VACUUM SYSTEMS

IN THE

EDIBLE OIL INDUSTRIES

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STEAM JET VACUUM EJECTORS
IN THE EDIBLE OIL AND RELATED INDUSTRIES

The basic idea for the design of STEAM JET EJECTORS has to be considered in that way that the available raw materials and available energy (in which ever form that they take) should be converted with the least possible waste and therefore the best possible efficiency.

For the present and immediate future one has to live with the fact that only part of this general requirement can be fulfilled . In all transformation processes not only there is a limitation by the physical constraints but also financial aspects have to be observed.

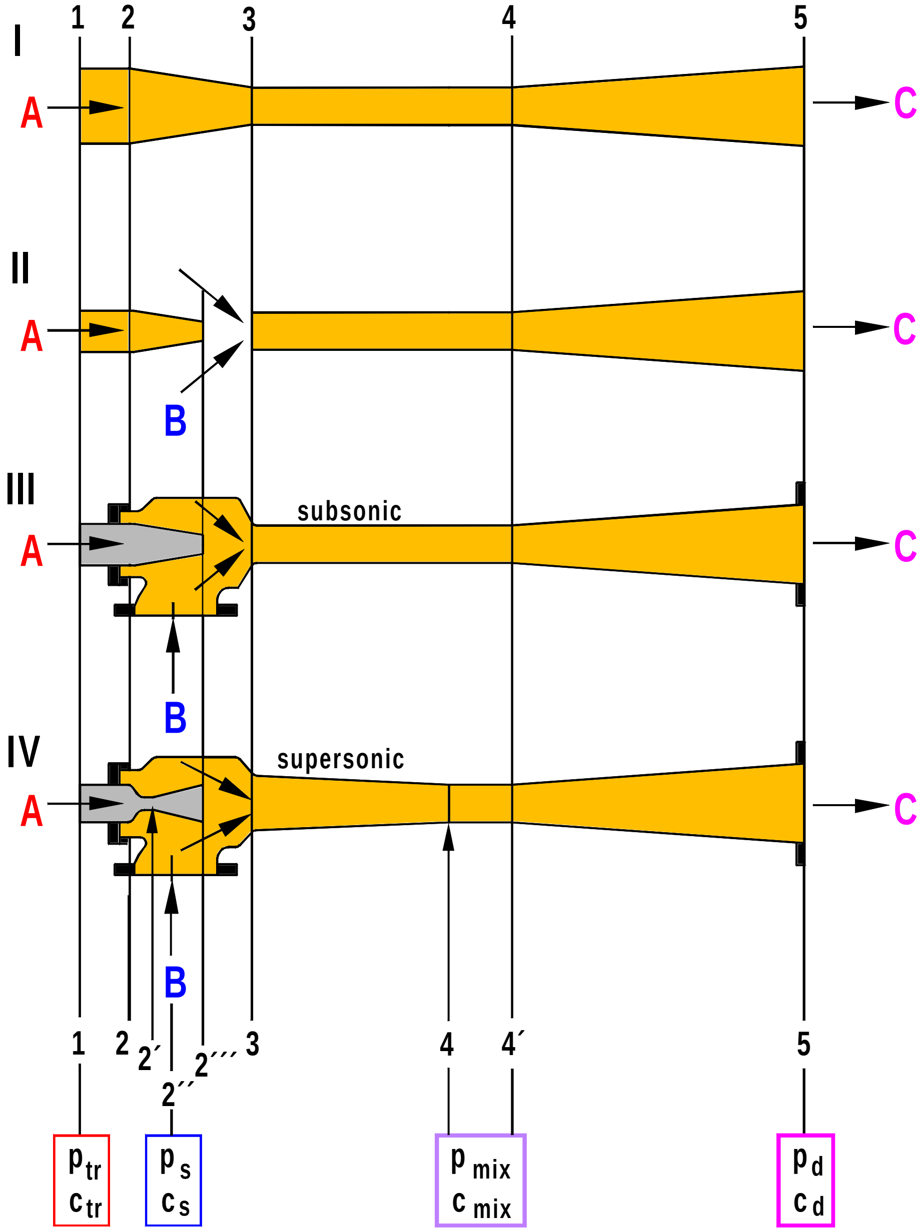
In this respect every material processing plant and every machine has to represent a compromise between that which is desired, that which is possible and that which makes financial sense.

This statement is also true for the vacuum ejector systems that will be presented in this paper. With regard to this topic the application of these systems in the edible oil industry will be shown.

However, that which is true for this branch of industry is also true for related industries, e. g. fats and soap production, and indeed for all processes in which products are manufactured for human consumption.

In the past steam ejectors were - and sometimes they are still today - reputed of being "steam guzzlers". This may be true in the case where ejectors are misdesigned or misoperated. But if they are well designed and properly operated, ejectors are a simple and robust equipment being capable to convey large mass flows from low pressure to a higher pressure level.

Venturi Tube / Ejector



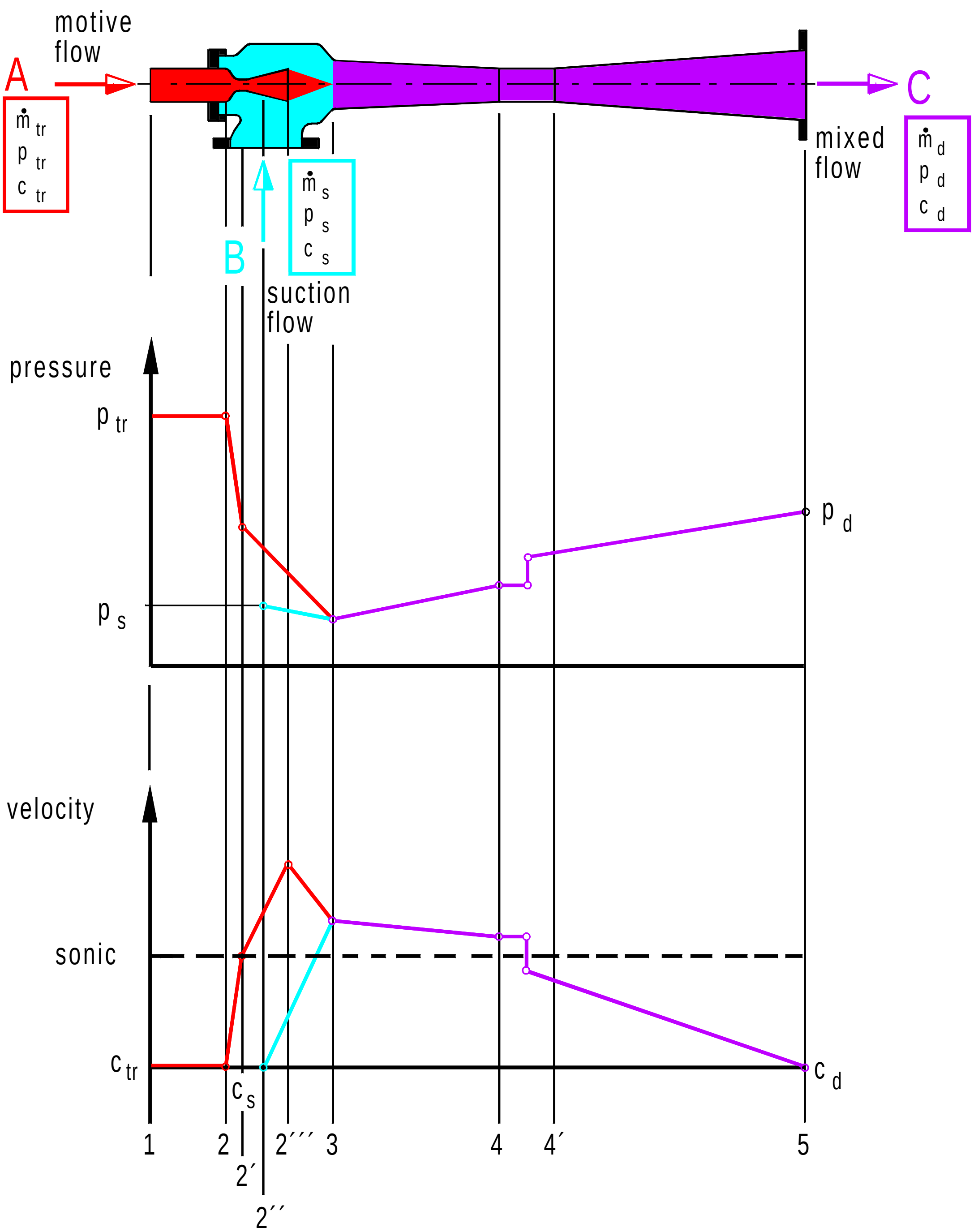
PART I In its simplest form an ejector is a Venturi Tube. In the converging section an acceleration with pressure drop takes place, and in the diverging section a retardation with pressure increase. If the acceleration and, consequently, the pressure drop is large enough, it is possible, for example, to achieve a lower pressure than the atmospheric pressure in the smallest section.

PART II At this point anything can be entrained.

PART III If the Venturi tube is cut at this point and a chamber is laid round the cutting, we have already the simplest form of a jet ejector, for example, a water jet ejector.

PART IV When these features are transferred to gaseous media such as steam, and when a Laval Nozzle is used, it is possible to convert the adiabatic difference into high velocities. Now, we have a steam jet ejector operating with sonic or supersonic velocity in the smallest mixing section.

Characteristic Curves of Pressure and Velocity

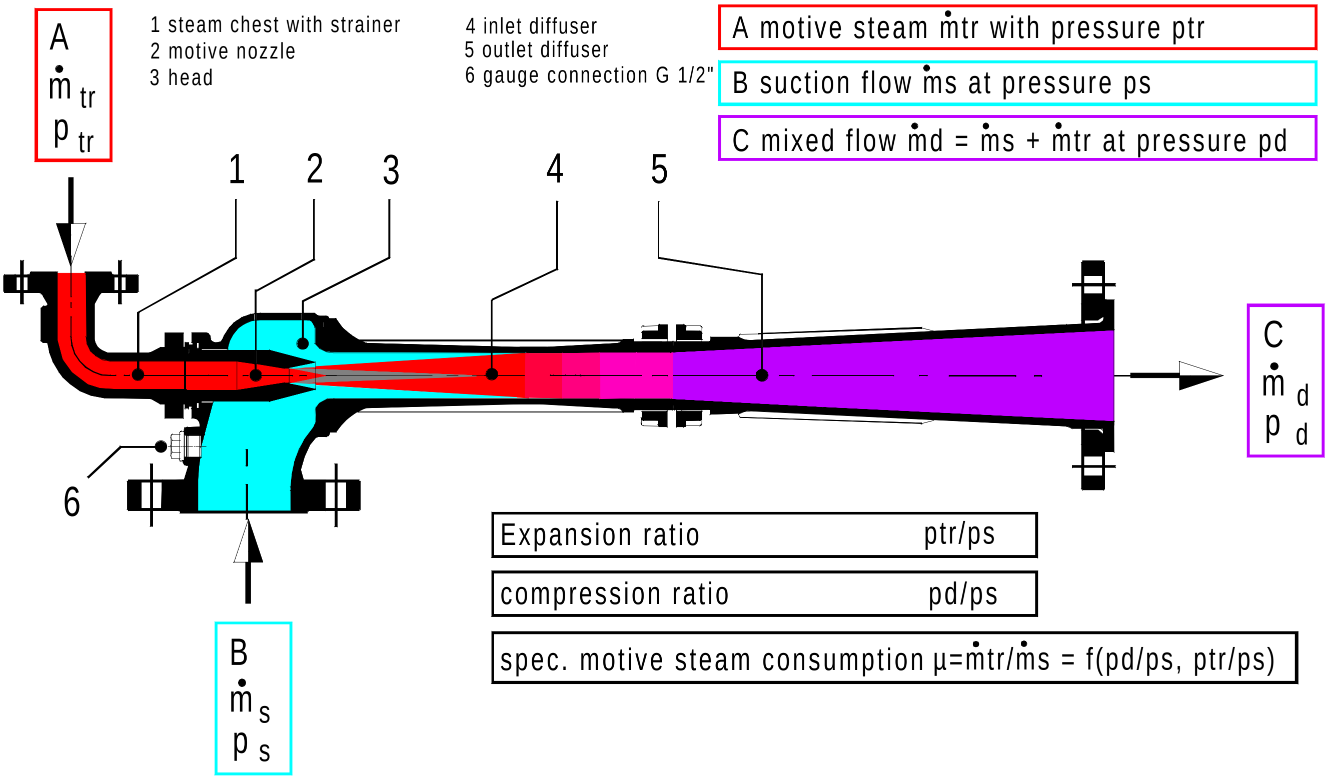


The motive flow enters the motive nozzle with a fixed pressure and velocity. It is not possible to transfer the high energy of the motive flow directly to the suction flow.

The LAVAL NOZZLE converts the pressure energy of the motive flow (steam) into kinetic energy, until the nozzle outlet the velocity will be increased up to supersonic velocity. At this point of the lowest pressure, the suction flow will be entrained, then accelerated and mixed with the motive flow. In the following converging supersonic diffuser, the mixing duct and the diverging subsonic diffuser velocity decreases with increasing pressure.

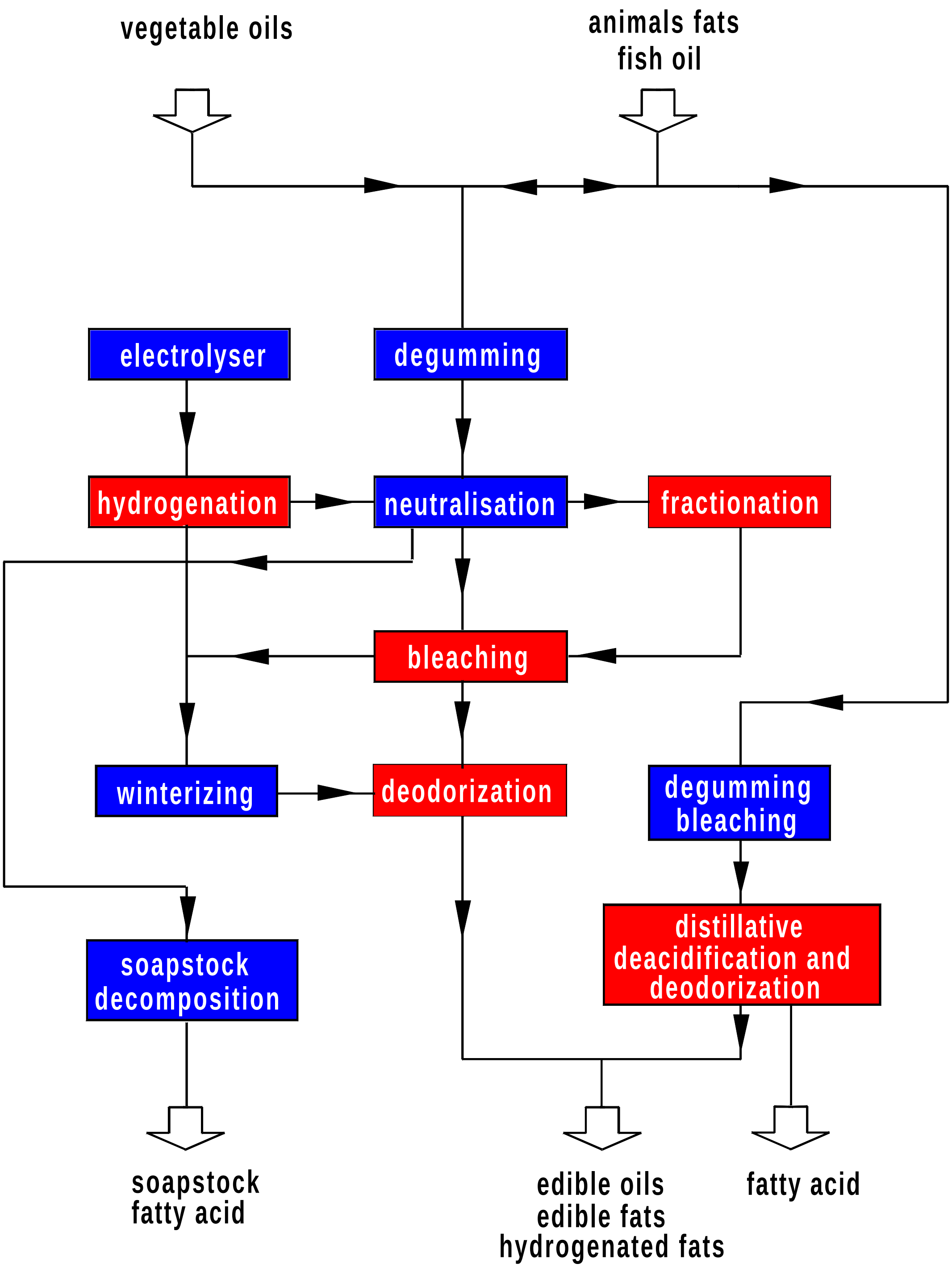
This finally results the discharge pressure of the ejector.

Standard terms for Ejectors



The compression attainable from the suction nozzle to the outlet nozzle is, dependent on the motive pressure, the specific motive steam consumption, and finally on the internal geometry of the ejector.

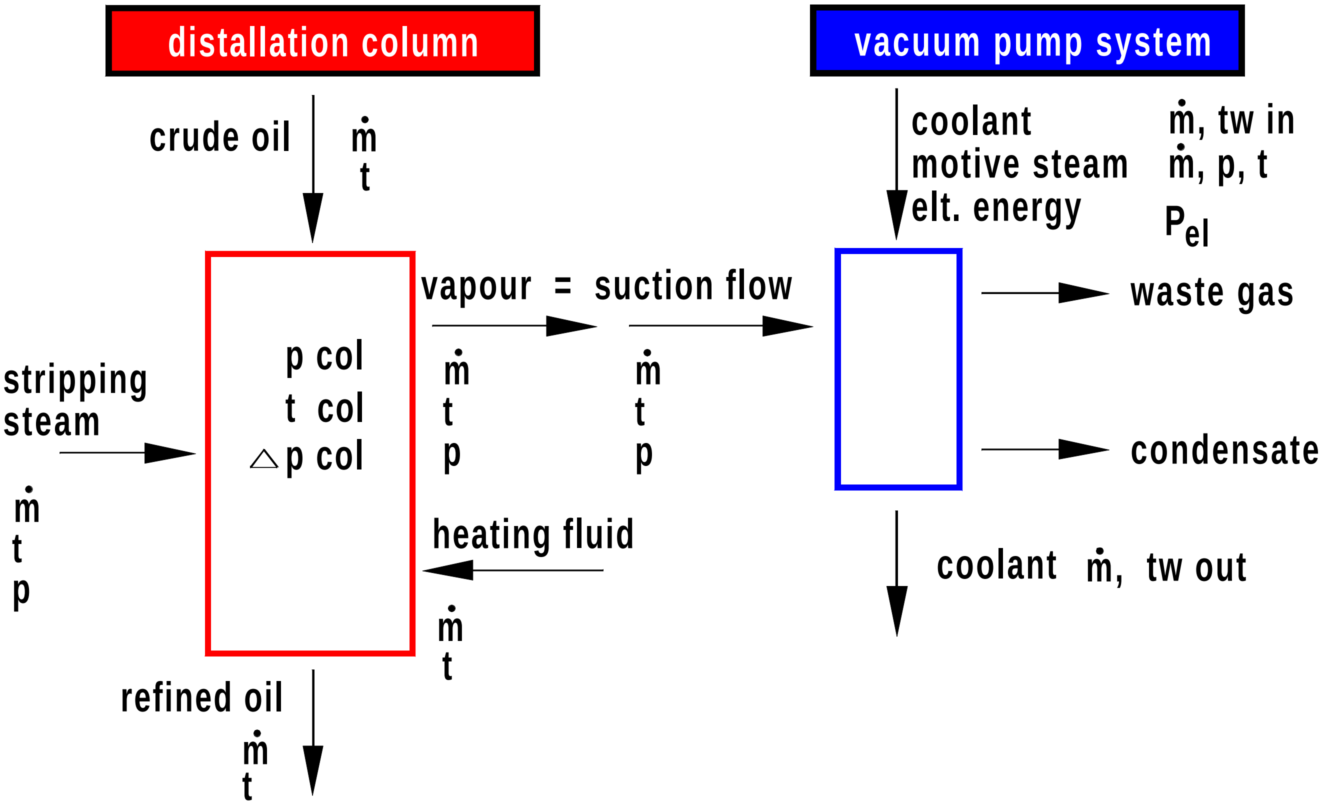
Vacuum in Vegetable Oil Processes



This picture shows the various process stages in the processing of edible oil.
The red fields show the stages of the process which are carried out under vacuum,

- separation,
- bleaching, drying,
- deodorising following alkaline deacidification,
- destillative deacidification with deodorization.

Design Parameters



In all of these process stages similar requirements must be fulfilled;

i.e. relatively large mass flows (mainly stripping steam and some non condensable gases) must be sucked from a vessel (column, dryer, reaction vessel) at a low absolute pressure and be compressed to atmospheric pressure.

In general atmospheric pressure is 1.000 mbar (at sea level).

Working pressure in a distillation column is generally these days taken to be 2,5...4 mbar (sometimes it can be lower).

I.e. ejector systems in such columns must be able to achieve compression ratios from 400..250 (max. compression ratio of a single stage is 12 ....14).

That is why multi-stage ejector systems are used. Those systems consist of ejectors with after connected condensers where all condensable vapours are liquefied.
The following ejector stage has only to compress the non condensable gases, which reduces the total motive steam consumption of a multi-stage system to a minimum.

Multi-Stage Ejector Vacuum System

Today nearly exclusively those ejector systems are used in the edible oil industry world wide.

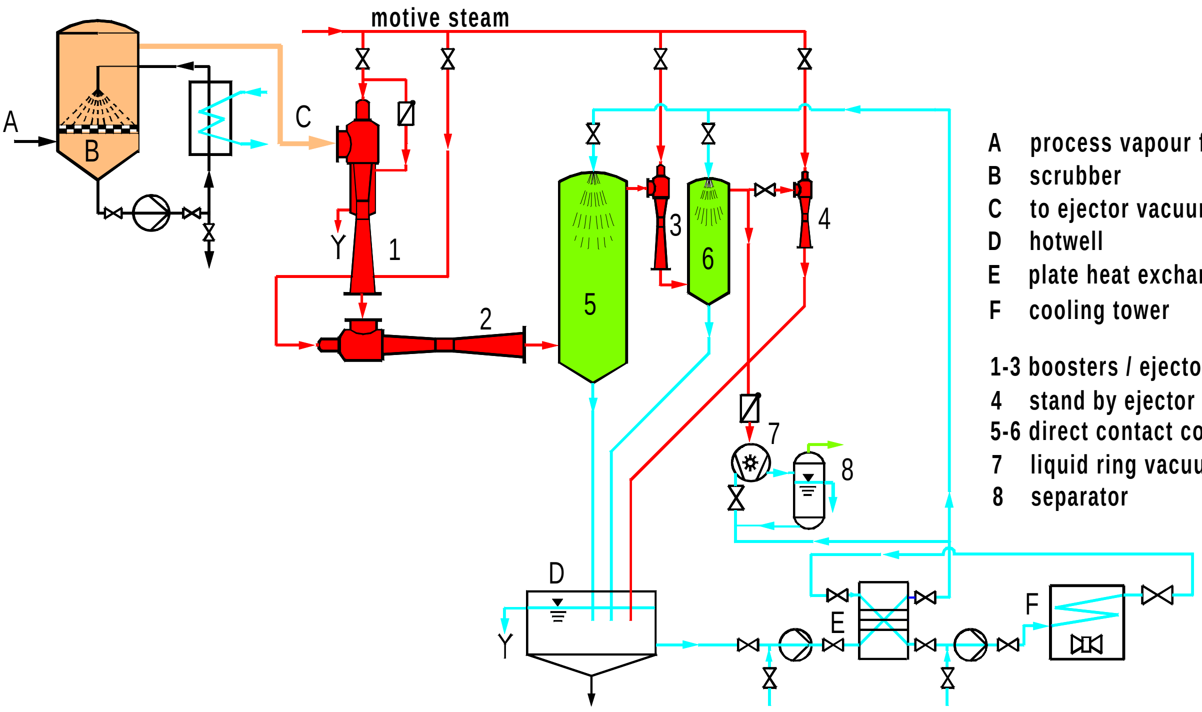
The advantages are obvious:

- large mass flows can be moved within acceptable plant sizes and sensible steam requirement figures (300 kg/h stripping steam at 2,5 mbar still represent a volumetric flow of 150 000 m³/h, that can be conveyed by 1450 kg/h motive steam = 0,4 MW therm.)

- low investment costs.

- low maintenance costs, easy to install and to operate.

Multistage Ejector Vacuum System with Liquid Ring Vacuum Pump



A process vapour from column
B scrubber
C to ejector vacuum system
D hotwell
E plate heat exchanger
F cooling tower

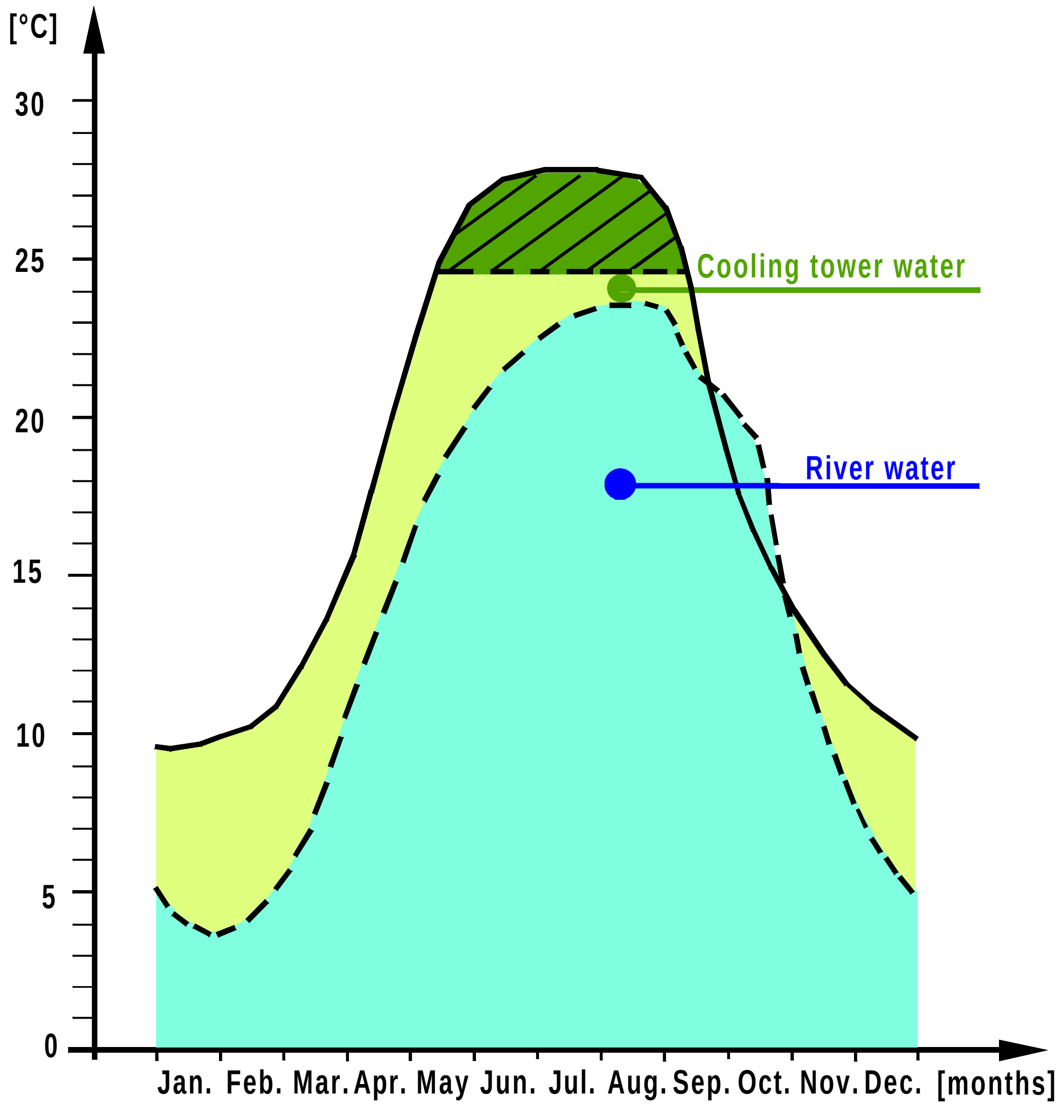
1-3 boosters / ejector
4 stand by ejector
5-6 direct contact condensers
7 liquid ring vacuum pump
8 separator

It is sensible in the case of multi-stage compressions to combine the advantages of steam ejectors and water ring pumps.

That means up to the first possible condensation stage the stripping steam is exclusively compressed by ejectors (so called boosters); after the first condenser a combination of steam ejectors and water ring pumps can be implemented.

The available coolant and its temperature have a decisive influence
on the design of the first inter condenser, the number of ejector stages and on the total motive steam consumption for the plant.

Cooling water temperature



The possibility of condensing the water vapour (suction- and motive flow), depends on the temperature of the coolant, which is mainly cooling water.

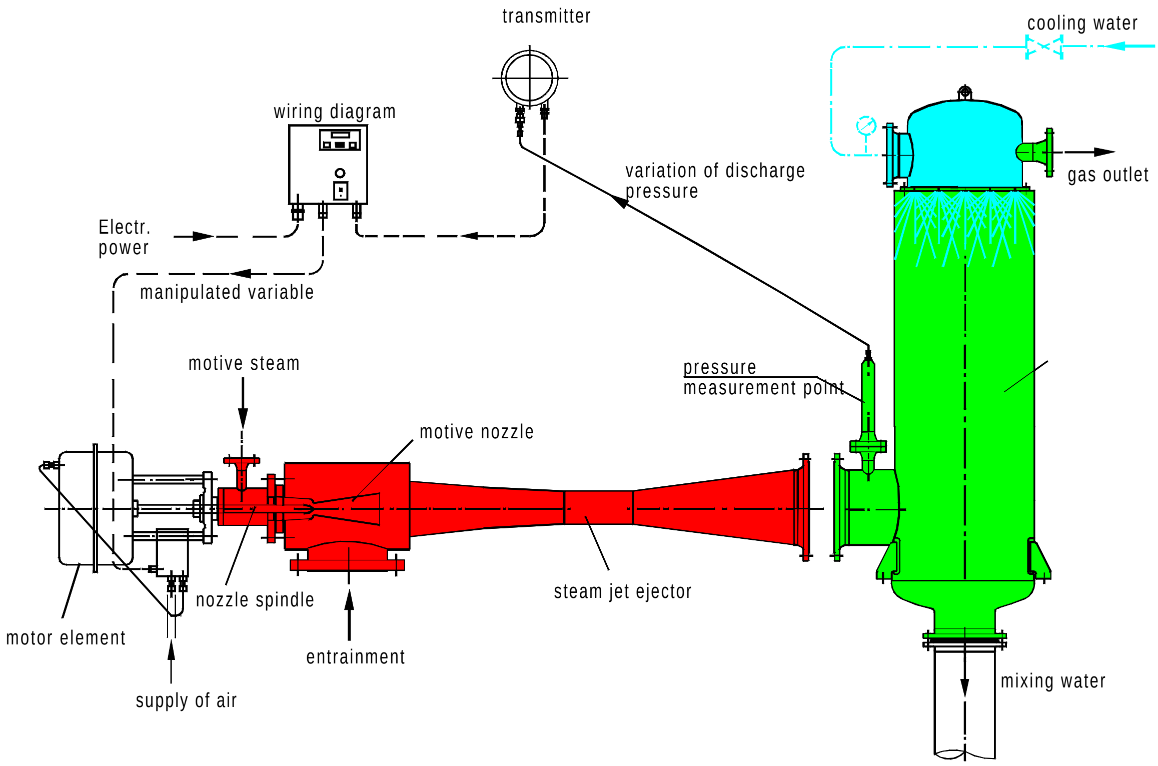
The graph shows the cooling water temperatures through a year. The corresponding saturation (condensation) pressure gives the limitation for any condenser (surface or direct contact type).

An ejector system has to be designed for the most unfavourable operating conditions,
i. e. for the max. stripping steam flow and the highest cooling water temperature.

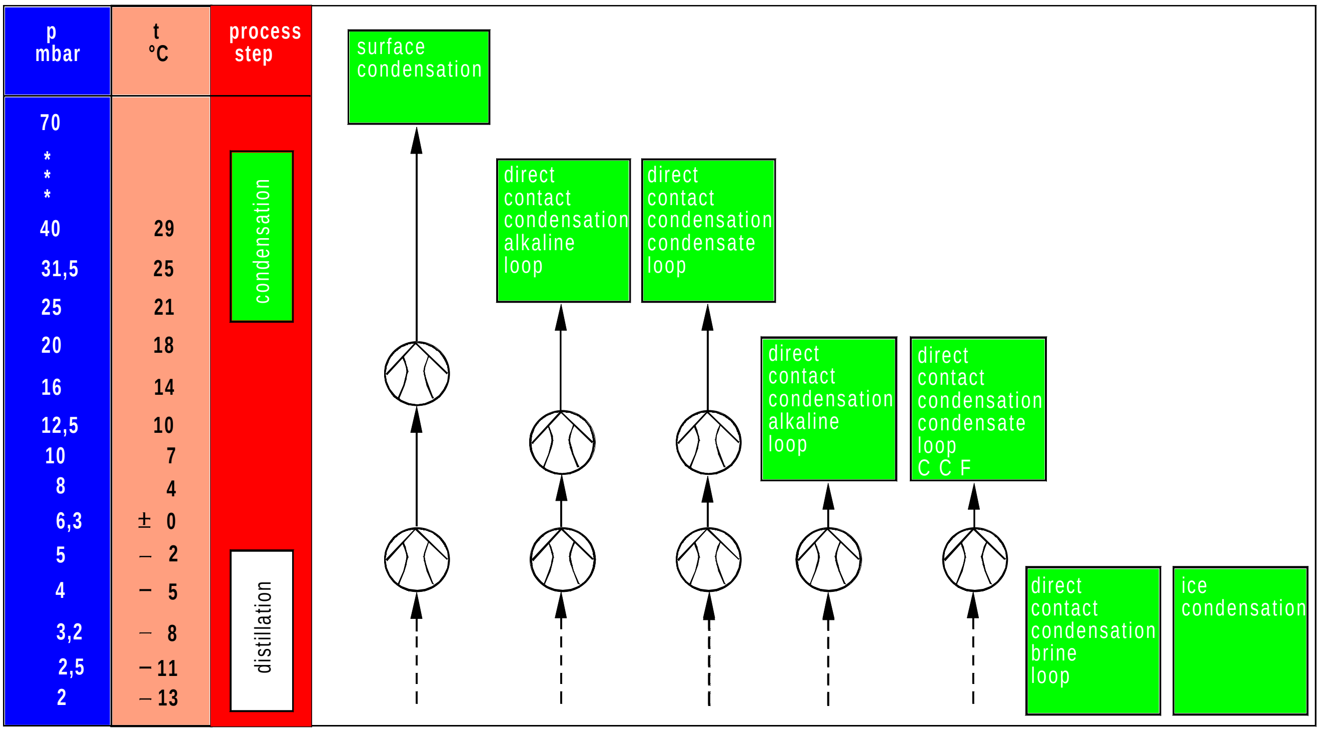
If -during operation- the cooling water temperature changes to a lower value and the system is not adaptable, energy will be wasted.

As far as the motive steam consumption is concerned, this problem can be overcome by adapting the motive steam consumption to the actual counter- or discharge pressure in the condenser which is varying with the cooling water temperature.

With decreasing water temperature, this can be done reducing the motive steam pressure or, in a more economic way, by reducing the nozzle throat diameter with a movable nozzle needle as shown below.



Vacuum Pump Systems, where Stripping Steam Condensate is strictly partitioned from Coolant



In the realisation of this separation numerous systems have been developed which are shown in the picture above:

on the left a pressure scale can be seen,

next to it a temperature scale (this shows the corresponding water boiling or condensation temperatures),

the green areas show at which temperature the first condensation takes place.

Furthermore the following can be seen:

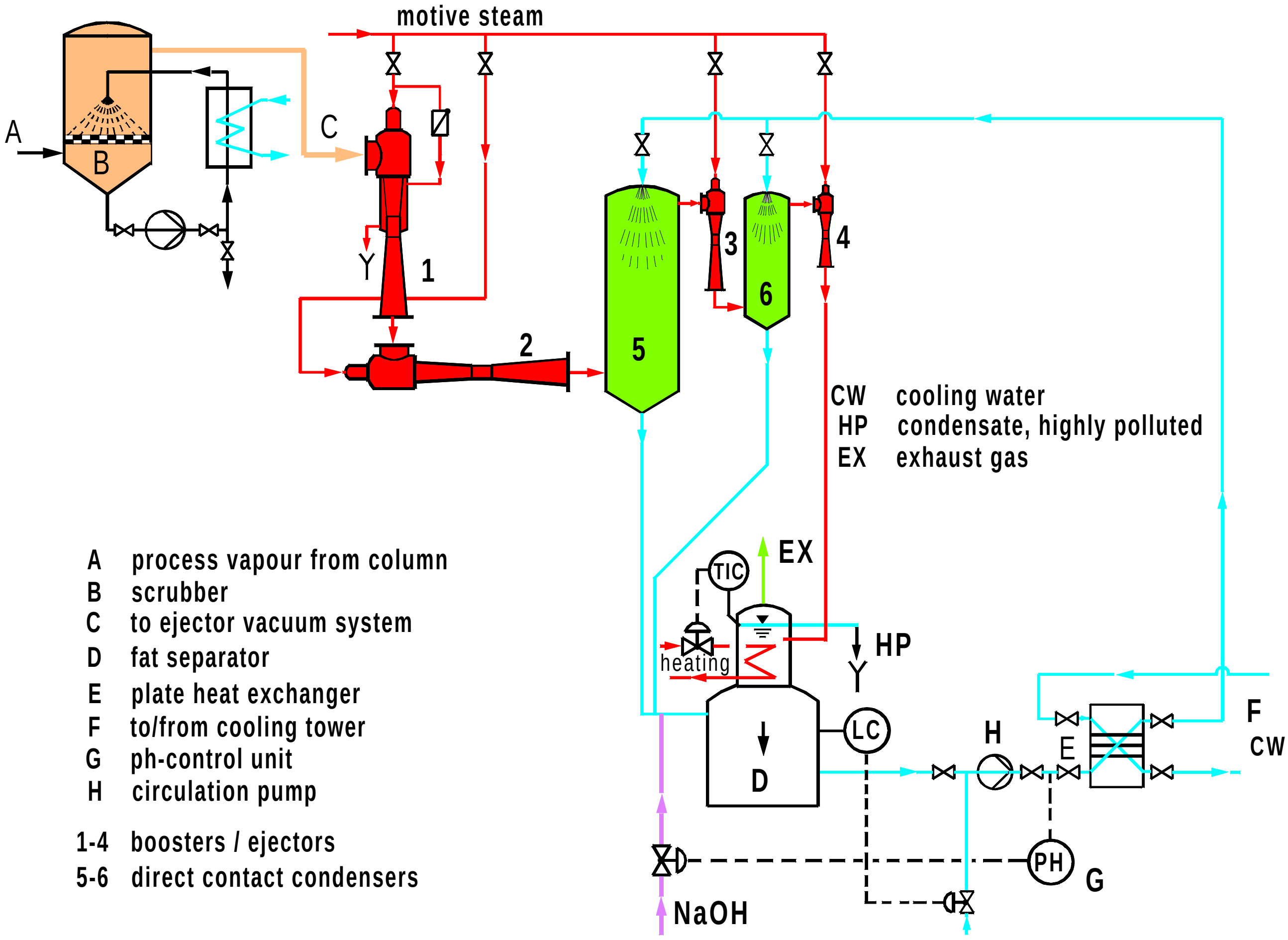
with "normal", cooling water temperatures, (cooling tower / river water), a two-stage pre compression with steam ejectors is unavoidable.

By using chilled water sets, i. e. water temperatures less than 10°C only one steam jet compression stage is sufficient.

Only with coolant temperatures far below 0°C it is possible to work without a steam ejector for pre compression; condensation is then done either by a salt solution in direct contact condensers or in so called ice-condensers with indirect condensation (shell and tube condensers).

Some of these systems are shown schematically on the following pages.

Alkaline System (ACL) Normal Cooling Water Temperature

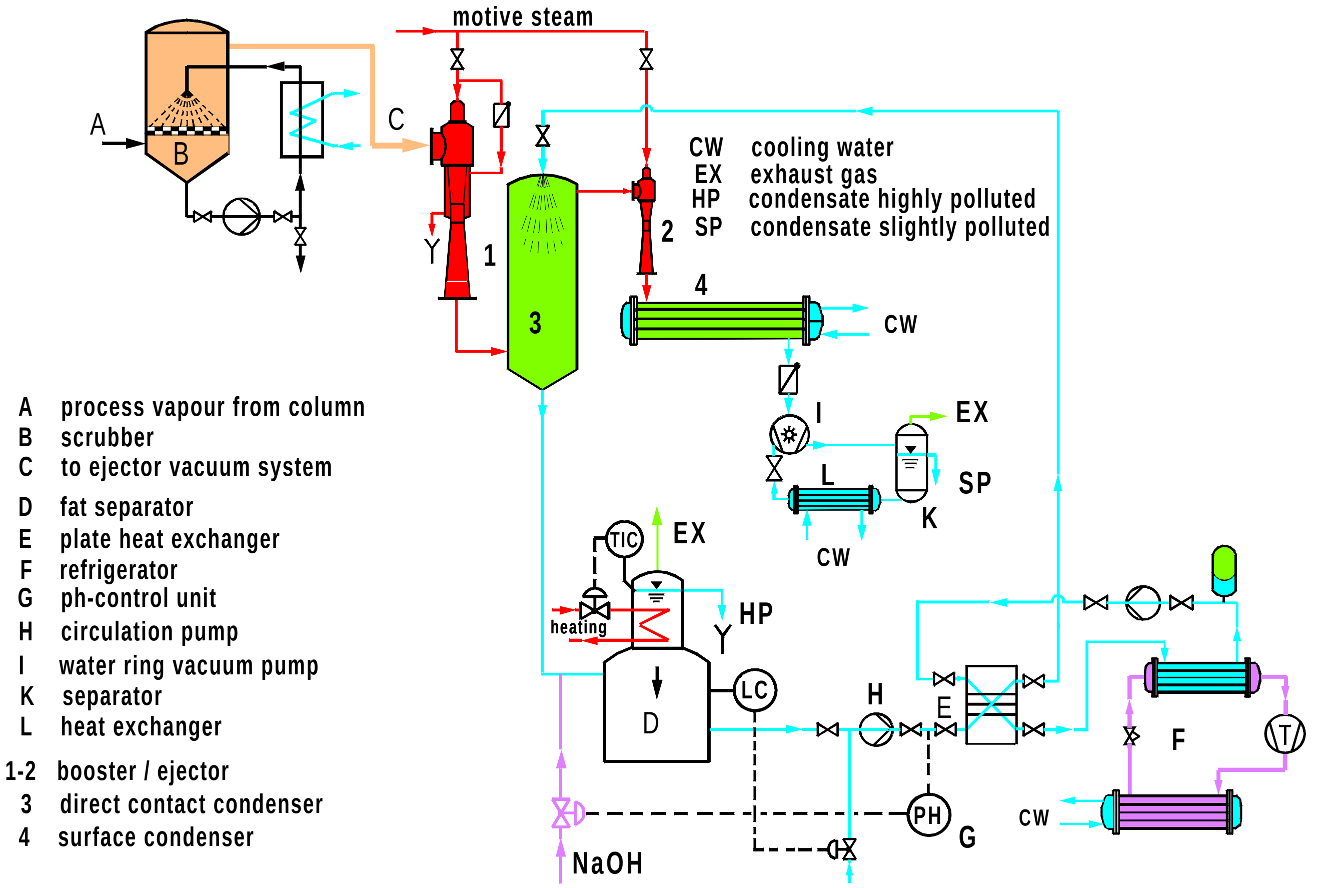


When using the proven mixing condenser, the mixture of condensed motive steam and stripping steam stays in a closed loop and this circulating water is cooled against "normal" cooling water in plate heat exchangers, i. e. cooling water at ambient temperature. Sodium hydroxide solution is added to the circulation fluid to avoid too fast fouling in the heat exchanges from crystallising fatty acids.
Using either the usual seal box or an especially developed separator and removing only the portion of the mixed motive steam and stripping steam condensate from the circulation leads to extremely waste water amount.

The benefits of these systems are:

- small amount of waste water,
- low investment costs,
- lowest maintenance costs.

Alkaline System (ACL) Low Cooling Water Temperature



With the help of a refrigeration system the circulating water is cooled to about 4...6 °C and is warmed by about 3...4 °C in the mixing condenser

As a result of this the pressure in the mixing condenser is no longer in the region of 50...70 mbar but about 11...15 mbar.

The necessary compression ratio before the condenser is no longer 20...30 but is now only 5...7; as a result of this one booster stage with a correspondingly low steam consumption may be used.

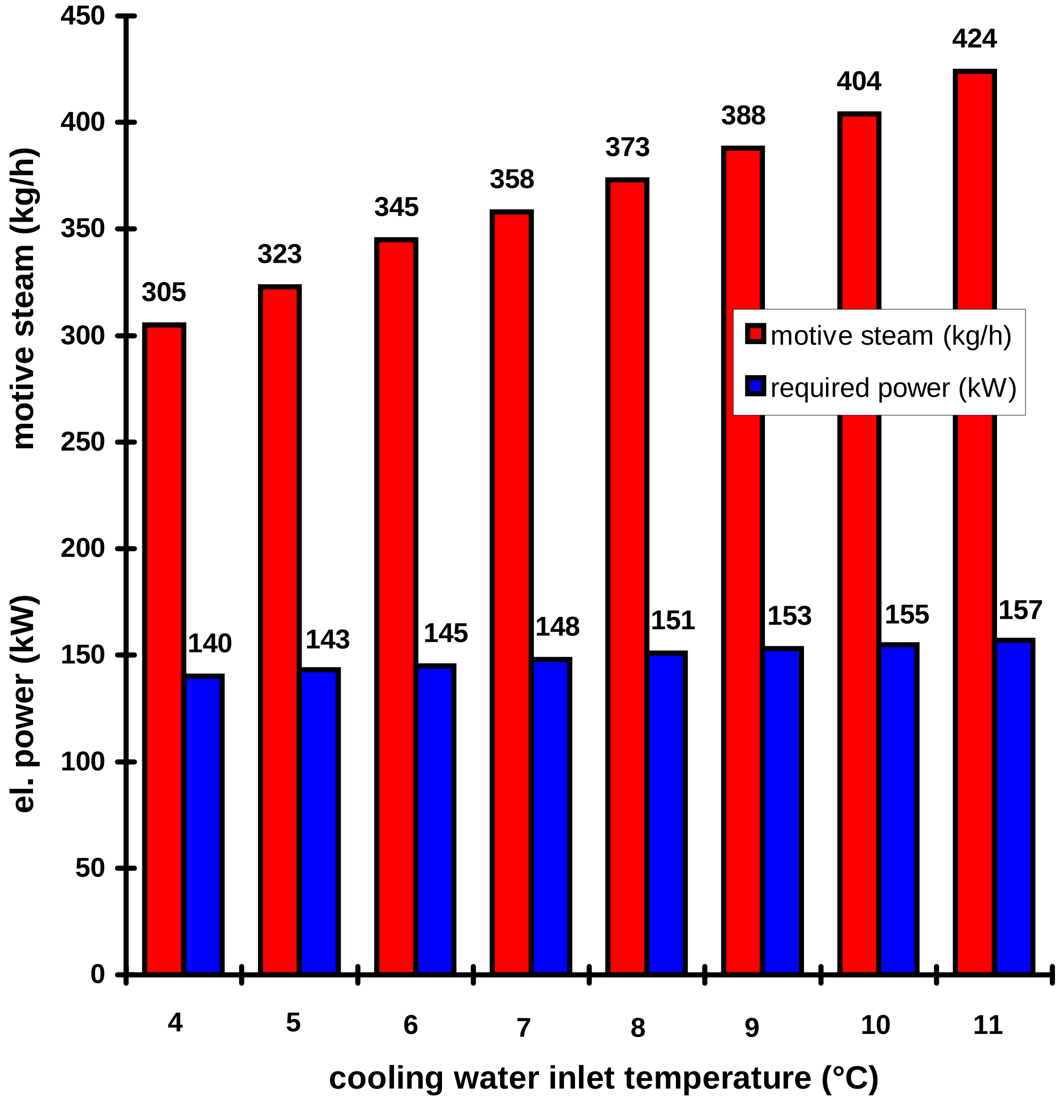
The compression of noncondensable gases does however require a somewhat higher motive steam consumption but the total costs for energy in the form of motive steam and electrical power are lower than for the „Normal Cooling Water Temperature“ system.

Due to the higher cost for the refrigeration system the whole system is more expensive.

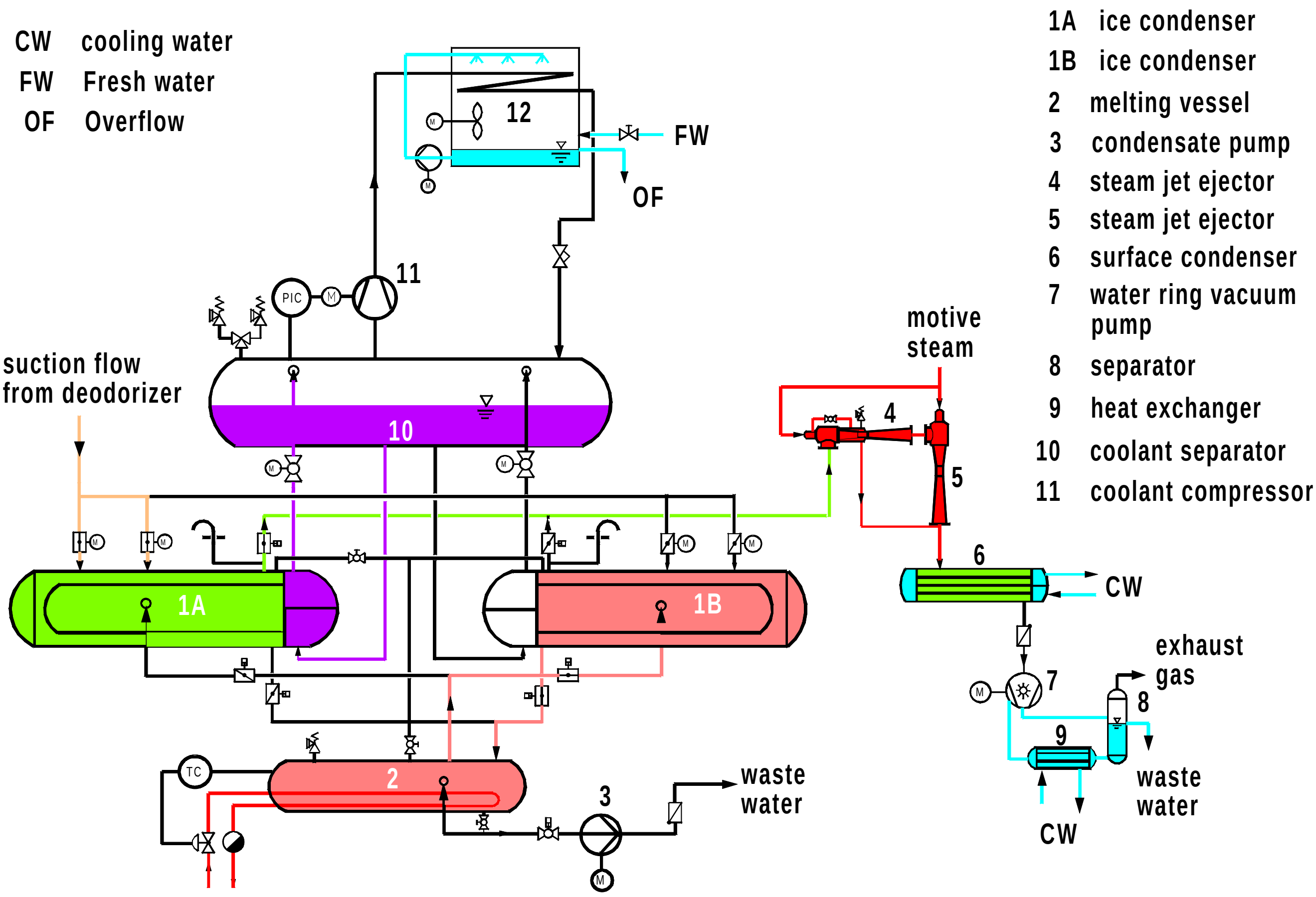
Comparison figures for Alkaline System (ACL) with chilled cooling water

design data :

Stripping steam rate	**:**	**200**	**kg/h water vapour**
	+	**6**	**kg/h air**
	+	**10**	**kg/h FFA**
Suction temperature	**:**	**120**	**°C**
Suction pressure	**:**	**2.66**	**mbar**
Motive steam pressure	**:**	**8**	**bar g./sat.**



Ice Condensation Vacuum System



Following the idea to condense the stripping steam at the lowest possible temperature and pressure leads to a system where the stripping steam can be condensed at the process working pressure of the column. In case this pressure is below 6 mbar, water vapour condenses into the ice phase.

This can be done:

- by direct connection between column and surface condenser which is cooled by an evaporating refrigerant (i.e. NH_3) having a temperature of less then- 20 °C.

That means:

- water vapour freezes outside the tube bundle
- at a certain load which can be chosen in appropriate limitations, the condenser has to be isolated from the column and the ice has to be molten by vapour generated in the melting vessel.
- meanwhile a second condenser has to be connected to the column for continuos operation.

This ice condensation system combines the smallest possible quantity of waste liquid with the lowest energy consumption when operating a vacuum system at a pressure below 6 mbar.
Even at the relatively high investment cost, it is worthwhile to invest in such systems because of steady increasing costs for energy and waste water treatment.

The picture shows a section of an ICE-condensation plant.