Basics of efficient and environmentally friendly vacuum systems

Christian Schulz, 17.06.2022

Figures, data & facts

- Manufacturer of leading products in vacuum and environmental technology
- Focus on engineering and core expertise in niche markets worldwide
- Subsidiaries and representative offices worldwide

OVER
80%
export ratio

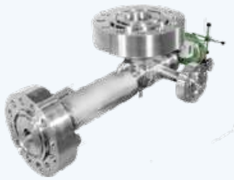
OVER
300
employees

OVER
€50 million
turnover

Product overview

EJECTORS AND VACUUM TECHNOLOGY

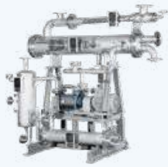
Jet ejectors

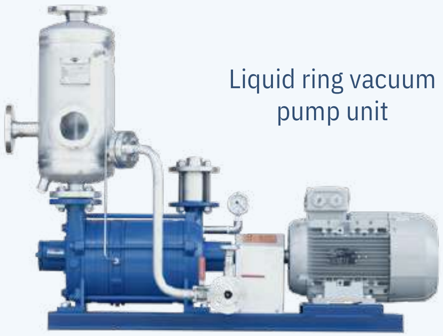


Condensers

Process engineering plants

Multi-stage steam jet vacuum systems





Liquid ring vacuum pump unit

Tank mixing systems with liquid jet mixing nozzles

WASTE GAS CLEANING AND ENVIRONMENTAL TECHNOLOGY

Venturi and jet scrubbers

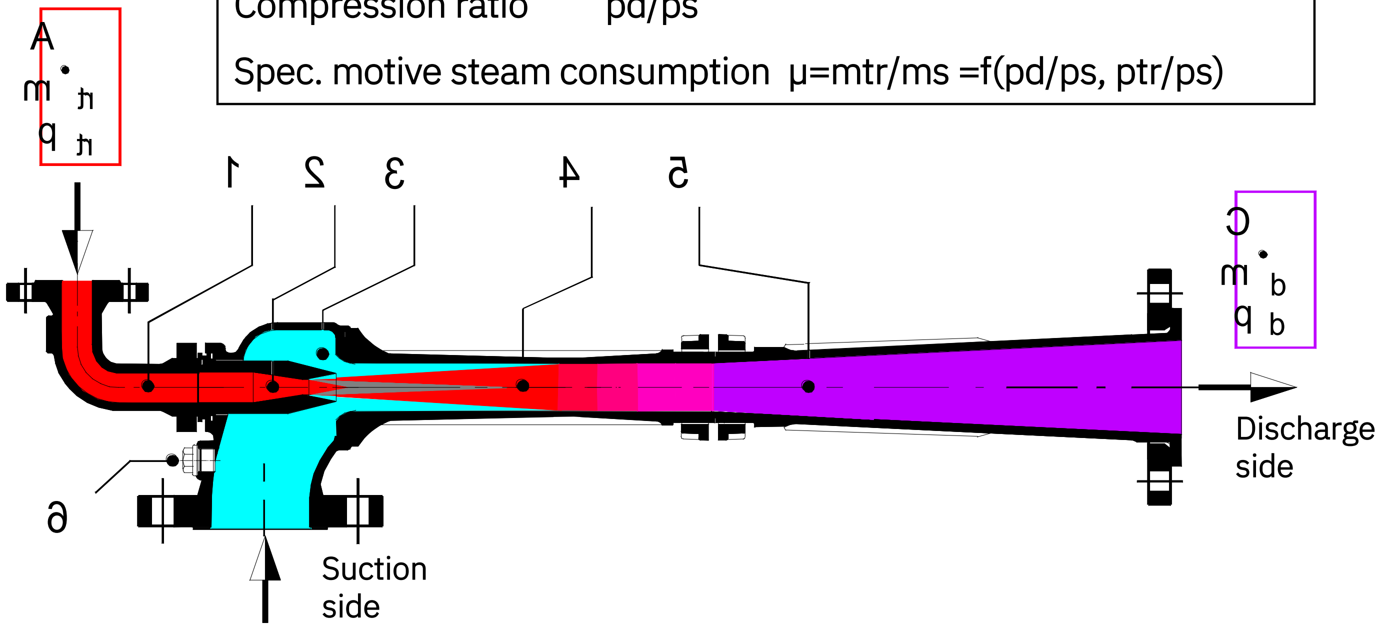
Transfer systems for air, ozone and oxygen

Caustic recovery plants (CRP)

Swirl droplet separators

The Steam Jet Ejector - more than just a T-piece

Expansion ratio	ptr/ps
Compression ratio	pd/ps
Spec. motive steam consumption	μ=mtr/ms =f(pd/ps, ptr/ps)



1 Steam chest
2 motive steam nozzle
3 head
4 inlet diffuser
5 outlet diffuser
6 gauge connection

The Idea Behind Ejectors

Thought experiment

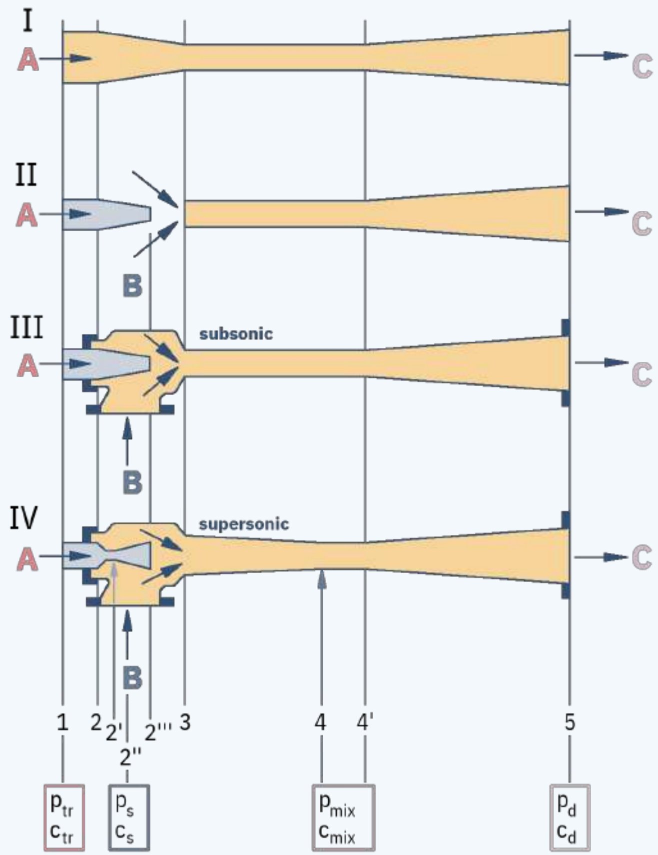
I. venturi tube – Bernoulli‘s equation shows that in the nozzle part the velocity will increase while pressure decreases, and vice versa in the diffusor part

II. if the velocity is high enough, the pressure in the middle section will be below surrounding condition -
by cutting the body, surrounding medium will be sucked in

III. when we build a head around that area, we get an ejector with subsonic speed behind the nozzle

IV. by applying this to compressible medium (gas or vapour) and by using a laval nozzle the speed of the motive medium can be accalerated to supersonic speed –
we now have e.g. a steam jet ejector

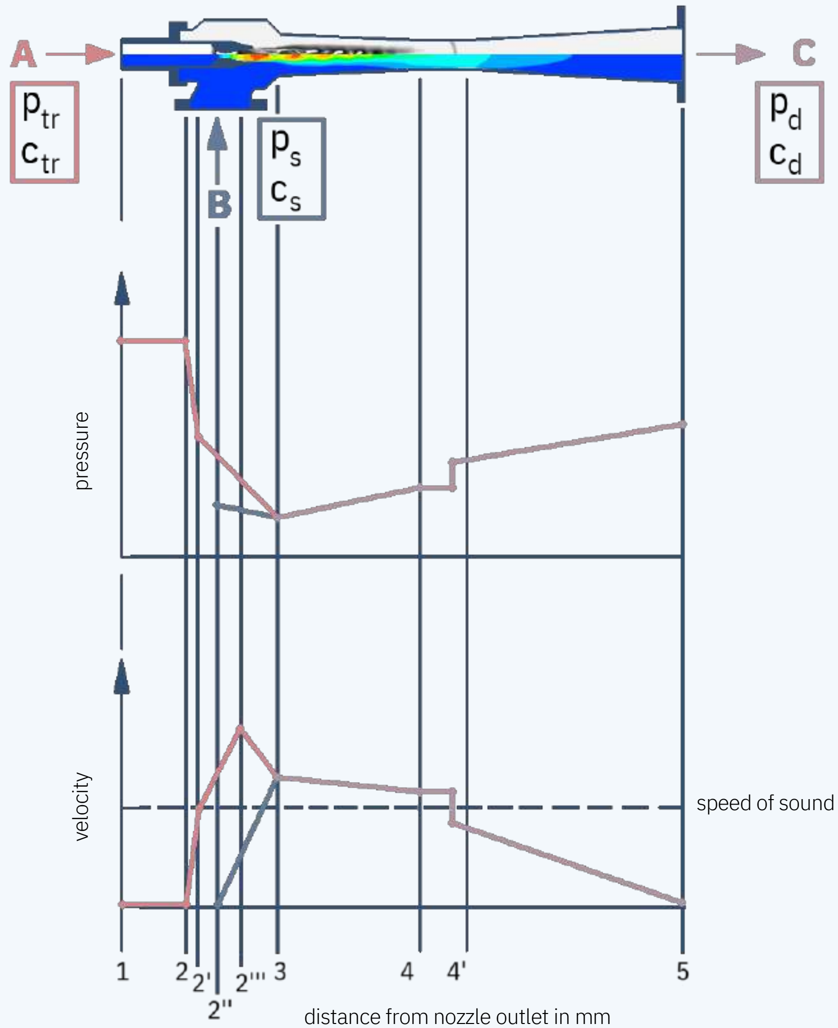
$$\rho g h + \frac{1}{2}\rho v^2 + p = const$$



Steam Jet Ejectors

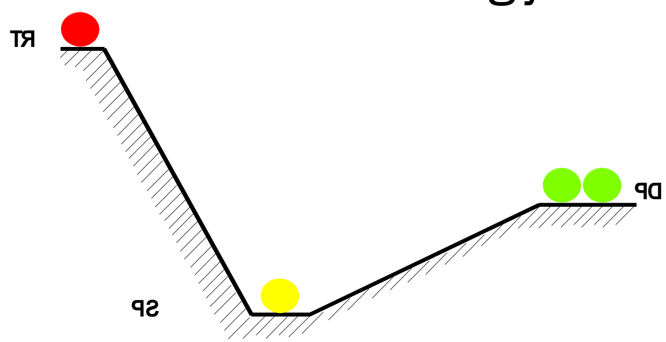
Physical background

- Criticial flow in nozzle throat of Laval nozzle (smallest cross section): fixed flow rate at speed of sound – derived by thermophysical laws (Laval, Körting)
  $p^* \approx 0{,}54\ p_{tr}$
- Further acceleration in laval part and downstream of nozzle to multiple Mach-numbers and $p < p_s$
- Suction medium is accelerated by motive jet (impuls transfer) to Ma > 1
- Pressure gain in inlet diffuser
- final mixing of suction and motive medium in cylindrical part
- Pressure shock (straight shock wave) in cylindrical part (design point)
- Pressure gain in outlet diffuser



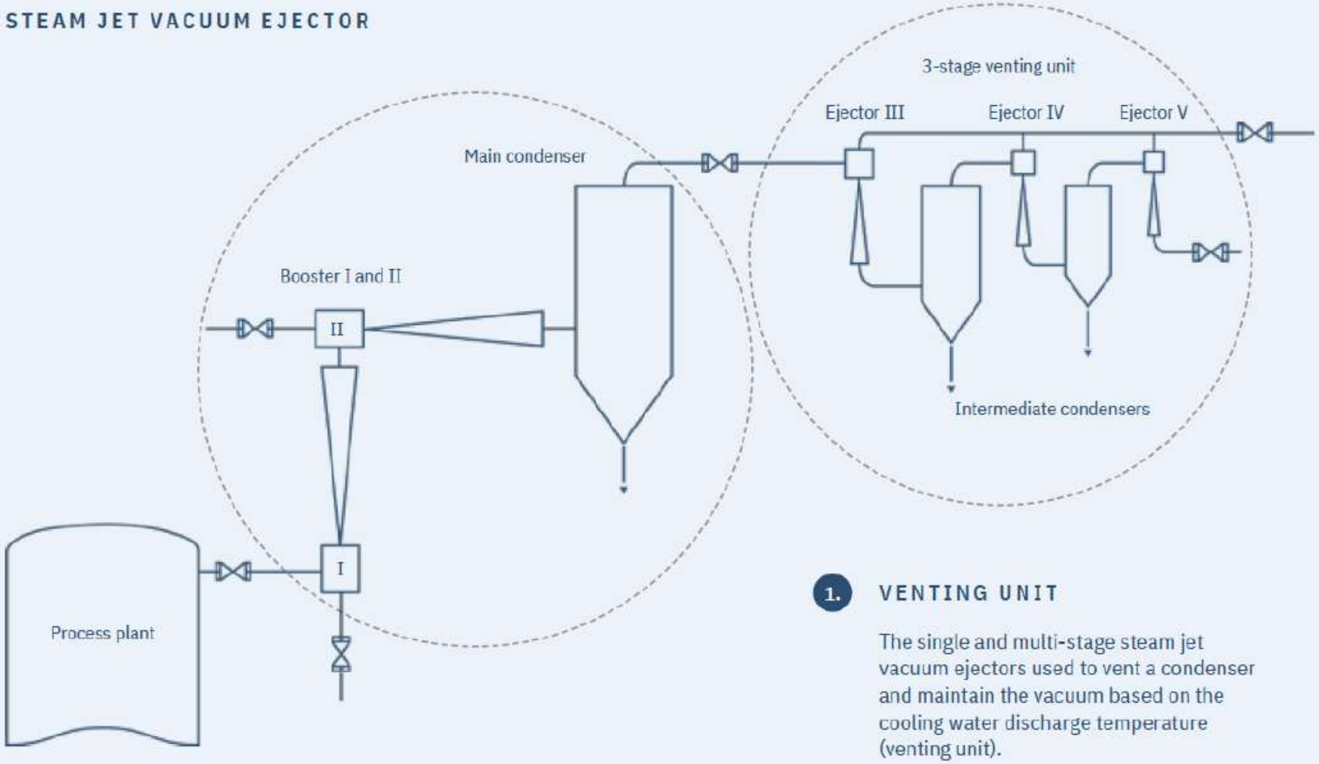
Steam Jet Ejector – Model of Function

Ball Analogy



Multi-stage steam jet vacuum systems

MULTI-STAGE STEAM JET VACUUM EJECTOR



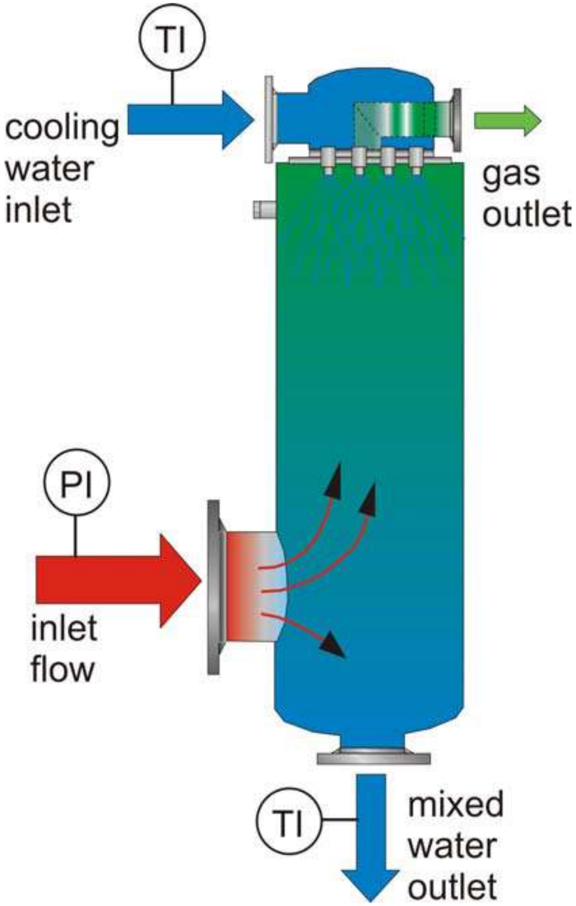
1. VENTING UNIT

The single and multi-stage steam jet vacuum ejectors used to vent a condenser and maintain the vacuum based on the cooling water discharge temperature (venting unit).

2. ONE OR SEVERAL STEAM JET COMPRESSORS IN FRONT OF THE MAIN CONDENSER

The multi-stage steam jet pumps that generate a higher vacuum than the condenser vacuum have one or several steam jet compressors (boosters) in front of the main condenser for this purpose.

Multi-stage ejector system with mixing type condenser (direct contact condenser)

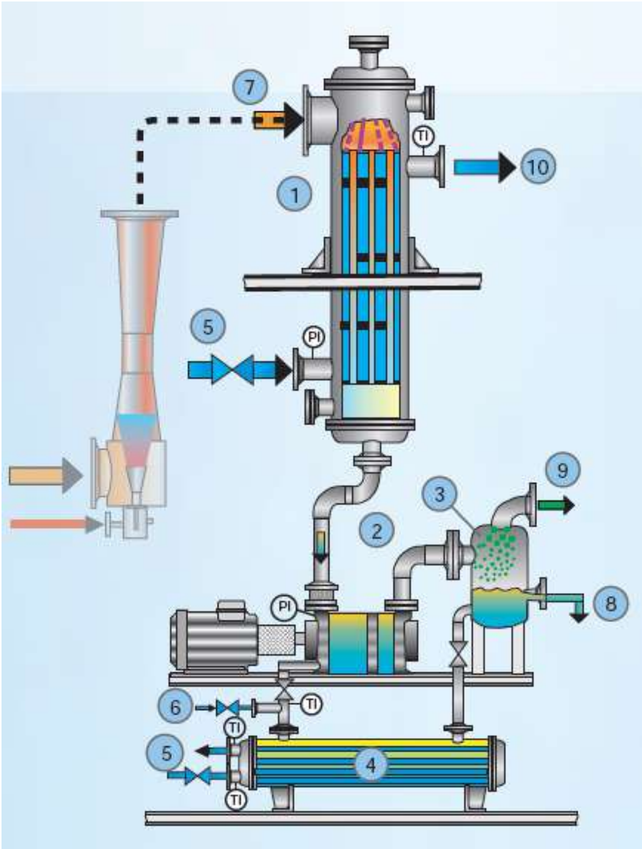


- direct contact between process steam and cooling medium
- most efficient way of steam condensation
- low operation costs and trouble-free and simple operation
- pollution resistance
- low investment costs compared to indirect cooling

Disadvantages:

- mixing of process flow and cooling water flow/ contaminated water
- dirty cooling tower

Multi-stage ejector system with Surface condenser (shell and tube condenser)



- strict separation of cooling water and process medium
- low air pollution and clean cooling tower
- Reduced waste water
- barometric or non-barometric installation

Disadvantages:

- higher investment costs
- Fouling inside the tubes, depending on processed medium
- higher energy consumption due to indirect heat transfer

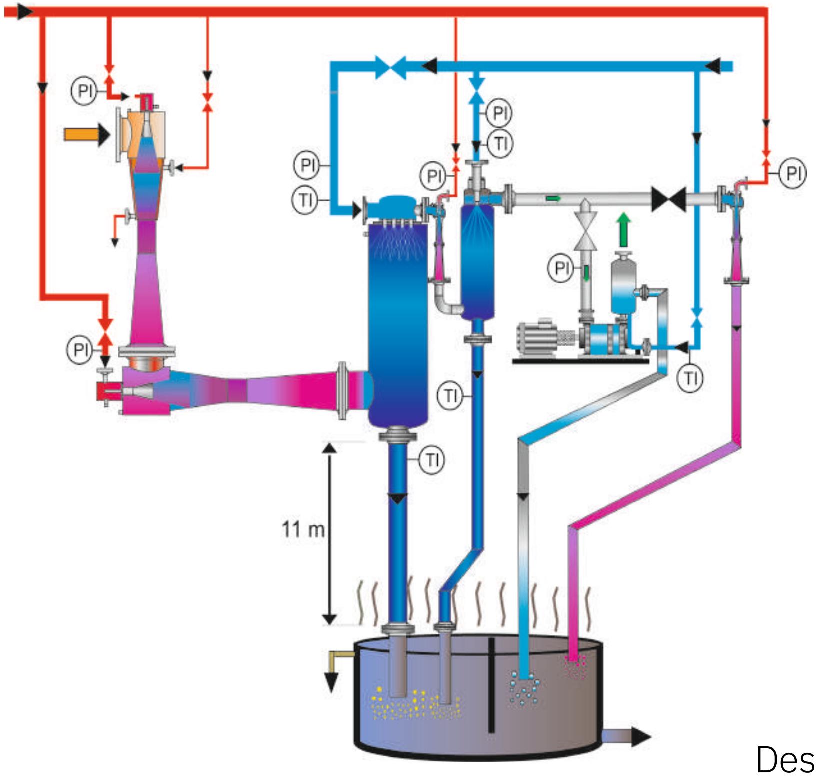
Required design figures for Layout

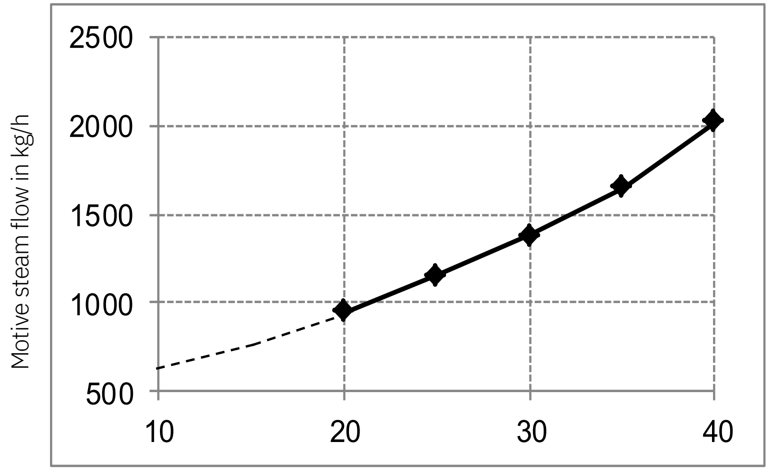
These are the essential available design figures:

- suction pressure
- suction load / mass flow rate
- motive steam pressure
- cooling water inlet temperature

If just one of these parameters changes to another value and the system is not adaptable, energy will be wasted!

Consumption figures of a Traditional Multi-Stage Steam Jet Vacuum System In relation to different cooling water inlet temperatures





Design figures:

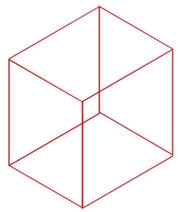
200 kg/h vapour + 10 kg/h air + 5 kg/h FFA @ 2.0 mbar , 100 °C
motive steam pressure 8 bar g.
cooling water inlet temperature of 40, 35, 30, 25 and 20 °C

Size of volume as a function of the pressure

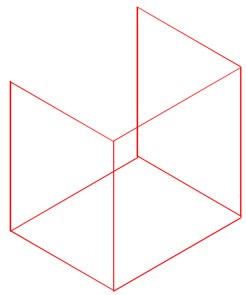
$$\boxed{V \sim p}$$

$$\frac{V_1 \cdot p_1}{V_2 \cdot p_2} \Longrightarrow V_2 = \frac{V_1 \cdot p_1}{p_2}$$

1 kg water vapour at

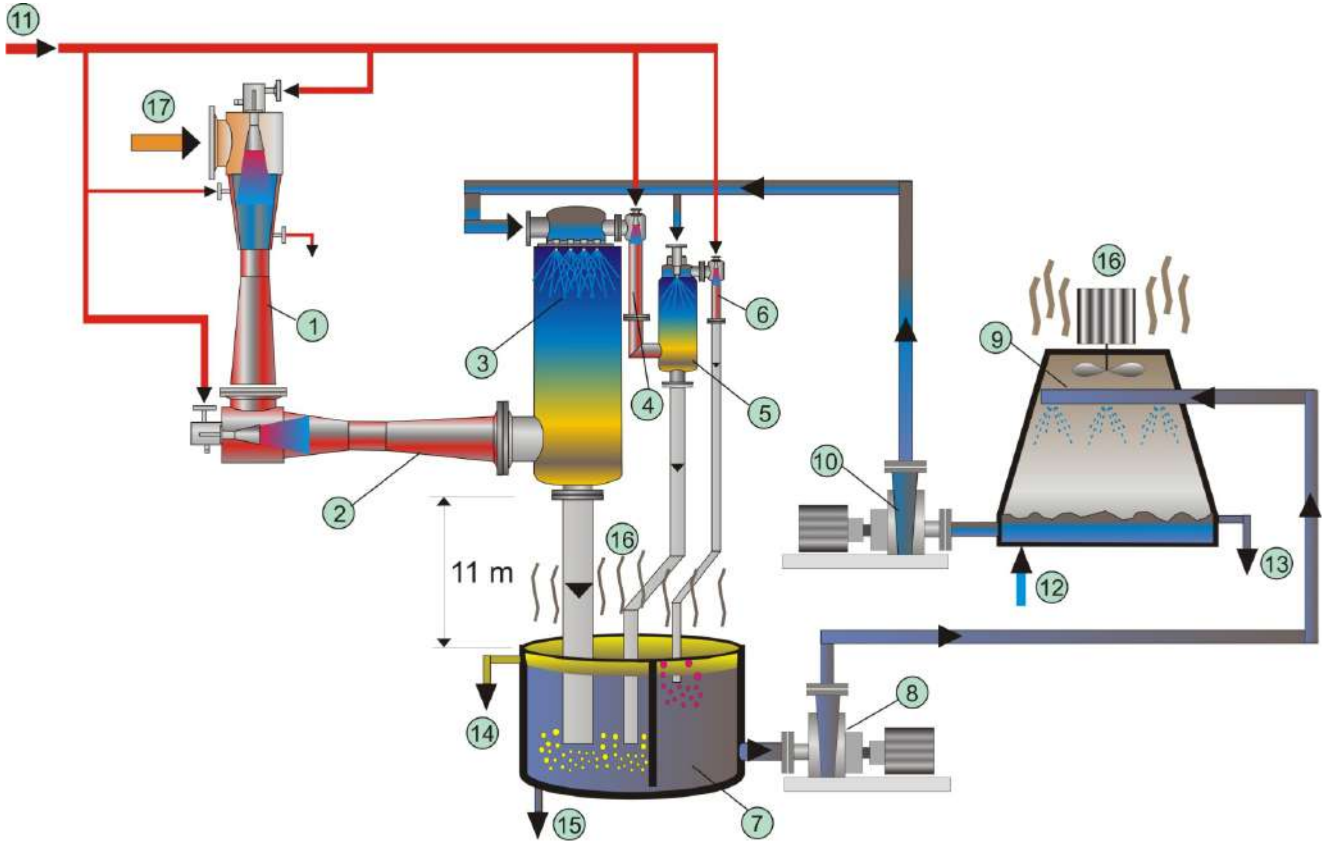


2 mbar => 630 m³

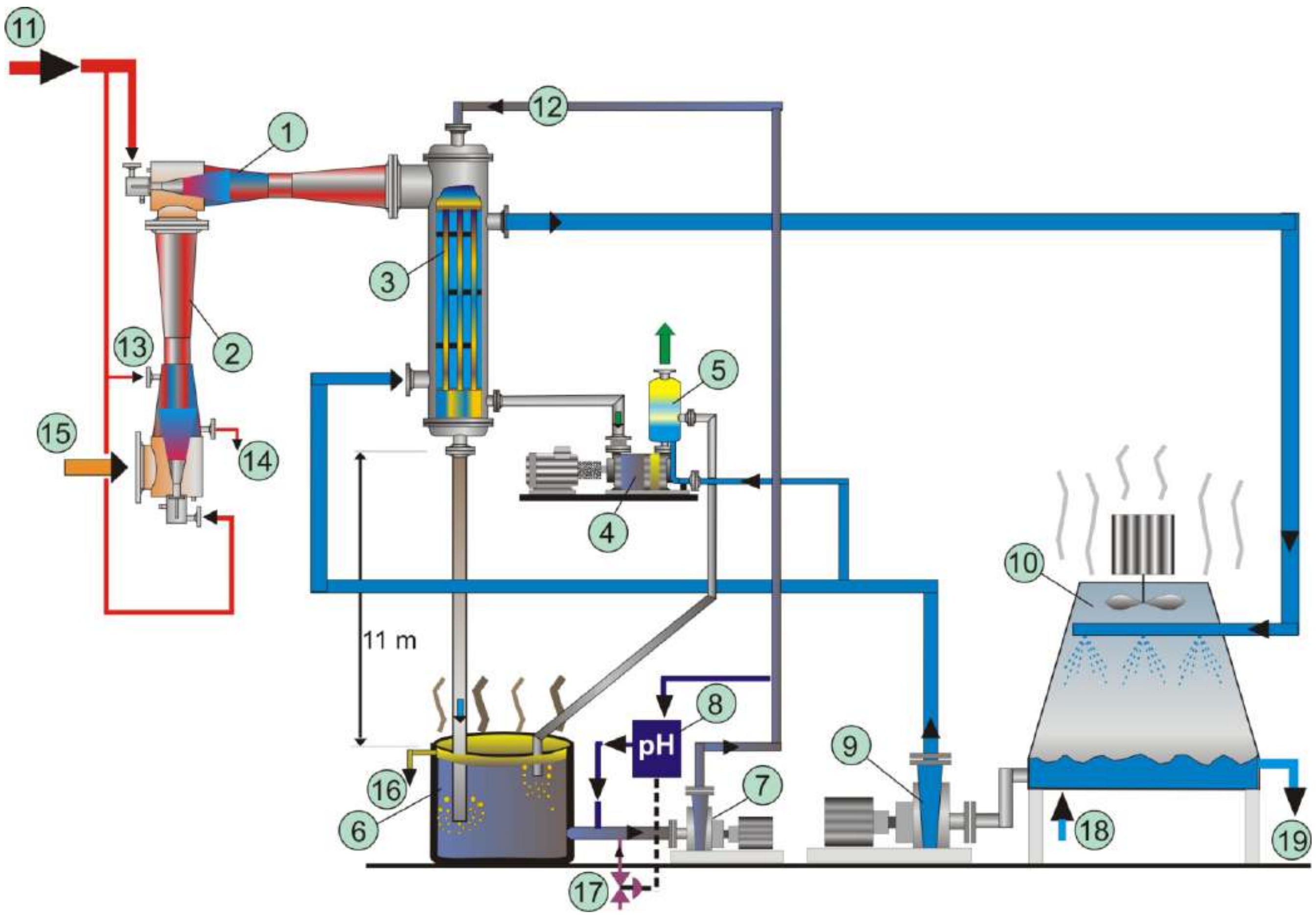


1 mbar => 1260 m³

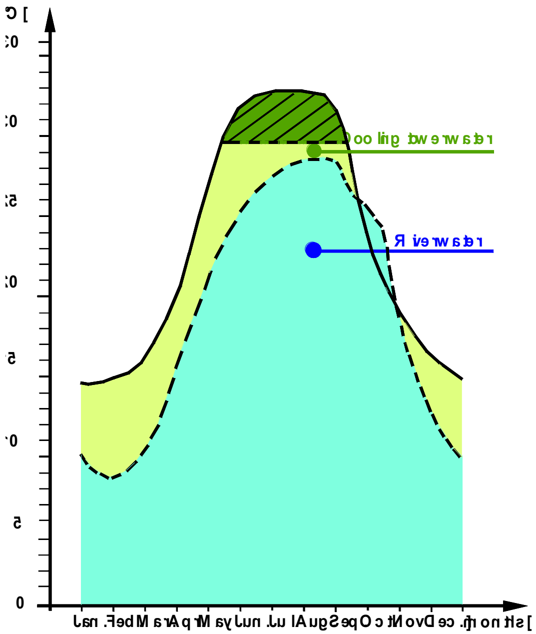
Traditional multi-stage ejector vacuum system with mixing type condensers



Vacuum system with surface condensation

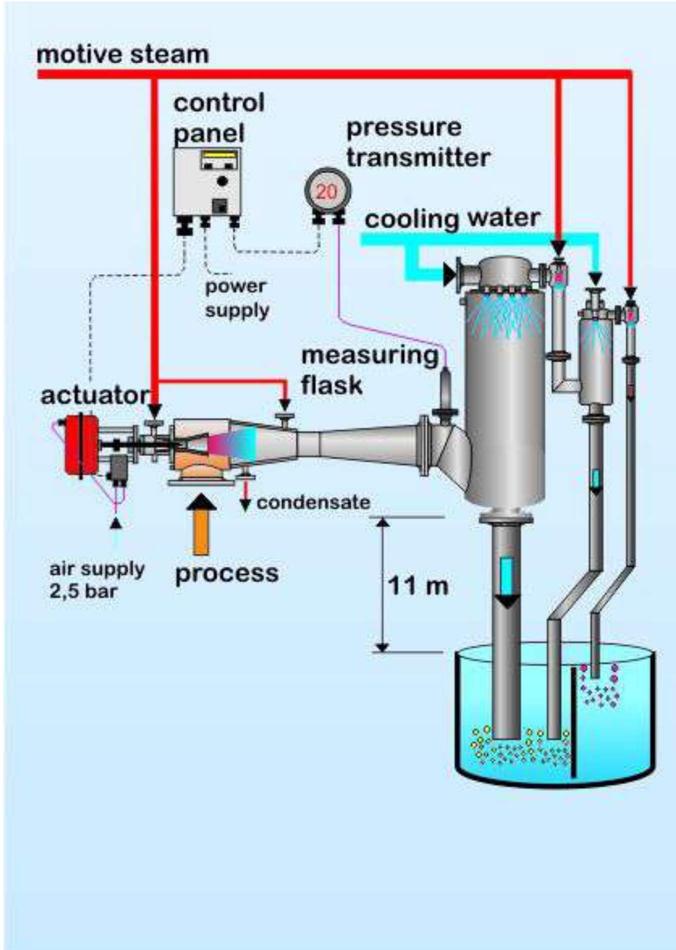


Controllable vacuum systems with mixing condensers

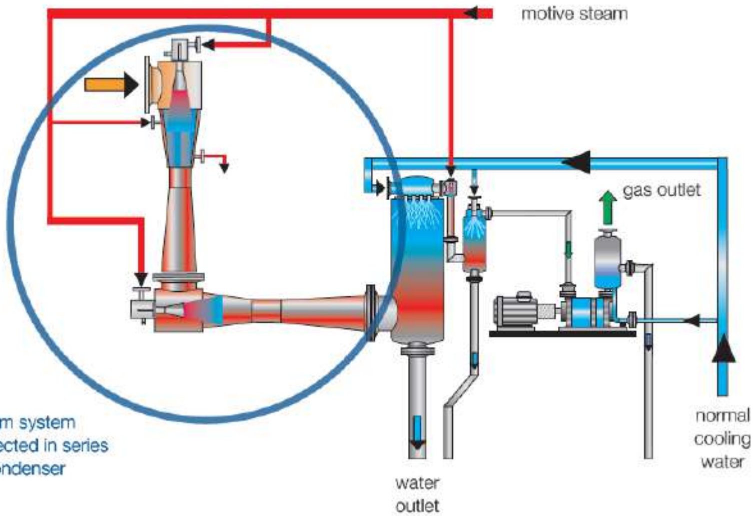


- Ejector design has been made for the most unfavourable operating condtitions

- Reduced energy costs at unchanged performance

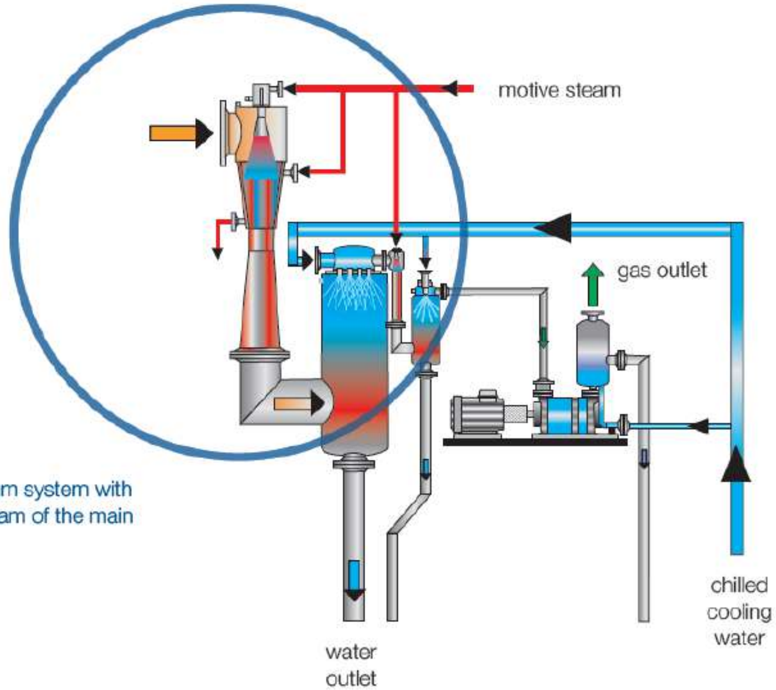


Alkaline vacuum system - normal cooling water vs. chilled water



4-stage steam jet vacuum system with two boosters connected in series upstream of the main condenser

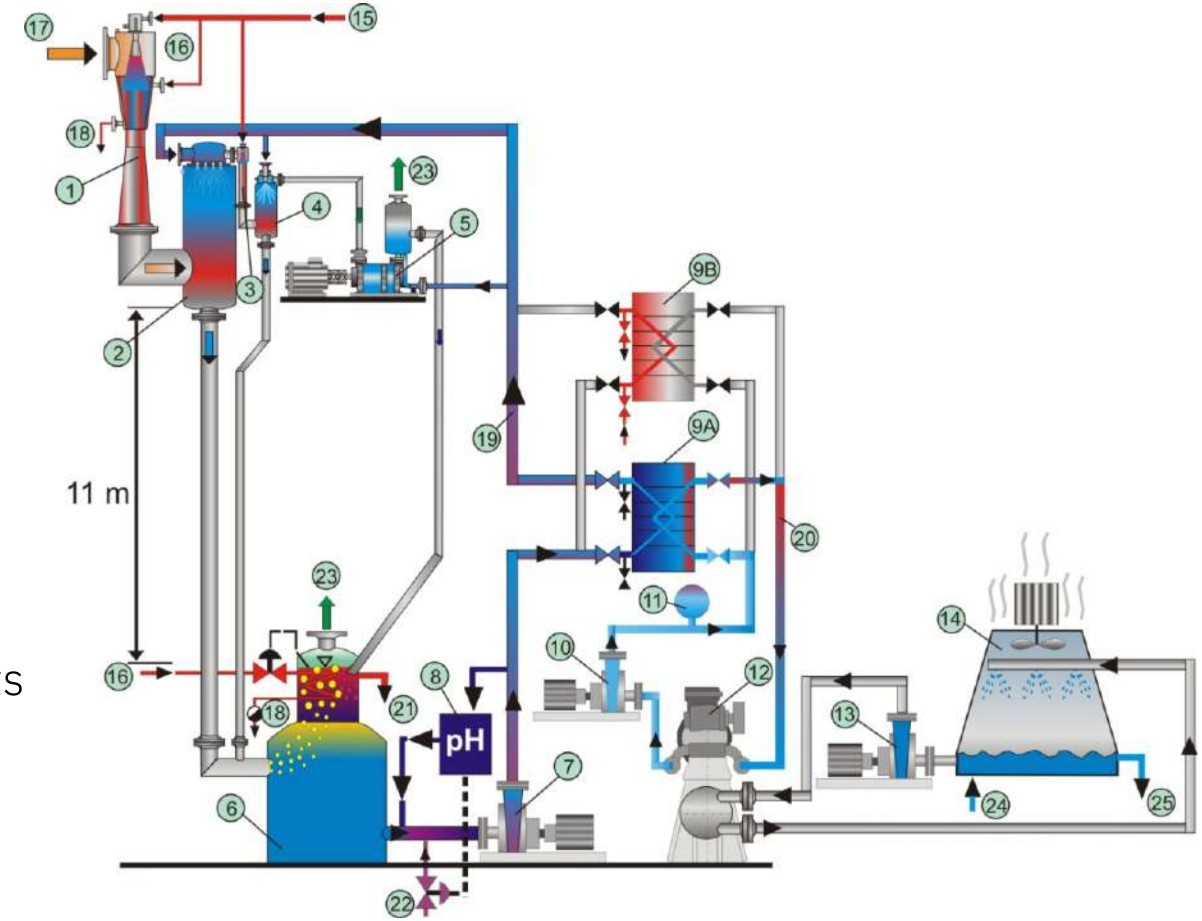
Less steam consumption by using chilled water.



3-stage steam jet vacuum system with only one booster upstream of the main condenser

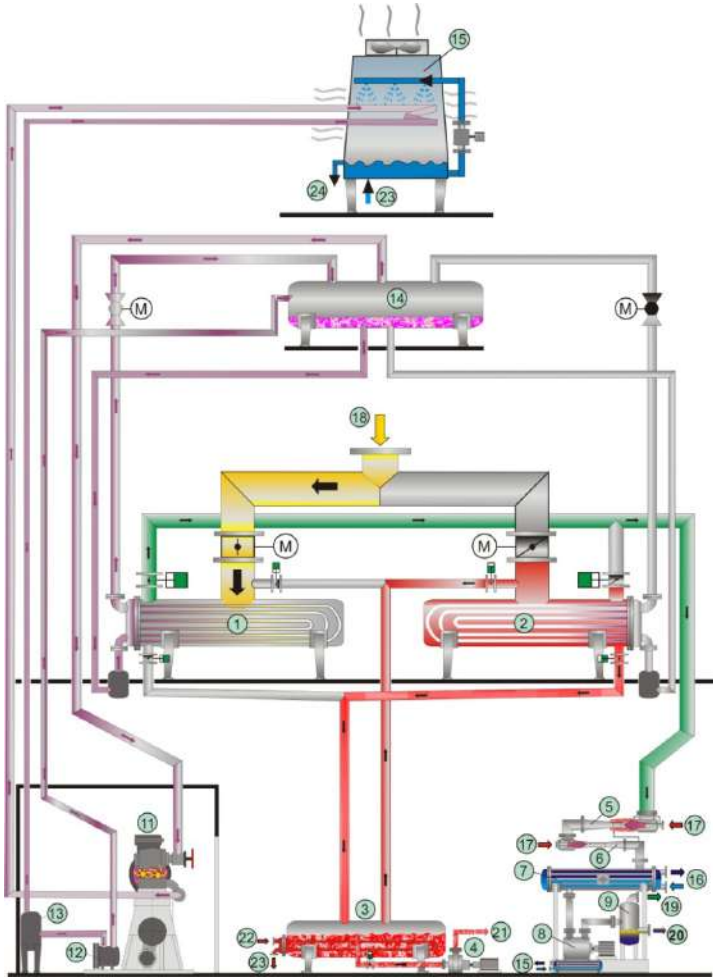
Alkaline closed loop vacuum system (chilled water)

- significant saving of motive steam
- only one booster is necessary
- environmental effects are reduced
- minimized air and water pollution/ clean cooling tower
- safe and reliable operation (conventional vacuum technology)
- low operating and maintenance costs



Ice condensation vacuum system

- significant energy saving / high efficiency
- refrigerated coolant and polluted sparging steam are strictly separated
- nearly no air pollution will be produced
- minimum amount of waste water
- Simple and reliable in operation
- minimum space requirement (skid mounted units)
- non barometric installation possible



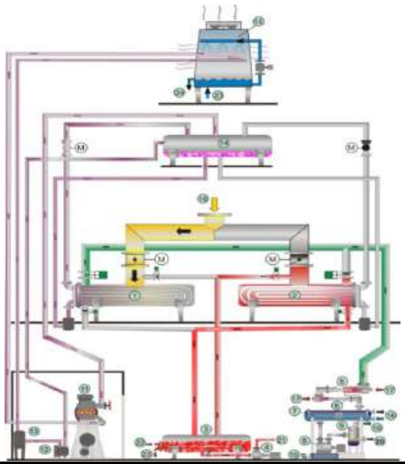
Comparison of the various systems

Design data:

Suction flow:	250 kg/h stripping steam + 10 kg/h air + 4 kg/h FFA
Suction temperature:	80 °C
Suction pressure:	1.5 mbar
Motive steam pressure:	10 bar abs / saturated
Cooling water inlet temperature:	30 °C

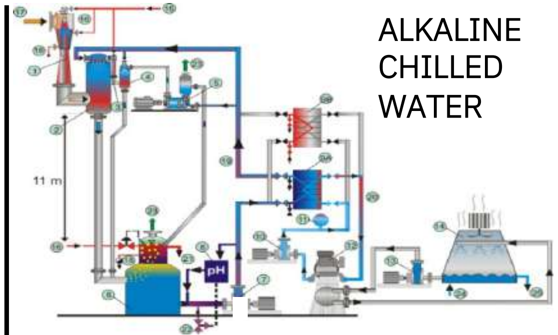
Comparison of the various system

ICE CONDENSATION



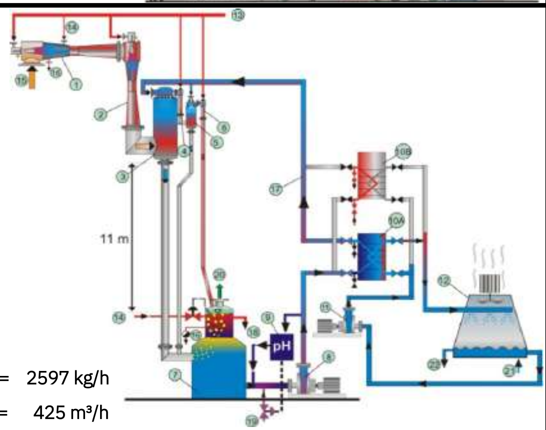
∑ Motive Steam consumption = 252 kg/h
∑ Cooling Water consumption = 40 m³/h
∑ Electrical Power consumption = 163 kW
∑ Waste Water consumption = 0,506 m³/h

ALKALINE CHILLED WATER



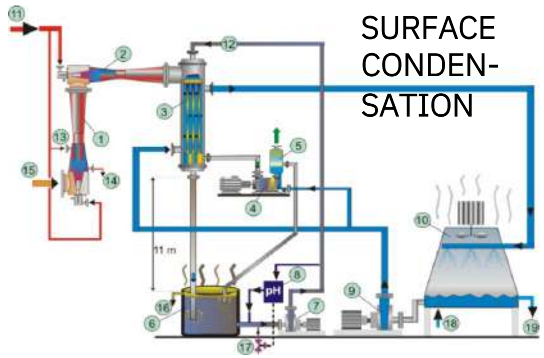
∑ Motive Steam consumption = 672 kg/h
∑ Cooling Water consumption = 212 m³/h
∑ Electrical Power consumption = 220 kW
∑ Waste Water consumption = 0,929 m³/h

ALKALINE NORMAL WATER



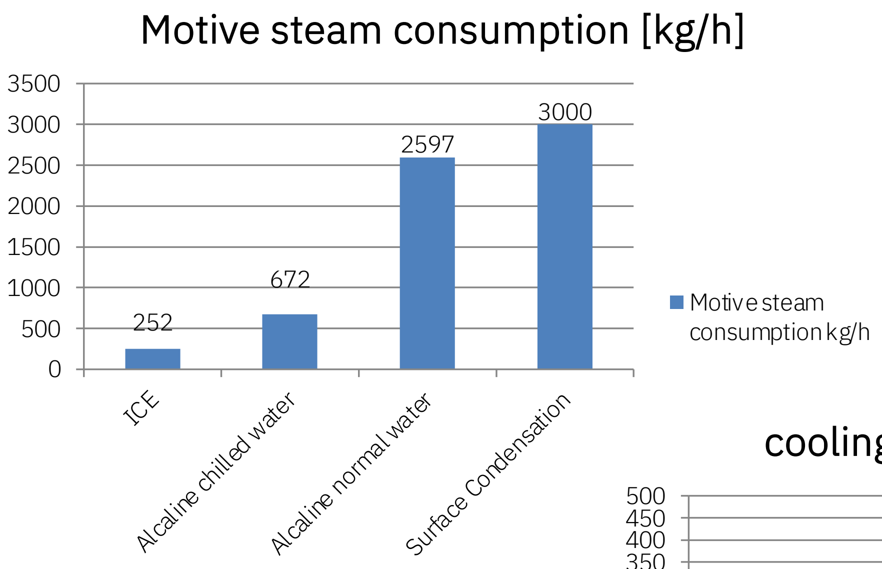
∑ Motive Steam consumption = 2597 kg/h
∑ Cooling Water consumption = 425 m³/h
∑ Electrical Power consumption = 40 kW
∑ Waste Water consumption = 2,854 m³/h

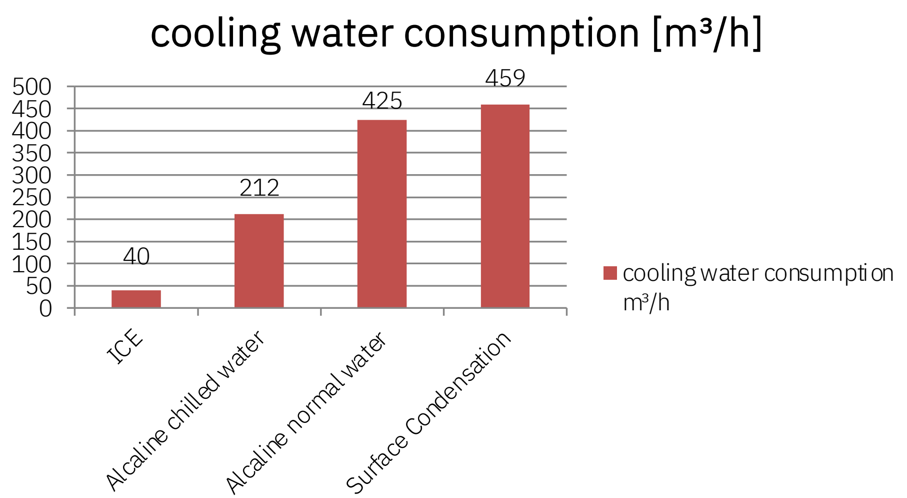
SURFACE CONDEN-SATION



∑ Motive Steam consumption = 3000 kg/h
∑ Cooling Water consumption = 459 m³/h
∑ Electrical Power consumption = 13 kW
∑ Waste Water consumption = 3,257 m³/h

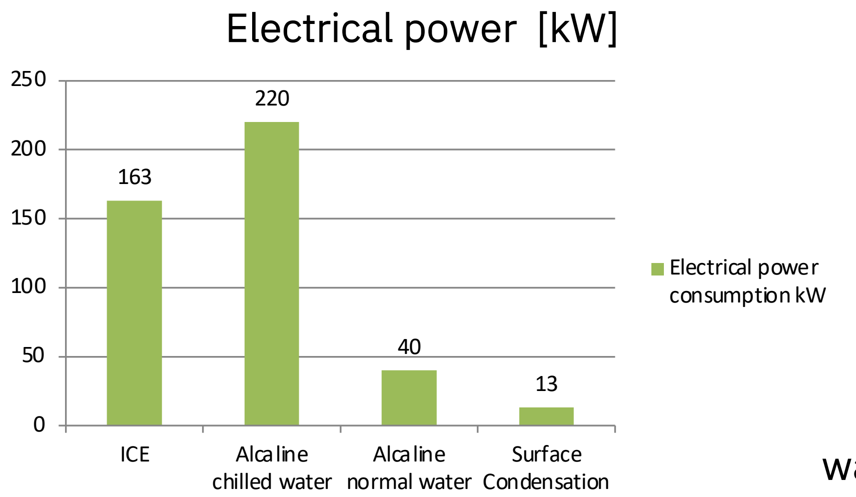
Comparison of the various system

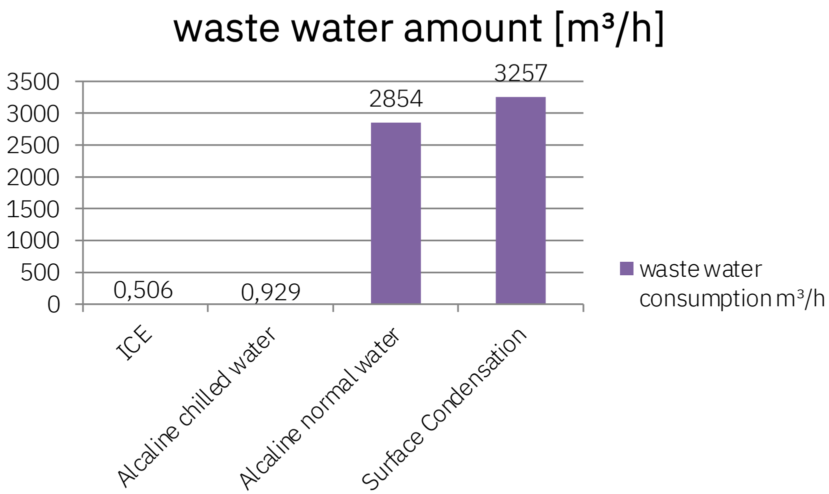




Comparison of the various system

KOERTING.DE





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