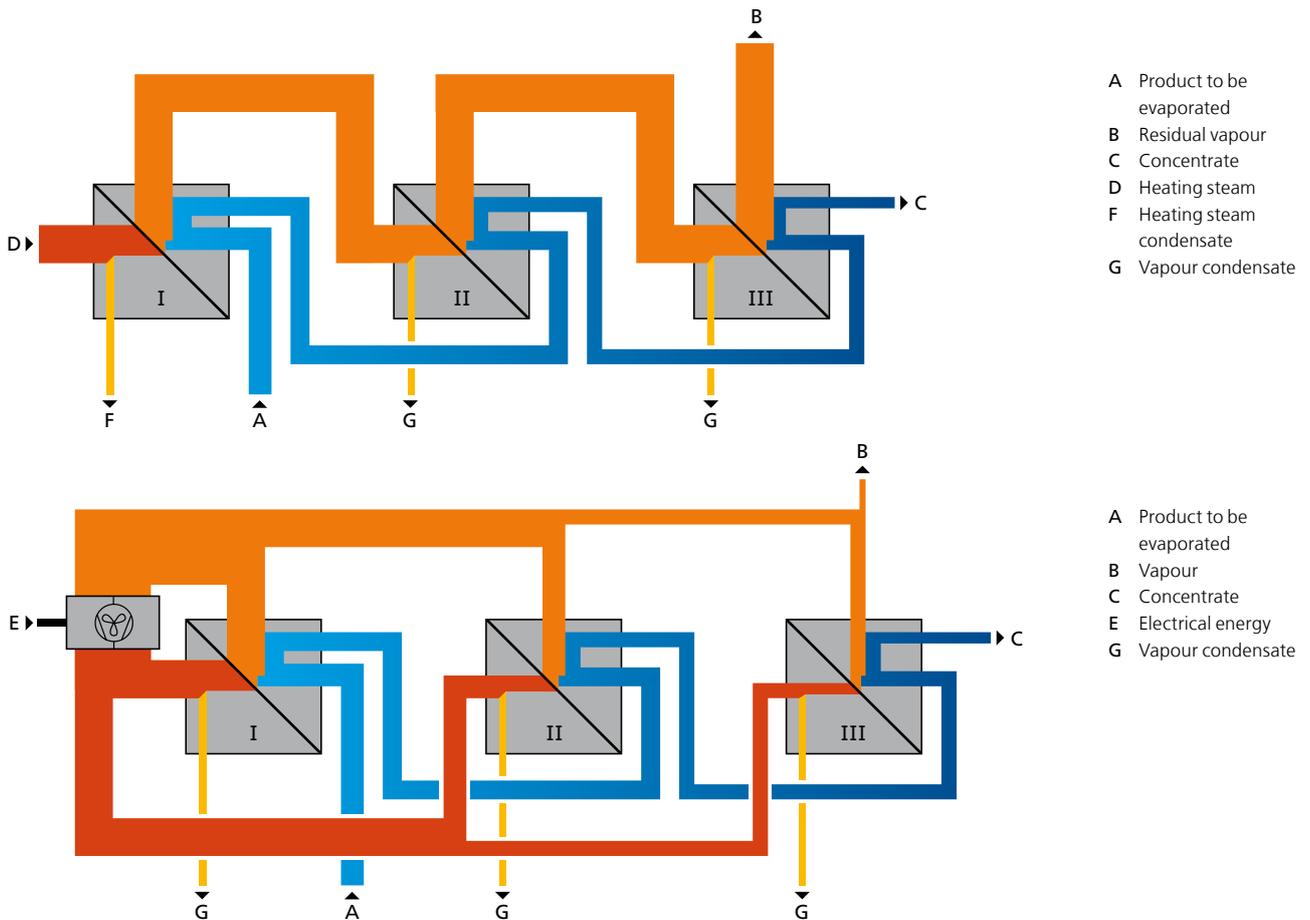
In many cases, the design of multiple-effect evaporation plants already considers small temperature differences at the respective heating surfaces so that they are suited for a heating by means of mechanical vapour recompression. After the retrofitting measures, the existing effects are heated in parallel. For this purpose, the existing vapour ducts are dismantled, one or more mechanical

recompressors are installed and new vapour ducts are installed. In this way, the energy flow in the plant is changed such that the major part of the evaporated vapour is now used to heat all effects. Only very small quantities of live steam and cooling water are required.

The following heat flow diagrams represent this situation by the example of a three-effect plant.

Investment

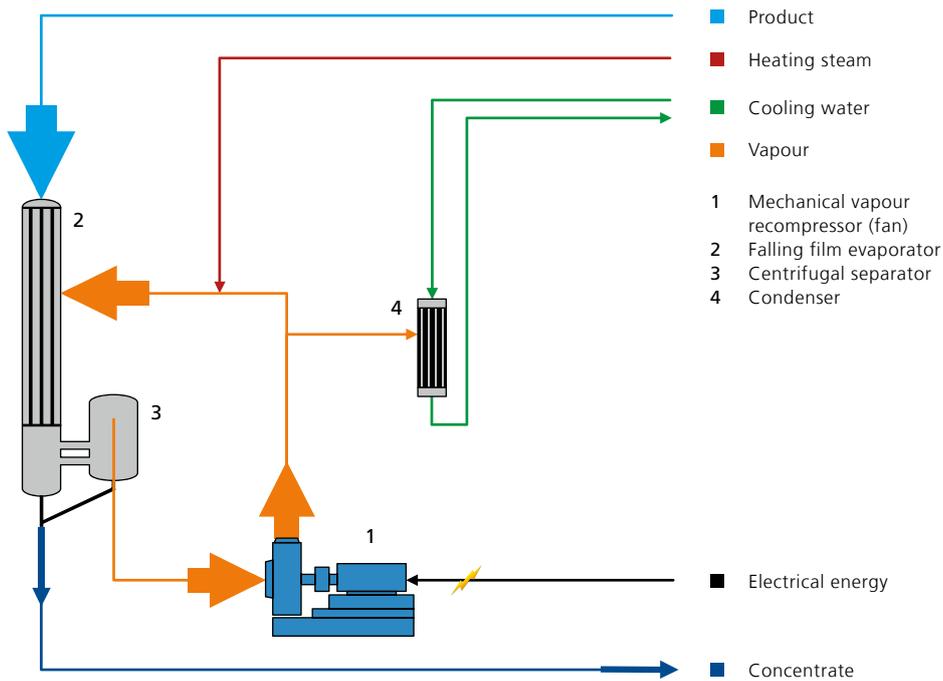
The costs for such a retrofitting will amortize within a very short period of time, in analogy to the diagram shown on page 6.



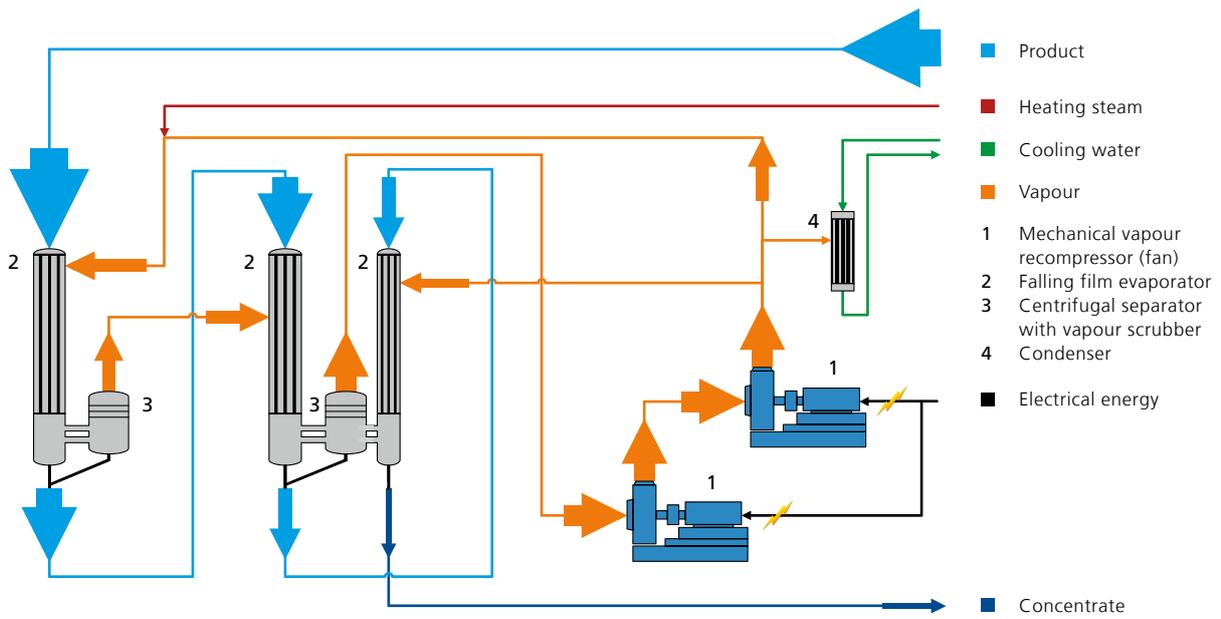
Top: Heat flow diagram of a three-effect, directly heated evaporation plant

Bottom: Heat flow diagram of this plant after retrofitting to heating by means of mechanical vapour recompression

Examples for evaporation plants with centrifugal fans

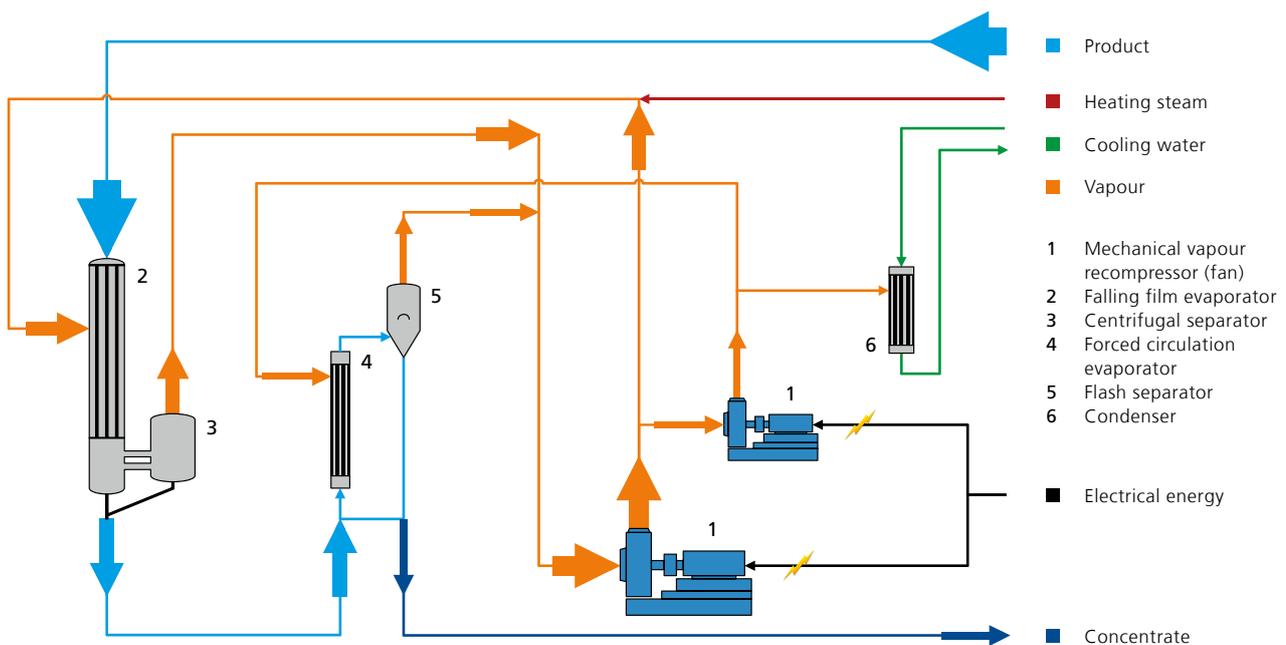


Single-effect falling film evaporator with centrifugal fan for mechanical vapour recompression



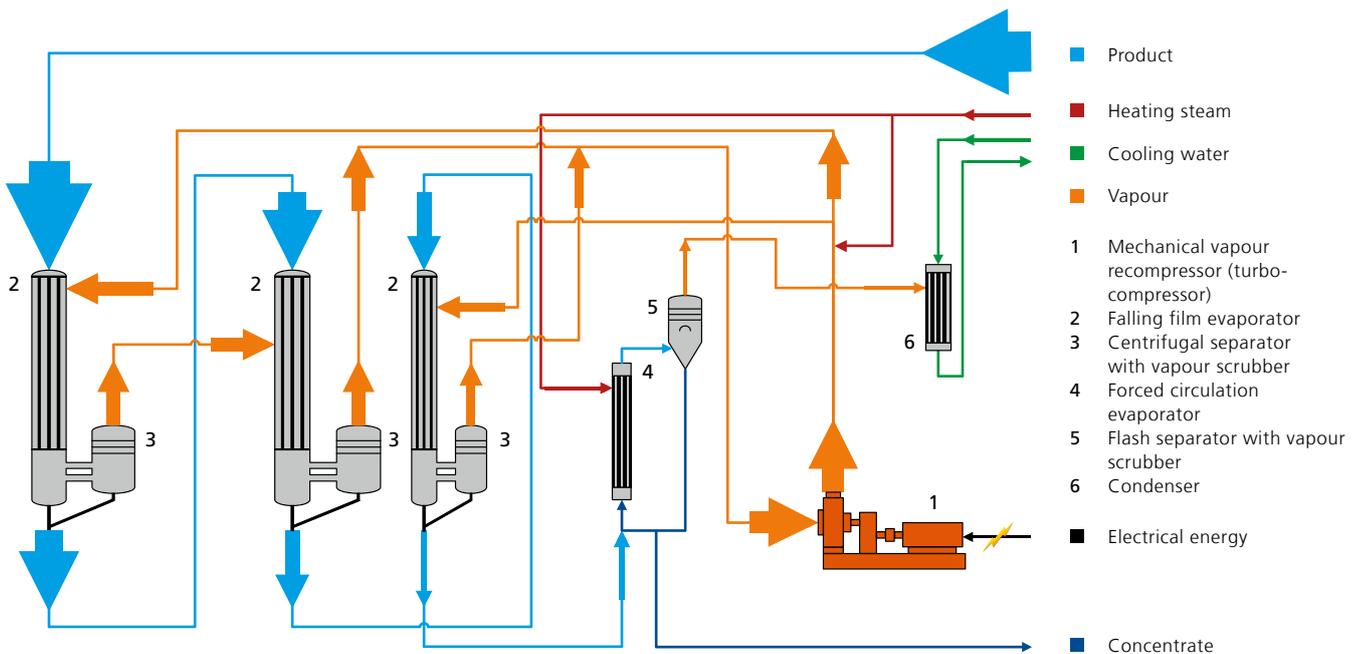
Two-effect falling film pre-evaporator and finisher arranged in parallel with two centrifugal vapour fans arranged in series

Examples for evaporation plants with centrifugal fans



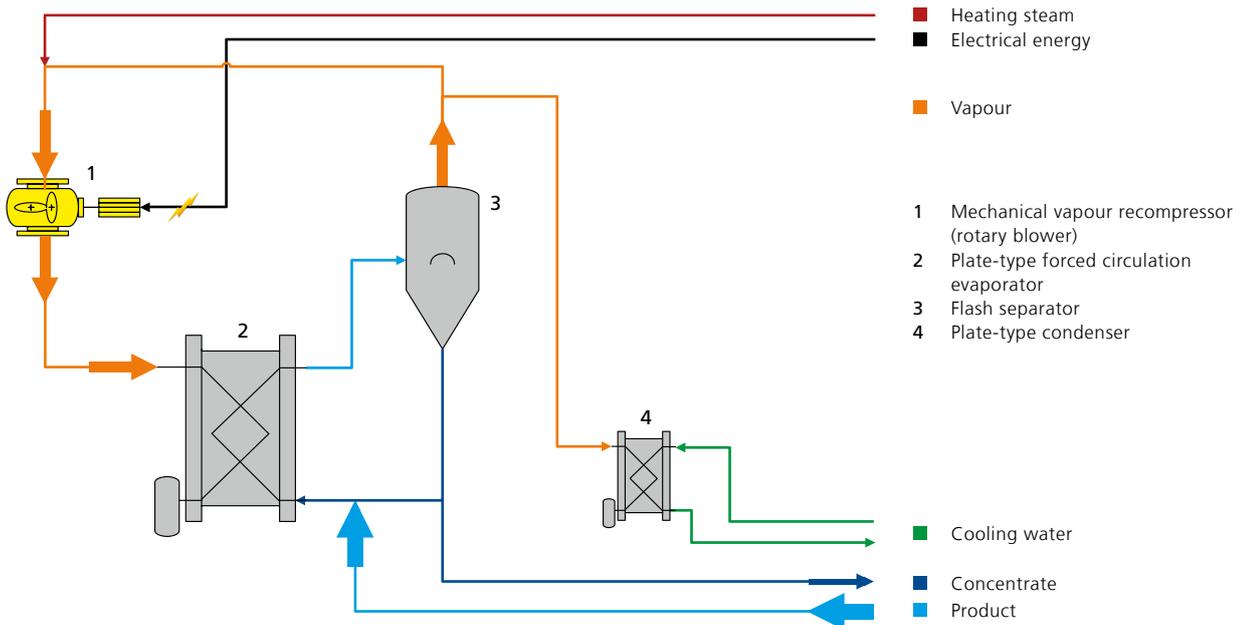
Two-effect falling film forced circulation evaporator with centrifugal vapour fan as main recompressor and a second smaller partial flow fan (booster)

Example for evaporation plants with turbo-compressors

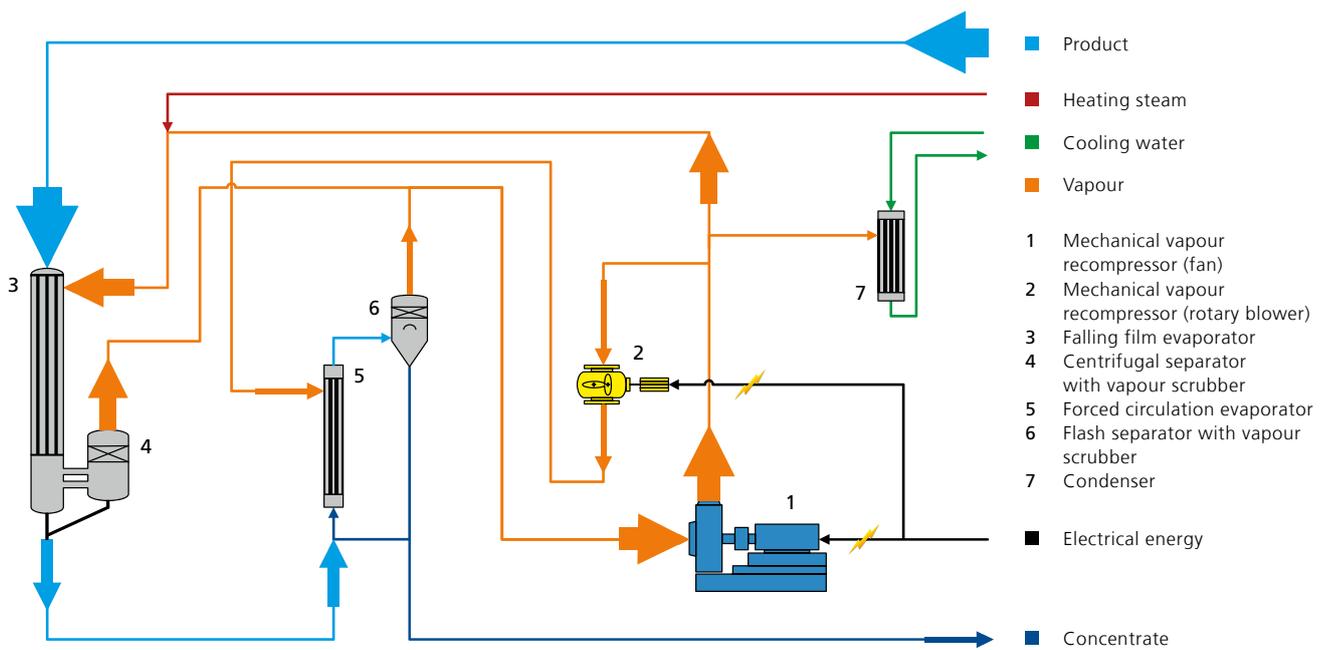


Three-effect falling film pre-evaporator with centrifugal (turbo) recompressor and forced circulation finisher directly heated by steam

Example for plants with rotary blowers



*Single-effect forced circulation evaporator with rotary blower.
The heating body of the evaporator is designed as plate heat exchanger.*



Single-effect falling film pre-evaporator with centrifugal fan and single-effect forced circulation finisher with booster rotary blower



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