

Cooling under Vacuum



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Cooling is an expensive process. Ongoing increases in energy costs demand alternatives to traditional systems (mechanical compressors). More and more, flash cooling plants offer an environmentally friendly and economical solution.

GEA Wiegand has more than fifty years of experience in the design and construction of flash cooling plants.

GEA Wiegand reference plants:

water
aqueous nitric acid/phosphoric acid
aqueous plaster suspension
calcium milk
barium hydroxide solutions
various waste waters
fruit juice
milk
glue

The steam jet cooling plants may have a capacity between approximately 10 and 20 000 kilowatts. As an example, water may be cooled down to a temperature of approximately 5 °C.

Comparison between compression cooling plants and steam jet cooling plants

Type of cooling plant	Compression cooling plant	Steam jet cooling plant
Cooling		
process	evaporation	evaporation
heat transfer	indirect	direct or indirect
equipment	evaporator	flash vessel
Vapour Compression		
process	mechanical	fluid dynamic
equipment	screw, turbo or piston compressor	jet pump (vapour compressor)
Motive power of the compressor		
	electrical energy (motor)	thermal energy (motive steam)
Discharge of heat energy		
process	condensation	condensation
heat transfer	indirect	direct or indirect
equipment	liquefier	condenser

Steam Jet Cooling Plants – Construction Details and How They Work

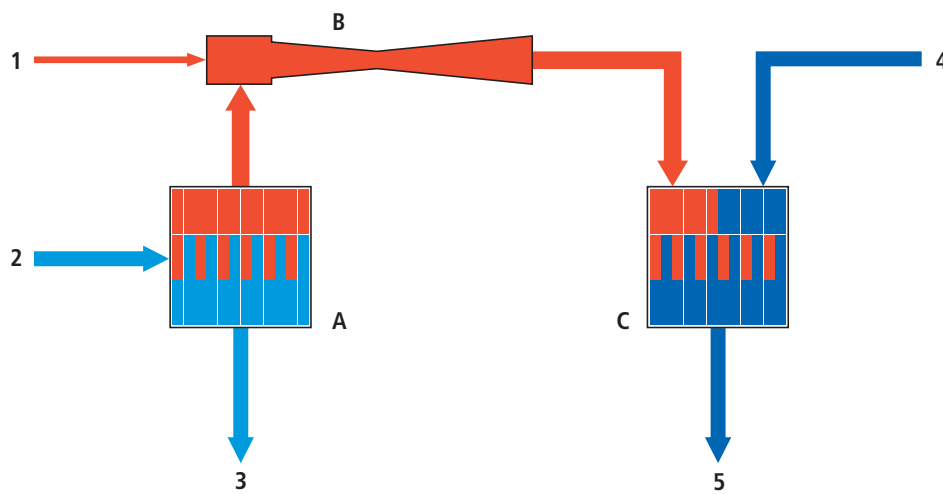


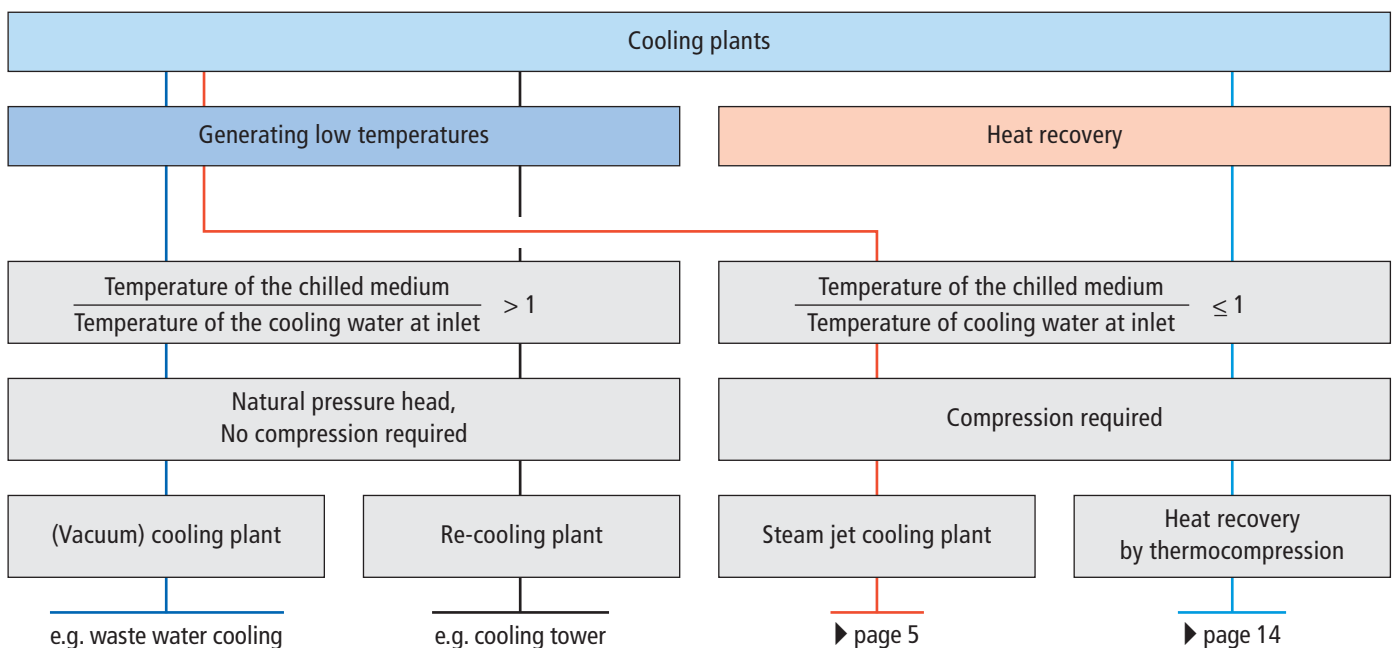
Fig. 1: Diagram of a steam jet cooling plant with mixing condenser

Advantages of flash cooling plants

- simple and robust construction
- reliable and safe to use
- very little wear and tear owing to no moving parts
- minimal maintenance
- direct and indirect cooling is possible; with indirect cooling, the cooling medium is almost always water and therefore easy to handle
- very low chilled-medium hold-up volume
- frequent or fast change of load possible
- minimum electrical energy required
- waste heat and flash steam used as the motive media
- used very efficiently during seasonal and /or batch operation
- coefficient of performance* value may be further improved by employing a motive steam saving control

* Coefficient of Performance = chilling capacity divided by motive power

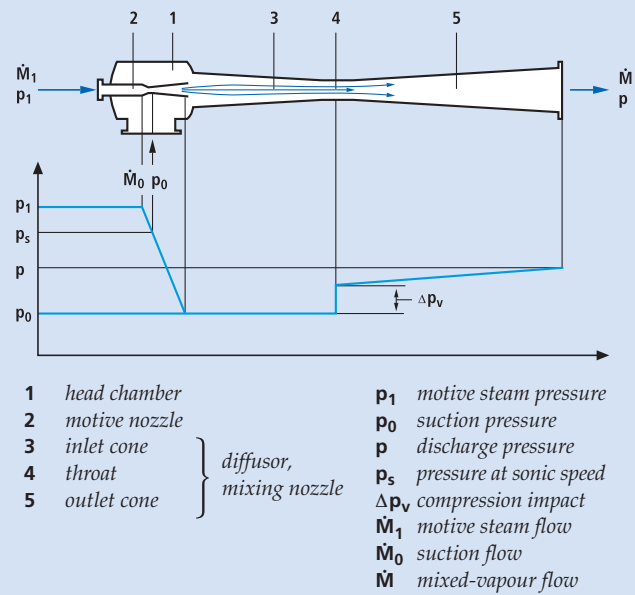
Classification of flash cooling plants



Vapour compression using jet pumps

Jet pumps are compressors driven by a fluid and have no moving parts: the vapour, flashed from the suction medium (i. e. the medium to be cooled) passes through the suction nozzle, into the head of the jet pump. The motive medium (usually steam) is expanded, after passing through a motive nozzle, where the pressure energy is transformed into kinetic energy. This energy stream impinges with and conveys the suction medium (i. e. the medium to be cooled), accelerating it into the inlet cone of the mixing nozzle. After passing through the throat of the mixing nozzle, into the diffuser, the kinetic energy of the mixed vapour stream is gradually converted back into potential energy, i. e. the medium is compressed to a higher discharge pressure (fig. 2).

Fig. 2: Construction of a jet pump and variation of pressure



Flash cooling

For each type of fluid the evaporation pressure requires a particular evaporation temperature. A liquid will start to boil if it is subjected to a pressure that is lower than its evaporation pressure. The correlation for water within a temperature range of between 0 °C and 100 °C is shown in the diagram (fig. 3). In flash cooling plants, only a small proportion of the medium to be cooled is evaporated (vapour flow [kg/s]). The thermal energy required for this process is taken from the remaining medium: its temperature drops until the boiling temperature to the lower pressure has been reached.

The vapour flow conveys the thermal energy from the cooled medium into a condenser thereby transferring the thermal energy to another system (heat consumer, re-cooling system etc.).

Fig. 3: Saturation curve (water) : $t_s = f(p_s)$

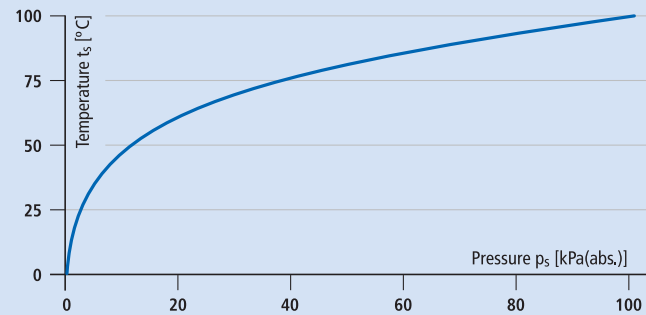
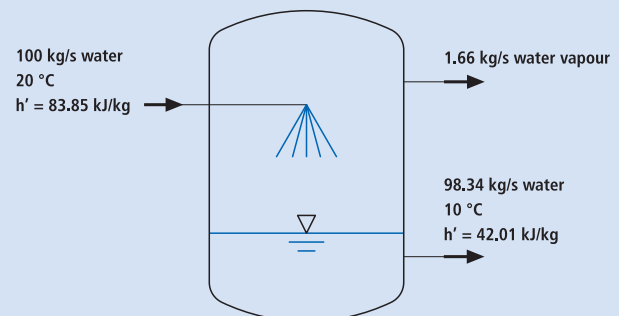


Fig. 4: 100 kg/s water at 20 °C are cooled down to 10 °C by evaporation of 1.66 kg/s of water resulting in 98.34 kg/s water at the outlet.

A pressure of approx. 1.23 kPa (abs.) must be maintained in this chamber. The evaporation enthalpy is 2478 kJ/kg resulting in a chilling capacity of 2478 kJ/kg x 1.66 kg/s = 4113 kW.



Steam Jet Cooling Plants – Types

Basically, there are three different types of steam jet cooling plants:

- compact design for small capacities;
- column design for medium capacity and large capacities where there is little floor area;
- bridge design for high capacities.

Steam jet cooling plants of compact design

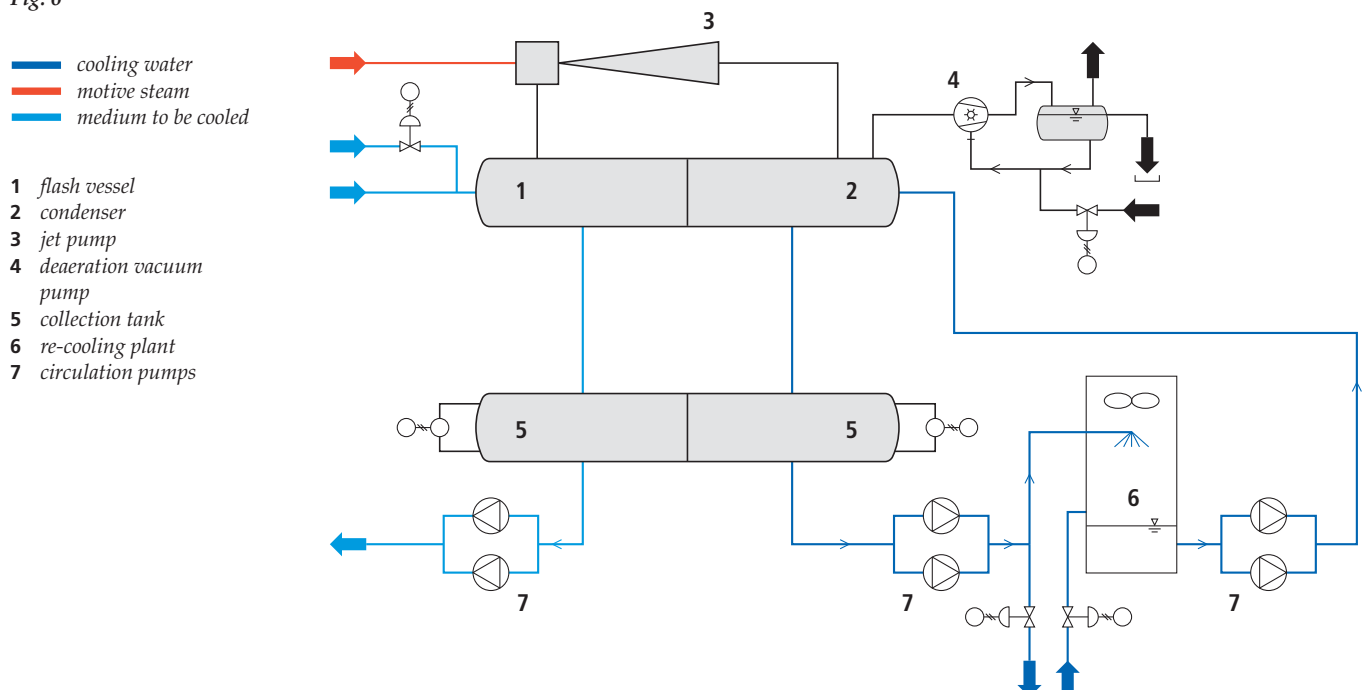
These consist of horizontally designed equipment: one flash vessel (1) and one condenser stage (2) being installed in a common horizontal vessel. The jet pump (3) is arranged in parallel to this vessel. A small liquid ring vacuum pump (4) is installed as a deaeration unit. The condensation heat is removed via the cooling water – e.g. by a cooling tower (6). The plant is controlled by an operation control system.

This type of design requires relatively little floor space and not too much height.



Fig. 5: 2-stage steam jet cooling plant of compact design, cooling 44 m³/hr of water from 30 to 10 °C.

Fig. 6



Steam jet cooling plants of column design

These are of vertical construction: flash cooling chamber (1) and condenser chamber (2) are mounted one on top of the other. The flash vessels and the condenser chambers of each stage are connected to each other through piping or a jet pump for vapour compression (3). In many cases, a cooling tower (6) is installed in order to re-cool the cooling water. Generally, a steam jet vacuum pump is provided as a deaeration unit. The plant is controlled by an operation control system.

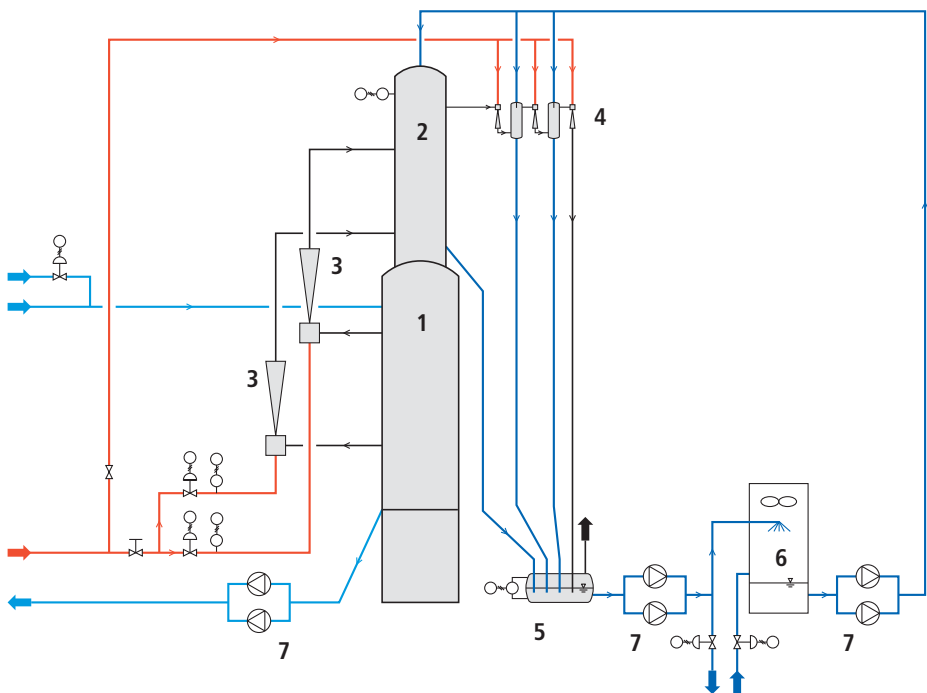
This type of design requires a relatively small floor space, but greater height.



Fig. 7: 2-stage steam jet cooling plant of column design, cooling 200 m³/hr of water from 10 to 5 °C. Chilling capacity: 1163 kW

Fig. 8

- cooling water
 - motive steam
 - medium to be cooled
- 1 flash vessel
 - 2 condenser
 - 3 jet pumps
 - 4 deaeration vacuum pump
 - 5 collection tank
 - 6 re-cooling plant
 - 7 circulation pumps



Steam jet cooling plants of bridge design

These consist of vertically or horizontally arranged flash cooling chambers (1), horizontally mounted jet pumps (3) and vertically designed condenser chambers (2). The flash vessel and condenser chambers of each stage are connected by piping or a jet pump for vapour compression (3). In many cases, a cooling tower (6) is included for re-cooling of the cooling water. A steam jet vacuum pump for deaeration is also included. The plant is controlled by an operation control system.

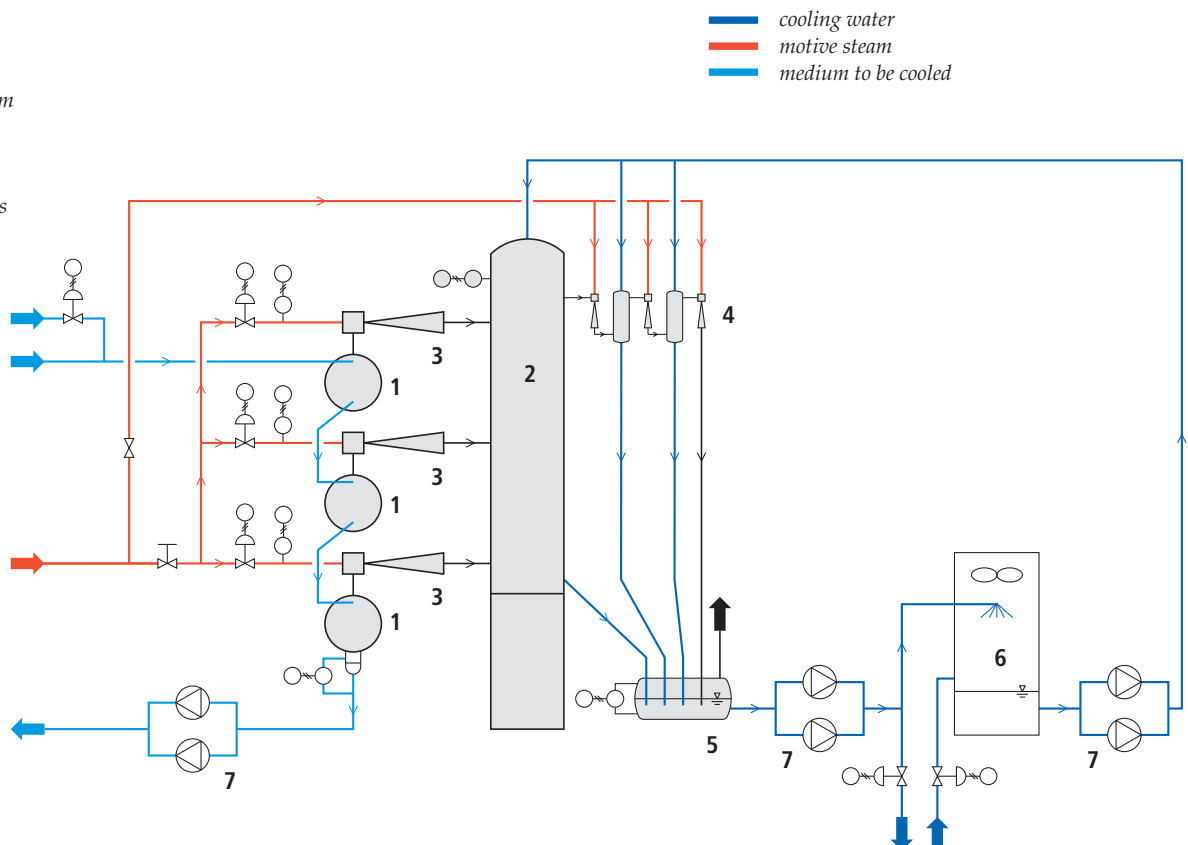
This type of design requires relatively little height but more floor space.



Fig. 9: 3-stage steam jet cooling plant of bridge design, cooling 194 m³/hr of water from 28 to 15 °C. Chilling capacity: 2 900 kW

Fig. 10

- 1 flash vessel
- 2 condenser
- 3 jet pumps
- 4 deaeration vacuum pump
- 5 collection tank
- 6 re-cooling plant
- 7 circulation pumps



Standardised steam jet cooling plants – sizes

GEA Wiegand offers standardised plants.

Advantages:

- simple design
- low investment costs
- shorter delivery times

Eight standardised sizes are available for particular applications (table). Tailor-made design is available on request. The given dimensions refer to the pictures on the right / next page (fig. 11, fig. 12 and fig. 13).

Net chilling capacity	kW	20	100	300	600	1 000	3 000	7 500	15 000
Medium to be cooled (water)									
inlet temperature	°C	12	12	12	12	12	12	12	12
outlet temperature	°C	6	6	6	6	6	6	6	6
volume flow	m³/h	2.9	14.5	43.5	87	145	435	1 086	2 172
nozzle sizes: inlet/outlet	DN	25/40	50/80	80/150	150/200	150/250	250/400	400/700	600/1 000
Cooling water									
inlet temperature	°C	30	30	30	30	30	30	30	30
outlet temperature	°C	40	40	40	40	40	40	40	40
volume flow	m³/h	8	37	95	190	305	855	2 140	4 275
nozzle sizes: inlet/outlet	DN	40/50	80/100	150/200	200/250	250/350	400/600	600/1 000	900/1 400
Motive steam (0.4 MPa (abs.))									
summer (100 % load)	kg/h	95	440	1 100	2 150	3 450	9 450	23 500	47 000
spring/summer ¹⁾ 60 %	kg/h	appr. 60	appr. 260	appr. 660	appr. 1 300	appr. 2 070	appr. 5 700	appr. 14 000	appr. 28 000
winter ¹⁾ 20 %	kg/h	appr. 20	appr. 90	appr. 200	appr. 430	appr. 700	appr. 1 900	appr. 4 700	appr. 9 400
Make-up water demand (e.g. 12 °C)	m³/h	0.03	0.14	0.44	0.87	1.45	4.36	10.90	21.81
Number of stages		1	1	2	2	2	3	3	3
Type of design		compact	compact	column	column	column	bridge	bridge	bridge
Installation		non-barom.	non-barom.	non-barom. ²⁾	non-barom. ²⁾	non-barom.	barometric	barometric	barometric
Electrical power									
liquid ring pump vacuum pump	kW	0.7	0.7	(without)	(without)	(without)	(without)	(without)	(without)
cooling water pump 1 ³⁾ (100 %)	kW	0.5	2.5	10	18	36	110	270	620
cooling water pump 2 ³⁾ (100 %)	kW	0.5	2.0	8	15	25	80	200	450
chilled media pump ³⁾ (100 %)	kW	0.5	1.0	3	6	12	50	120	280
cooling tower fan (100 %)	kW	0.5	2.0	6	11	18	52	128	256
total	kW	2.7	8.2	27	50	91	292	718	1 606
Dimensions (steam jet cooling plant)									
length	m	2.5	3.5	2.0	2.5	3	15	20	22
width	m	1.0	1.5	2.0	2.5	3	5	7	13
height	m	2.5	3.0	12.0	14.0	17	13 ⁴⁾	20 ⁴⁾	30 ⁴⁾
Weights⁵⁾									
empty	t	1.3	2.2	8	13	20	25	75	150
operating	t	1.5	3.0	10	16	25	32	100	200
filled with water	t	2.0	4.0	14	28	40	70	240	550

1) Central Europe

2) plus supply tank for cooling medium discharge

3) with reference to +/- 0.0 m

4) plus barometric height (11 m)

5) without platforms, pumps, cooling tower and piping

Fig. 11: Column design

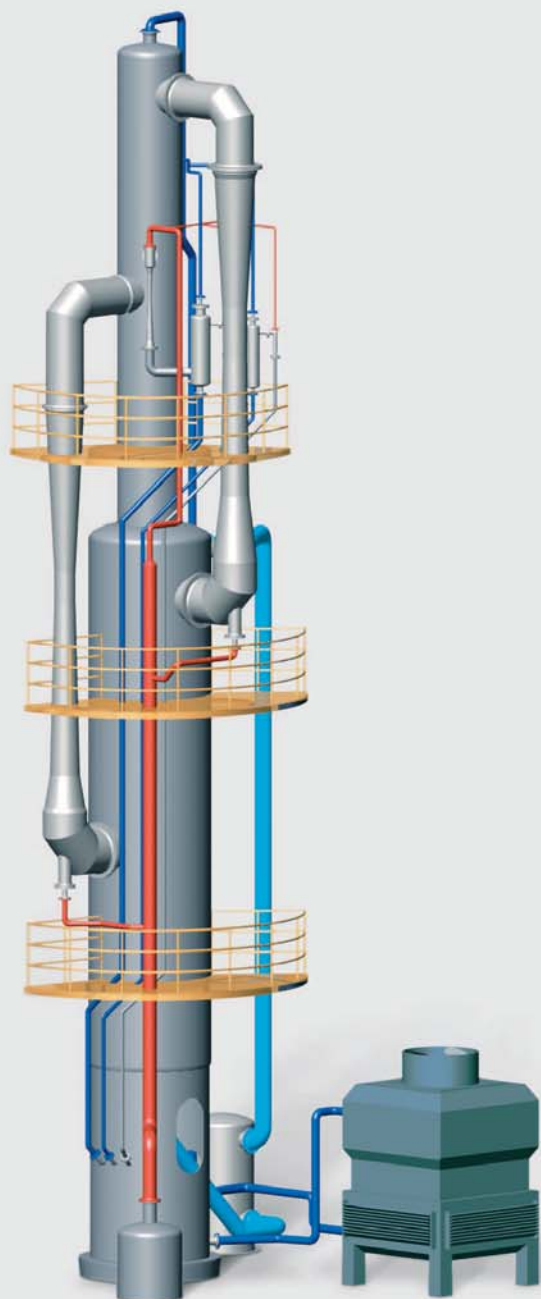


Fig. 12: Bridge design

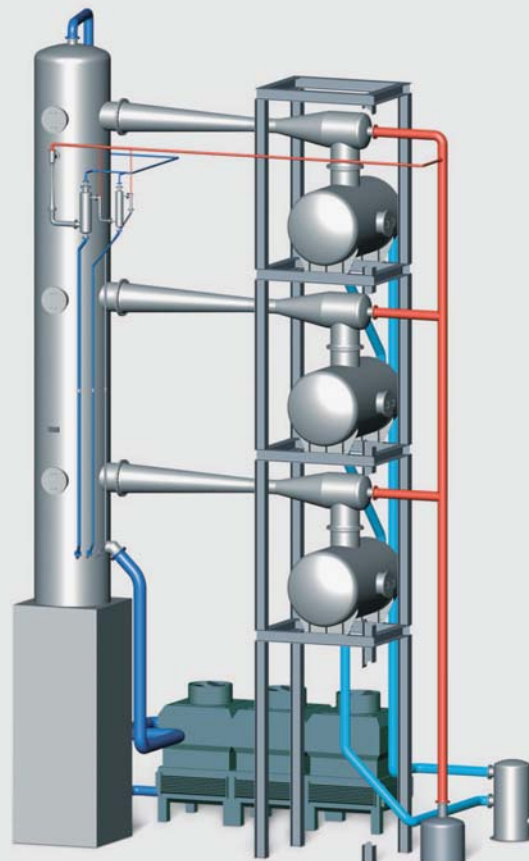
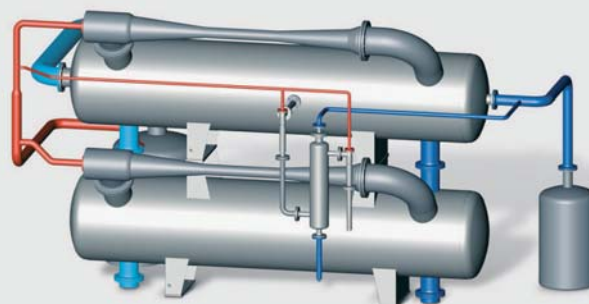


Fig. 13: Compact design



Installation and Control

Possible combinations

Cooling plants usually consist of three components:

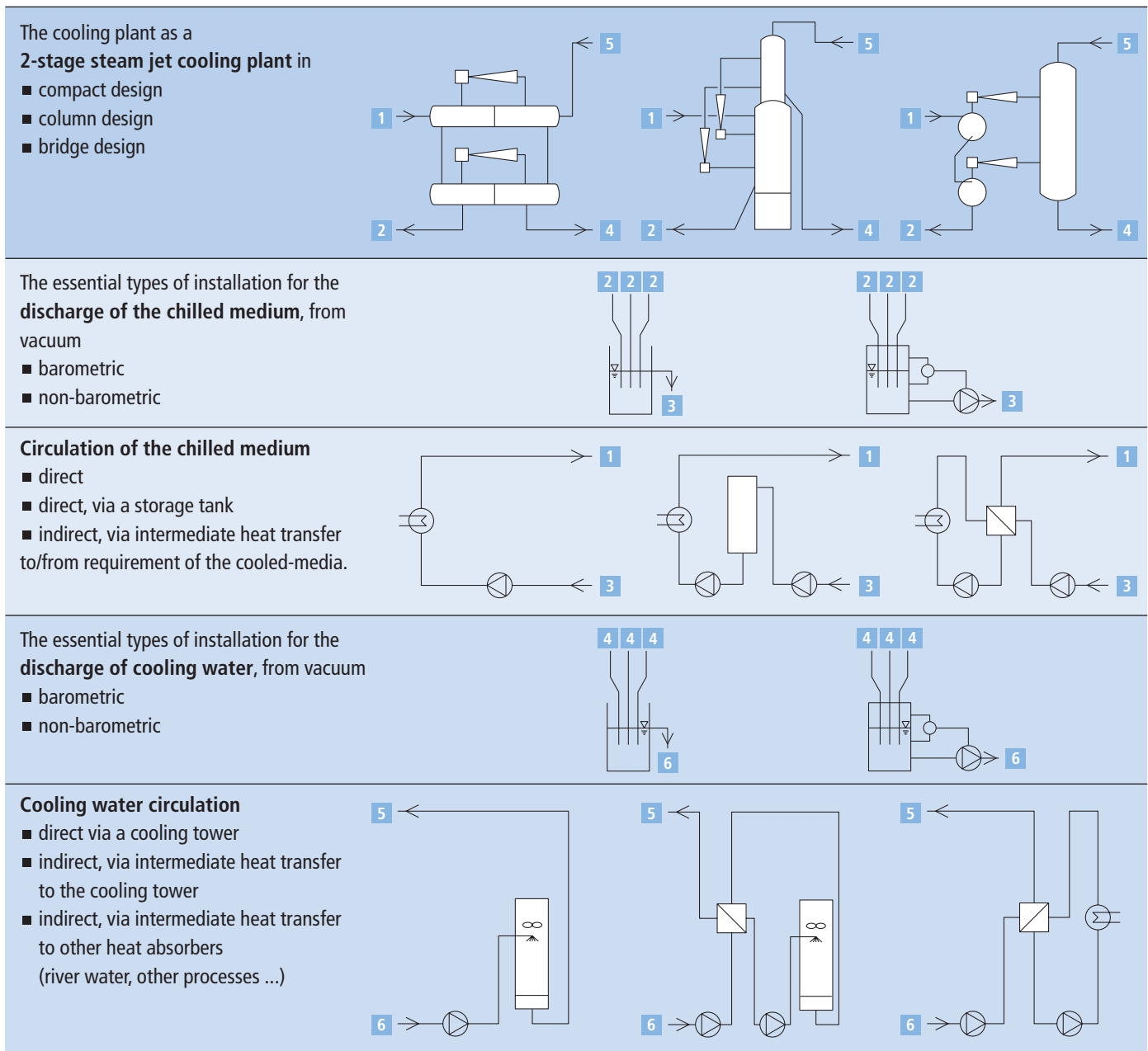
- cooling plant itself
- circulation of the chilled medium
- circulation of the cooling water

Most of the flash cooling plants are operated under vacuum. The chilled medium and/or the cooling water must then be conveyed from that vacuum and fed into the relevant circulation process.

A barometric arrangement allows a particularly simple discharge from the vacuum. If however, a minimum 11 m height for this arrangement is not available, than non-barometric installation is required (page 11).

The table shows numerous possible combinations of design and installation: a cooling plant may have a barometric or a non-barometric discharge, each with three design alternatives for the circulation of the chilled medium as well as for the cooling water circulation. The table below illustrates this.

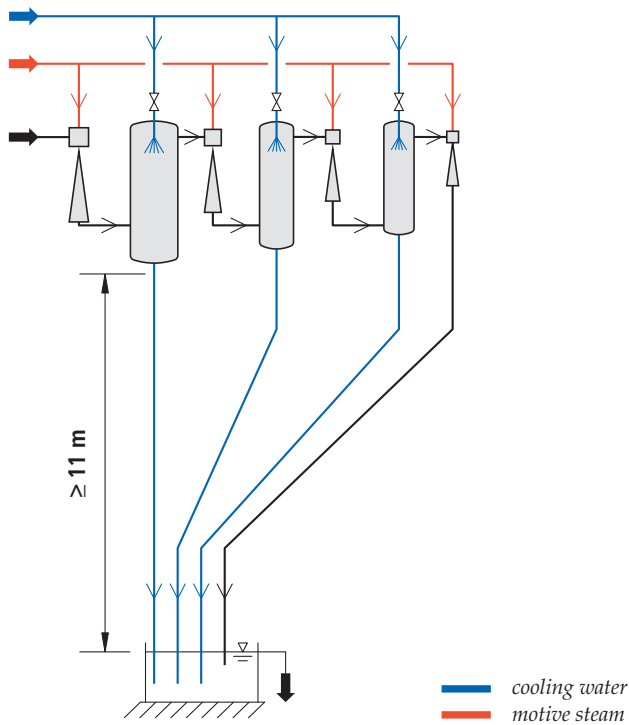
Possible combinations of design and installation



Installation alternatives

Installation may be barometric or non-barometric:

Fig. 14: Barometric installation



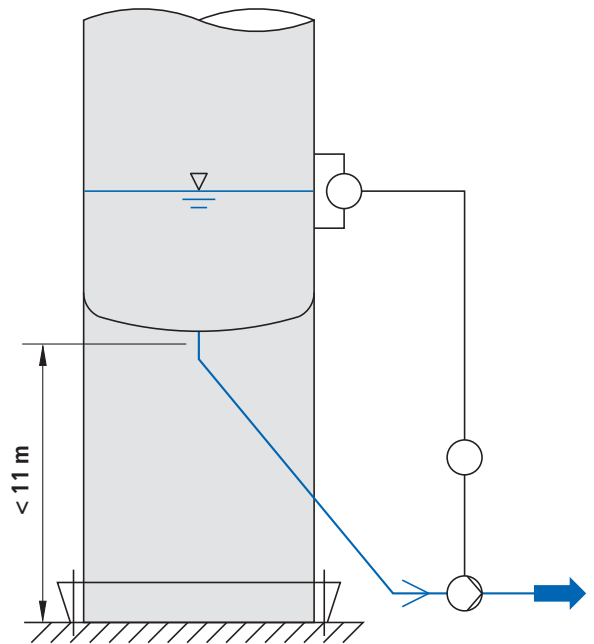
Advantages:

- The suction pressure of the circulation pump is always higher than or equal to atmospheric pressure, therefore hardly any risk of cavitation.
- The vacuum chamber is only separated from atmospheric pressure by liquid column in the barometric leg.
- Usually this system cannot be considered as pressure vessel because this arrangement does not allow the build up of over-pressure.

Note:

- The installation height of the vacuum chambers must be at least 11 m above the seal water pot.

Fig. 15: Non-barometric Installation



Advantages:

- The difference in height between the vacuum chambers and the seal water pot may be less than 11 m.

Note:

- The suction pressure of the circulation pump is below atmospheric pressure, therefore, the circulation pump must be protected against cavitation.
- Because of the closed construction, the vessels will usually be considered as pressure vessels which may be subject to special requirements in design and manufacture.

Control of steam jet cooling plants

Steam jet cooling plants are controlled

- in order to match the chilling capacity to the relevant demand and/or
- to reduce operating costs.

Capacity control

The capacity of a steam jet cooling plant can be altered by turning on/off the motive steam valves of the individual jet pumps. Assuming a constant flow of the medium to be cooled, the chilling capacity can be controlled in accordance with the temperature of the chilled medium at the outlet of the steam jet cooling plant. This can be made either manually or by automatic control.

Control of the motive steam flow – motive steam saving control

Steam jet cooling plants are designed for the least favourable operating conditions which may occur, e.g. for the highest annual cooling water temperature.

The diagram (fig. 16) shows a typical temperature profile over a period of one year in central Europe. Given a constant cooling water flow, the condensation pressure is markedly below the value of the process design during most of the year. Accordingly, the vapour compressor may compress against a lower pressure than the process design value.

Corresponding to the characteristics of jet pumps, the maximum allowable discharge pressure at the outlet of the jet pump is proportional to its motive steam pressure within a certain range. The maximum allowable discharge pressure must always be at least as high as the condensation pressure in the downstream condenser.

If the temperature of the cooling water drops, the condensation pressure will drop correspondingly. Then the jet pump need not compress to the high process design discharge pressure and the motive steam pressure can be correspondingly reduced by means of a throttle valve. Thus, the motive steam consumption of the steam jet cooling plant is reduced while keeping the chilling capacity unchanged. The diagrams (fig. 17 and 18) illustrate this relationship.

This saving of motive steam contributes to improving the average annual COP* value.

* Coefficient of Performance = chilling capacity divided by motive power

Fig. 16: Maximum temperatures of the re-cooled water over one year (central Europe)

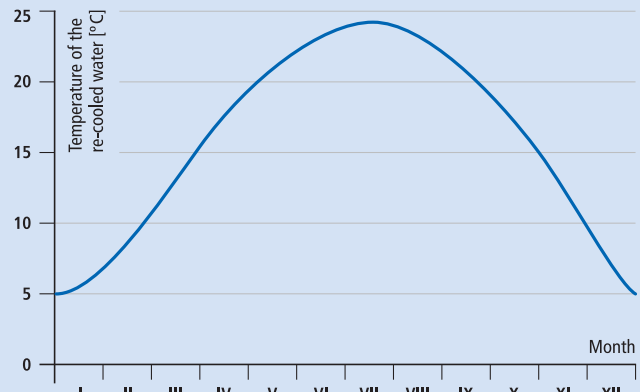


Fig. 17: Steam consumption depending on the cooling water temperature in a four stage plant (valid for cooling to 10 °C)

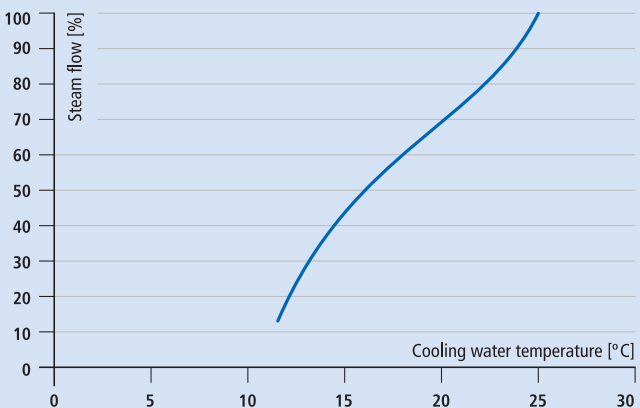
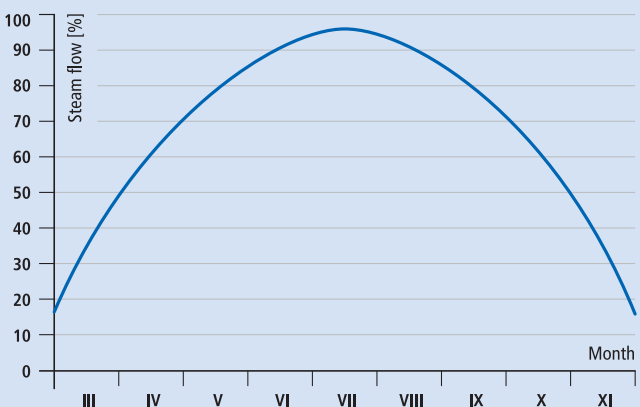


Fig. 18: Steam consumption profile
based on the ratios shown in the two diagrams (fig. 16 and 17).
Average steam consumption 72 % of the maximum value



Steam and cooling water requirement of steam jet cooling plants

The steam and cooling water requirement of steam jet cooling plants depends on

- the medium to be cooled
- the cooling water temperature
- the motive steam pressure
- the number of stages of the plant and
- the required chilled medium temperature at the outlet of the plant

Fig. 19 shows the motive steam and cooling water consumption. As an example, 100 m³/hr of water are cooled from 20 to 10 °C with a two-stage steam jet cooling plant. From the diagram of fig. 19, a cooling water demand of approx. 200 m³/hr (for heating of cooling water from 24 to 35 °C) and a motive steam consumption of approx. 1 800 kg/hr (7 bar (g)/170 °C) can be obtained. Furthermore, it shows that more stages reduce the operating costs, but increase the investment costs (and vice versa).

Optimum steam and cooling water requirement in steam jet cooling plants

The chilling factor R helps to calculate which level of cooling water heating can lead to low operating costs.

$$\text{chilling factor } R = K \cdot \frac{\text{steam price/t}}{\text{cooling water price/m}^3}$$

The value K refers to the average steam consumption in per cent. As an example, a relatively high steam price results in a big value R . As a consequence, a small cooling water temperature rise will save operating costs, and vice versa (see fig. 20). In the diagram, $K = 0.7$ (70 % of the process design value) is for cooling of 100 m³/hr of water from 20 to 5 °C, corresponding to a chilling capacity of 1 745 kW in a three-stage steam jet cooling plant with mixing condensation.

It is based on these conditions

- The cooling water flow remains constant.
- The steam flow is controlled.

Fig. 19: Steam and cooling water requirement of continuously operated steam jet cooling plants with mixing condensation

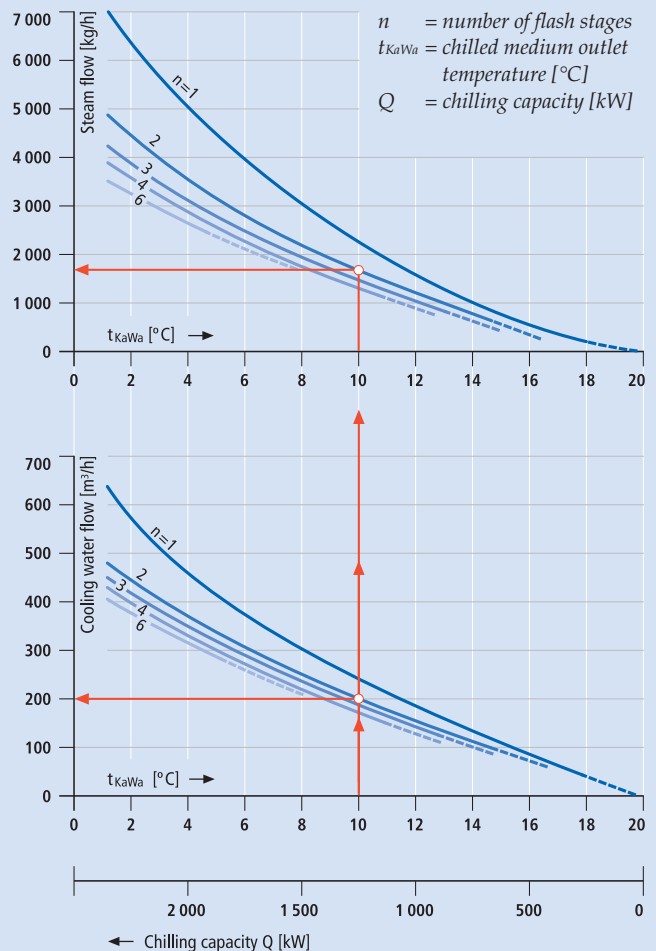
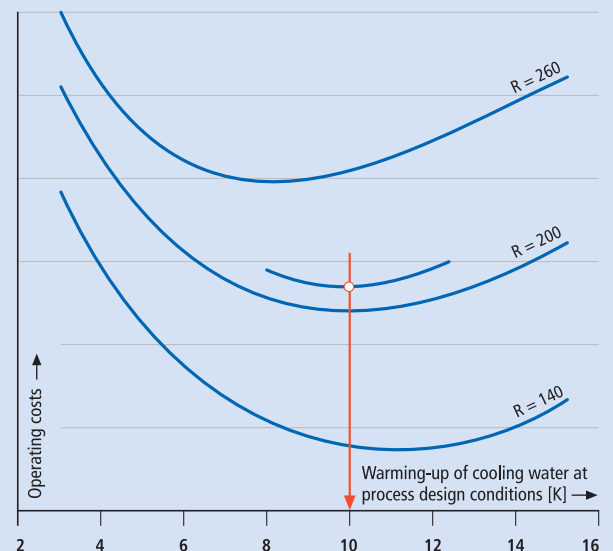


Fig. 20: Optimising the operating costs

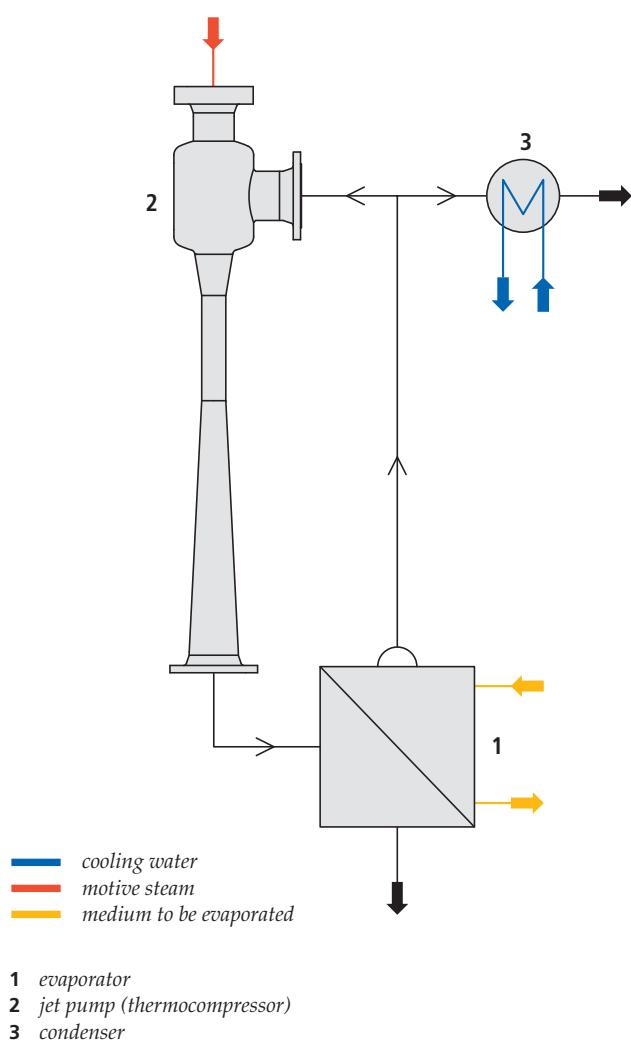


Heat Recovery Plants

Many processes discharge water or an aqueous liquid with a relatively high temperature. In this case, heat recovery plants may reduce

- the operating costs and
- pollution through better use of energy.

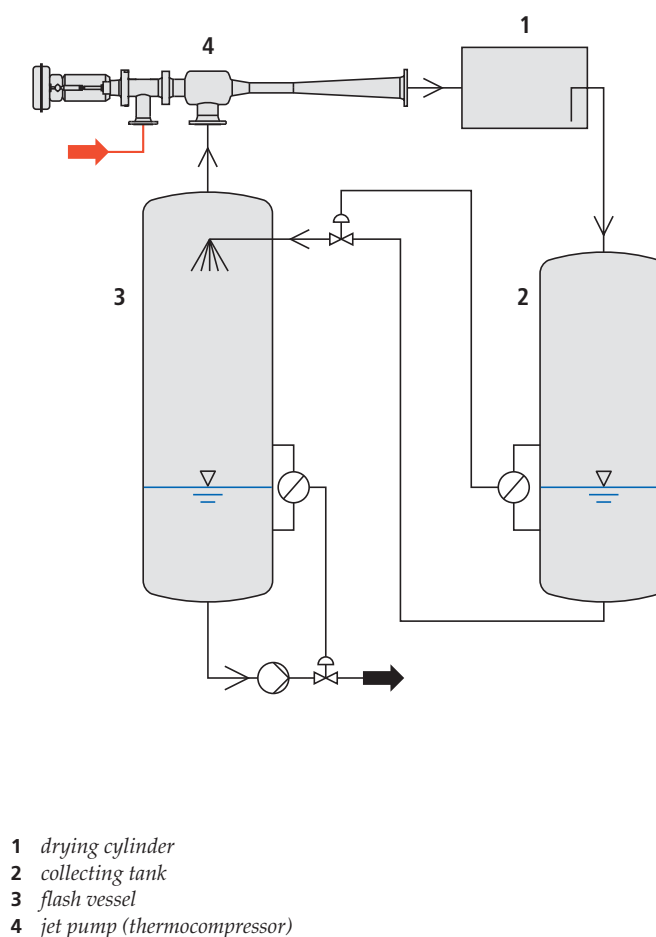
Fig. 21: Chemical industry



In an evaporator, vapour is generated at 200 kPa abs. and 60 °C. A large portion of the vapour can be re-utilised by a jet pump for heating. In the present example, and compared to heating with fresh steam, approximately 60 % of the fresh steam mass flow can be saved by re-utilising the vapour (assumption: fresh steam: 0.3 MPa (g)).

In principle, GEA Wiegand's heat recovery process is very similar to the flash cooling process, see page 4. However, the heat recovery process aims at a re-utilisation of the heat energy. The flashed / evaporated vapour is compressed to a higher pressure by a jet pump (= thermocompressor) in order to reclaim the heat energy at a higher temperature level.

Fig. 22: Paper industry



Heat is drawn by means of flash evaporation from the warm condensate coming from the drying cylinders of a paper machine. It is compressed by a jet pump to the higher heating steam pressure level. In this case, the jet pumps are designed for a variable flow (nozzle needle control) in order to correspond to the very precise control requirements of the paper industry.

Criteria for the Design of Steam Jet Cooling Plants

Despite standardisation, steam jet cooling plants are usually tailor-made plants. Due to the various application possibilities and the very individual requirements of the operators, their size, construction, arrangement and mode of operation are very different.

These questions should be answered first:

1. What shall be cooled/chilled?	Fluid characteristics such as boiling point elevation, crystal precipitation, etc.?
2. How much shall be cooled/chilled?	Mass flow or volume flow; in batches or continuously?
3. Cooling range?	Inlet and outlet temperature? Time period, in case of batch operation?
4. Driving Energy?	Which motive steam pressure levels are available? How much does the steam cost? Which mass flows are available (may waste steam or flash steam be taken into consideration)?
5. Method of cooling?	What type and quantity of cooling medium is available and at what cost?
6. How warm is the cooling medium?	What is the minimum and maximum temperature for the cooling medium during the operation process?
7. Type of installation?	Barometric or non-barometric?
8. Type of condensation?	Direct (condensate and cooling medium are mixed) or indirect (condensate and cooling medium are not mixed)?
9. Required chilling capacity?	What kind of load profile is expected (full load, partial load)?
10. Type of material of construction?	The type of operating medium, the place of erection, (climate etc.) along with the experience of the operators may require particular materials of construction.
11. Are there any further regulations	Are there any legal regulations or works standards that must be taken into account?
12. Special requests?	Has any particular experience been gained from the operation of similar plants, or are there any special requirements in relation to the steam jet cooling plant?
13. Notes:	



Overview on our Range of Products

Evaporation plants

to concentrate any type of fluid food, process water, organic and inorganic solutions and industrial waste water; with additional equipment for heating, cooling, degassing, crystallization and rectification.

Membrane filtration – GEA Filtration

to concentrate and process fluid food, process water and industrial waste water, to separate contaminations in order to improve quality and recover valuable substances.

Distillation / rectification plants

to separate multi-component mixtures, to recover organic solvents; to clean, recover and dehydrate bio-alcohol of different qualities.

Alcohol production lines

for potable alcohol and dehydrated alcohol of absolute purity; integrated stillage processing systems.

Condensation plants

with surface or mixing condensers, to condense vapour and steam/gas mixtures under vacuum.

Vacuum/steam jet cooling plants

to produce cold water, cool liquids, even of aggressive and abrasive nature.

Jet pumps

to convey and mix gases, liquids, and granular solids; for direct heating of liquids; as heat pumps; and in special design for the most diverse fields of application.

Steam jet vacuum pumps

also product vapour driven; also in combination with mechanical vacuum pumps (hybrid systems); extensive application in the chemical, pharmaceutical and food industries, in oil refineries and for steel degassing.

Heat recovery plants

to utilize residual heat from exhaust gases, steam/air mixtures, condensate and product.

Vacuum degassing plants

to remove dissolved gases from water and other liquids.

Heating and cooling plants

mobile and stationary plants for the operation of hot water heated reactors, contact driers.

Gas scrubbers

to clean and dedust exhaust air, separate aerosols, cool and condition gases, condensate vapours and absorb gaseous pollutants.

Project studies, engineering for our plants.



Process Engineering

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