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VALVOLE DI INTERCETTAZIONE E DI REGOLAZIONE E RELATIVI ATTUATORI PER L'INDUSTRIA DI PROCESSO

Milano, 8 luglio 2015
Auditorio TECNIMONT
Via G. De Castillia, 6/A – 20124 Milano

STEAM CONDITIONING AND STEAM TURBINE BYPASS SYSTEMS

Ambrogio Perego - PARCOL SpA

Why steam conditioning is required

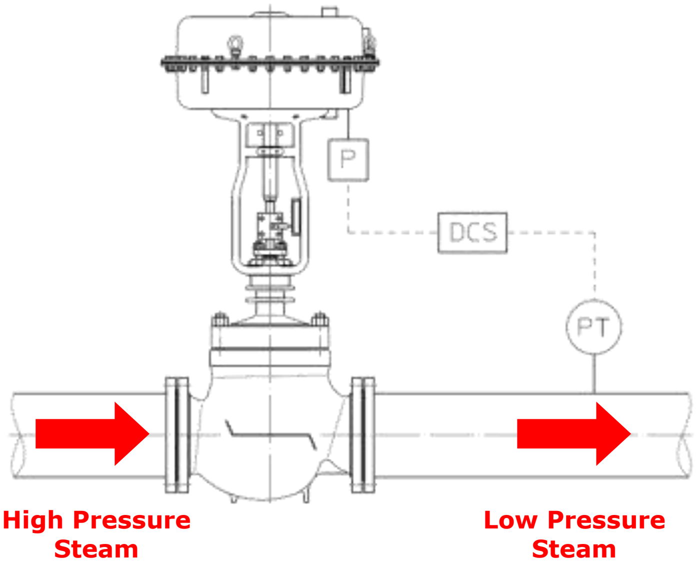
Steam conditioning is required on:

✓ **industrial applications**, where the technological steam ensures thermal energy for industrial processes or for the operation of particular equipment;

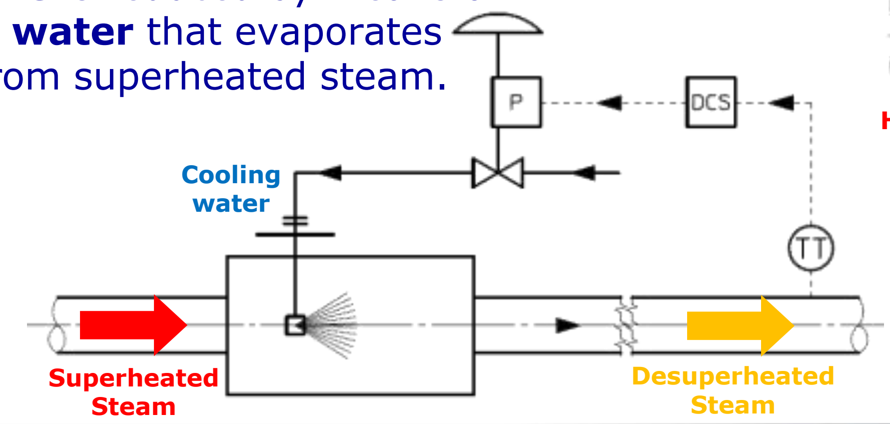
✓ **power plants**, where steam is the carrier fluid for the transport and the production of energy,

When thermodynamic properties of a steam (pressure and temperature) are different than required by specific application, steam conditioning is required:

A. **Steam Pressure** is reduced by means of a **control valve** operating an *isoenthalpic lamination* on the process fluid. *No appreciable reduction of fluid temperature* is produced by this transformation;



B. **Steam Temperature** is reduced by means of **injection of liquid water** that evaporates absorbing energy from superheated steam.



Steam desuperheating: Enthalpy

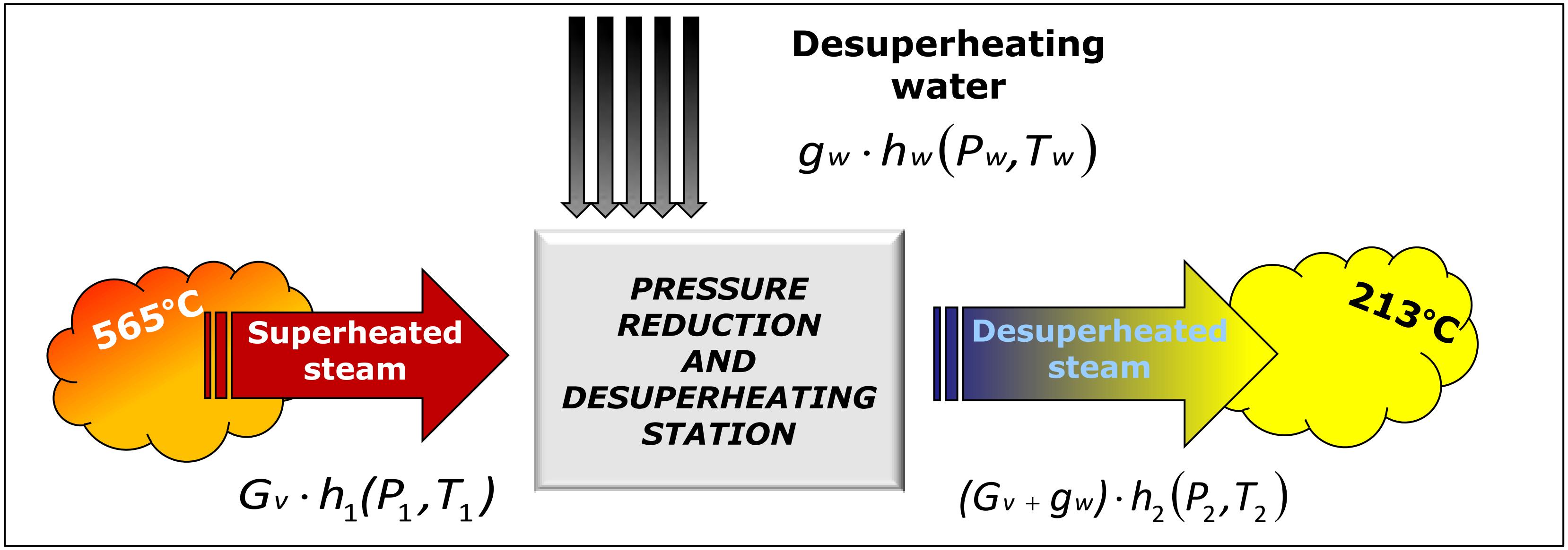
The *enthalpy* ***H*** represents the fluid energy, it is the sum of *internal energy* ***U*** plus *mechanical energy* ***p·V*** and it remains constant in a system that is not exchanging heat or work with exterior.

The *specific enthalpy* ***h*** is a *function of state* and it is *uniquely determined* by a couple of ***p*** and ***T*** values.

For this reason, the specific enthalpy ***h*** is used as *base for calculation, on steam conditioning systems*, by determining the required quantity of water to be mixed with the superheated steam to get the final specific enthalpy ***h***, correspondent to the pressure ***p*** and temperature ***T*** required.

Steam desuperheating: water flow calculation

Law of the Conservation of Energy: $G_v \cdot h_1 + g_w \cdot h_w = (G_v + g_w) \cdot h_2$



where:

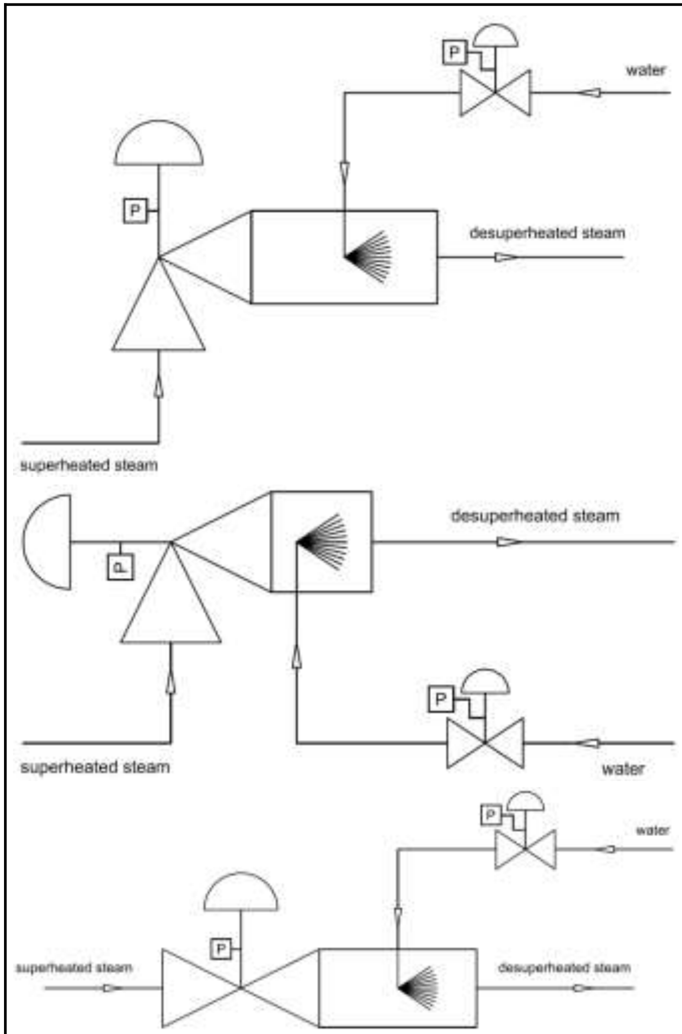
- G_v = *superheated steam flow*
- h_1 = *superheated steam enthalpy (function of P_1, T_1)*
- h_2 = *desuperheated steam enthalpy (function of P_2, T_2)*
- g_W = *desuperheating water flow*
- h_W = *desuperheating water enthalpy (function of P_W, T_W)*

The required water flow can be easily calculated by:

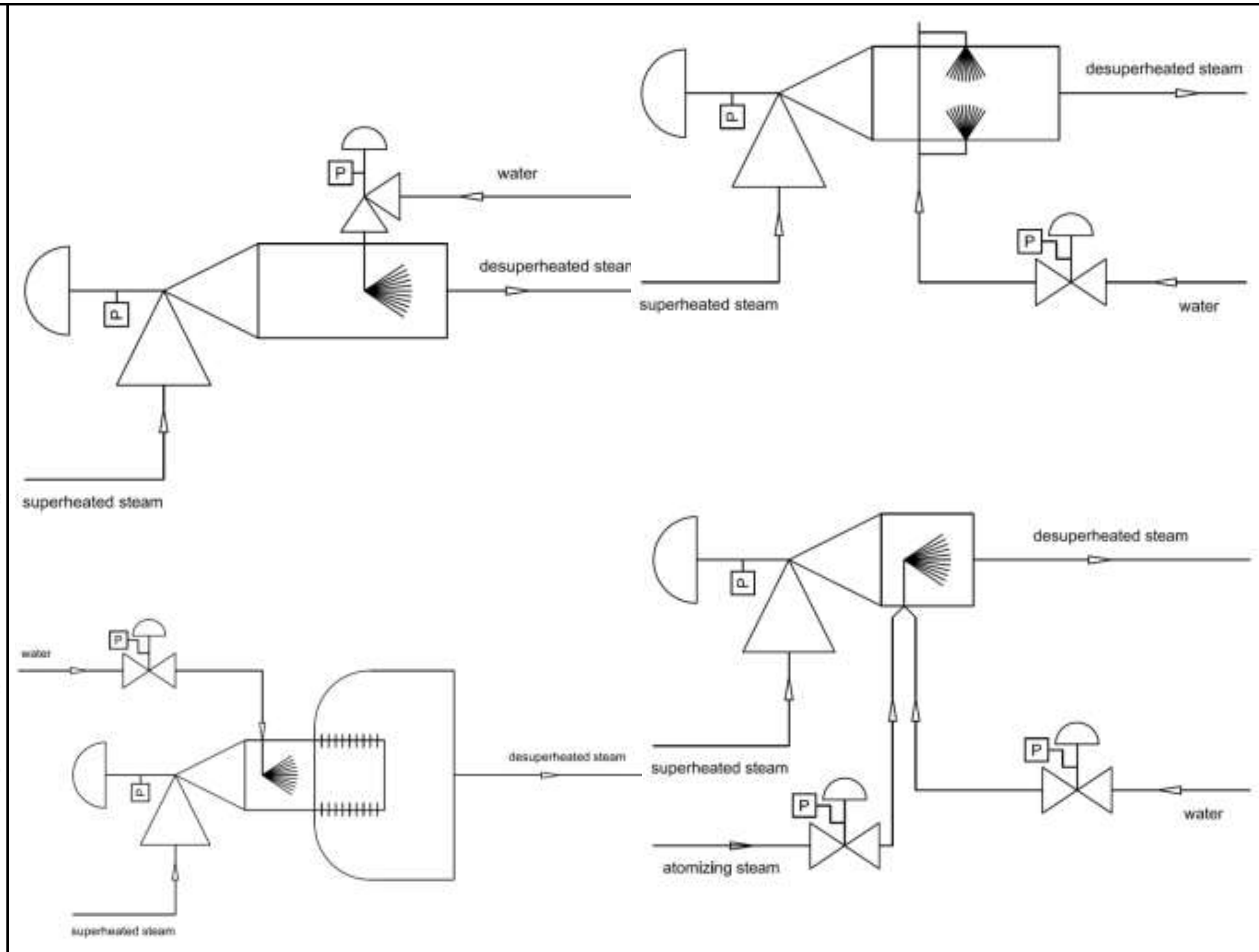
$$g_w = \frac{G_v \cdot (h_1 - h_2)}{(h_2 - h_w)}$$

Typical Pressure Reducing and Desuperheating Stations Configurations

Body Shape and Flow Direction



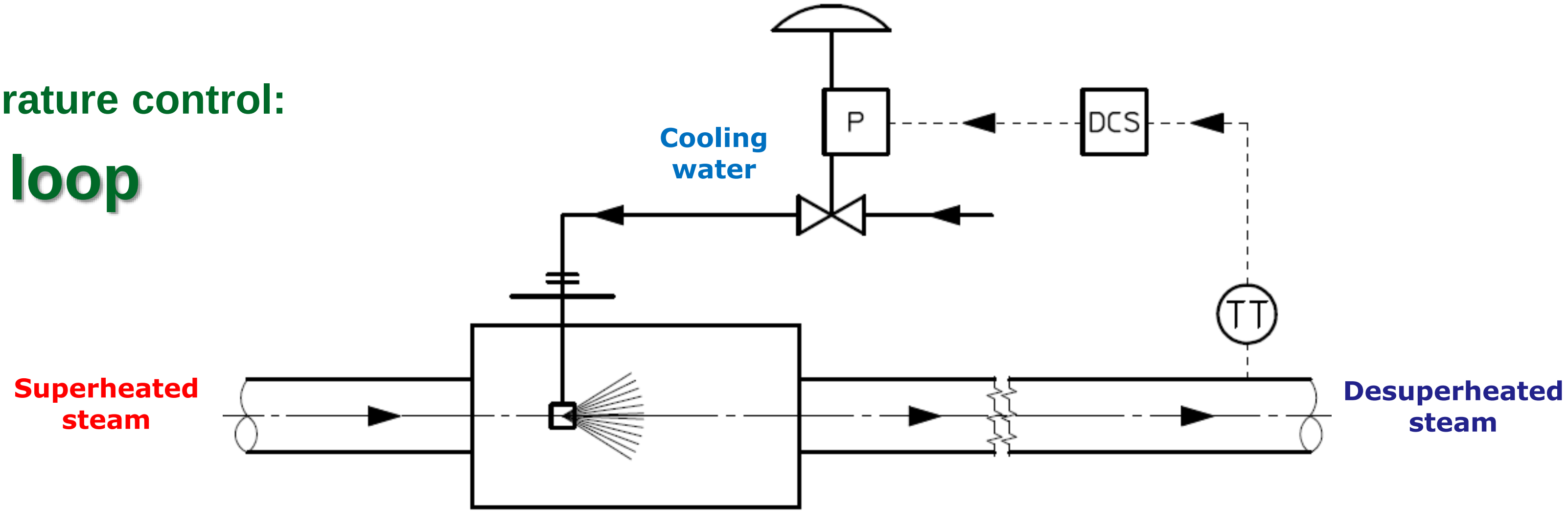
Water Injection Position and Typology



Temperature control systems:

Direct steam temperature control:

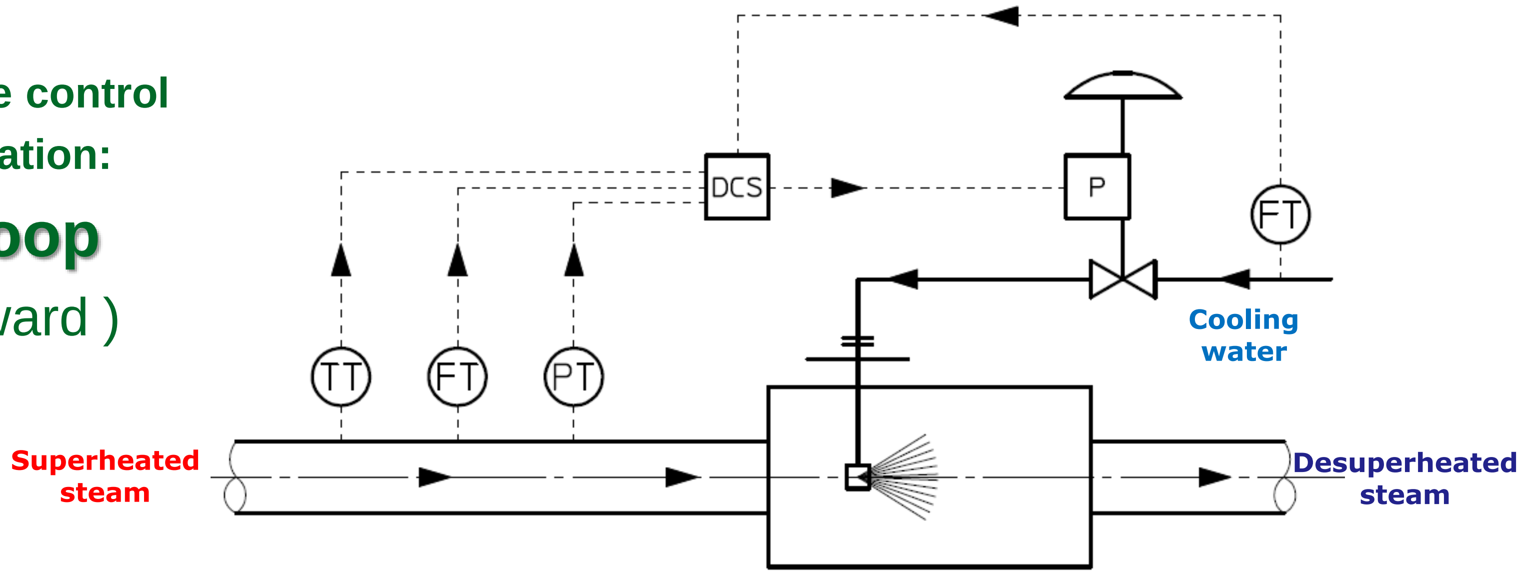
closed loop



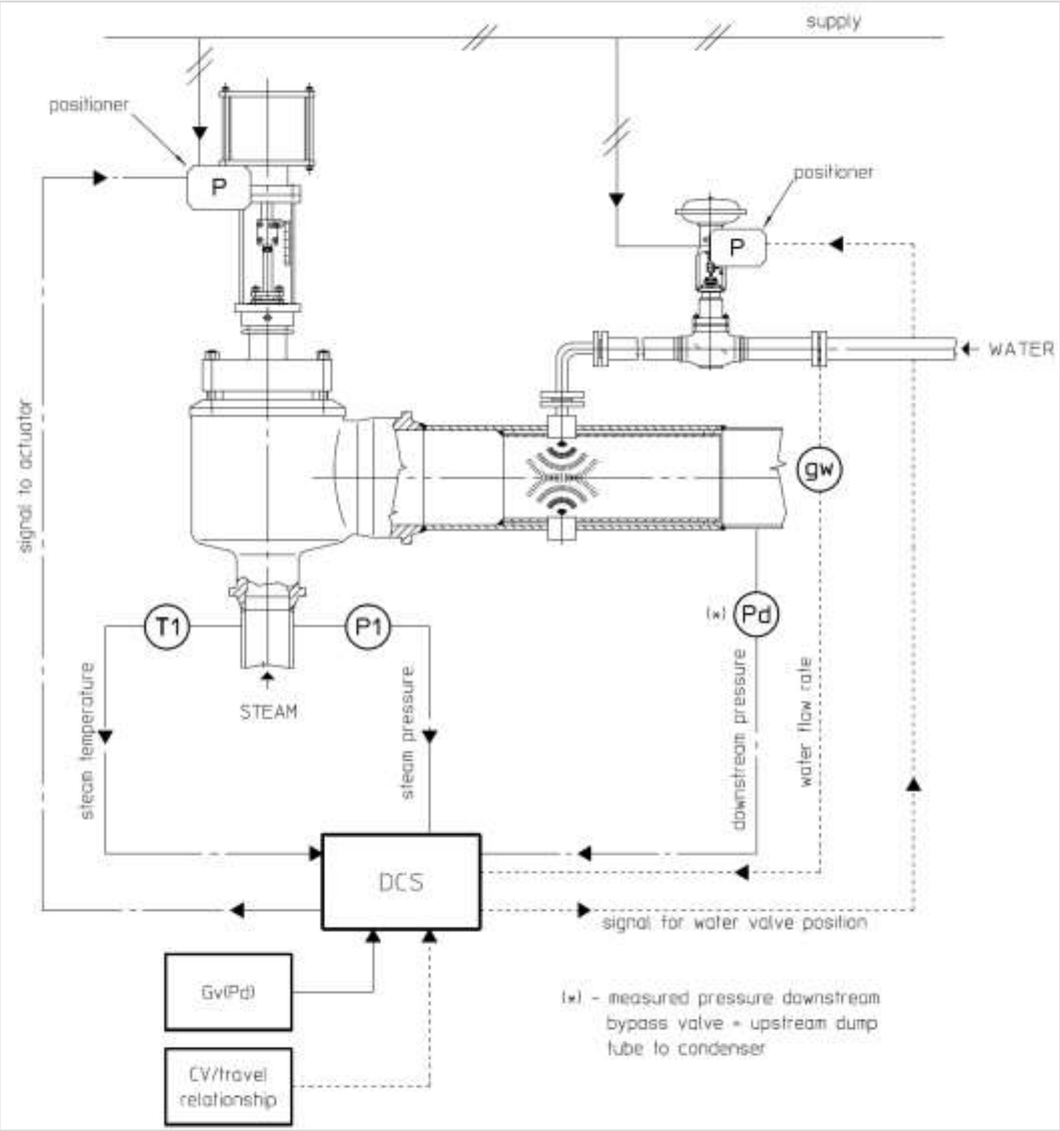
Steam temperature control by enthalpy calculation:

open loop

(feed forward)



Open loop temperature control by enthalpy calculation

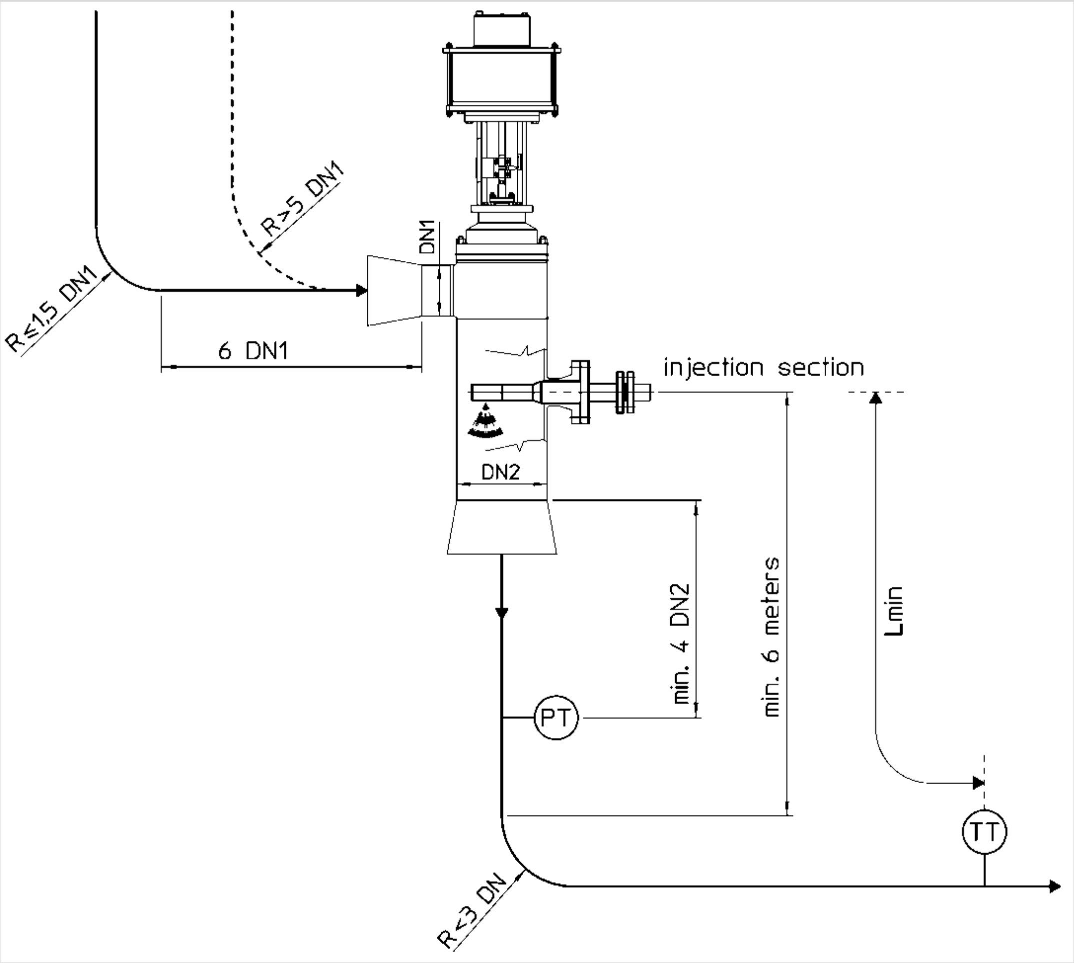


Different system configuration can be adopted to improve the accurately of the system.

More is the required precision, higher is the number of process variables involved in the calculation algorithm.

The purpose of temperature control by enthalpy calculation is to reduce steam temperature under stated limits, avoiding to introduce excessive water amount inside steam piping.

Closed loop temperature control



For all application when a precise temperature control is required, a control loop on conditioned steam temperature, is mandatory.

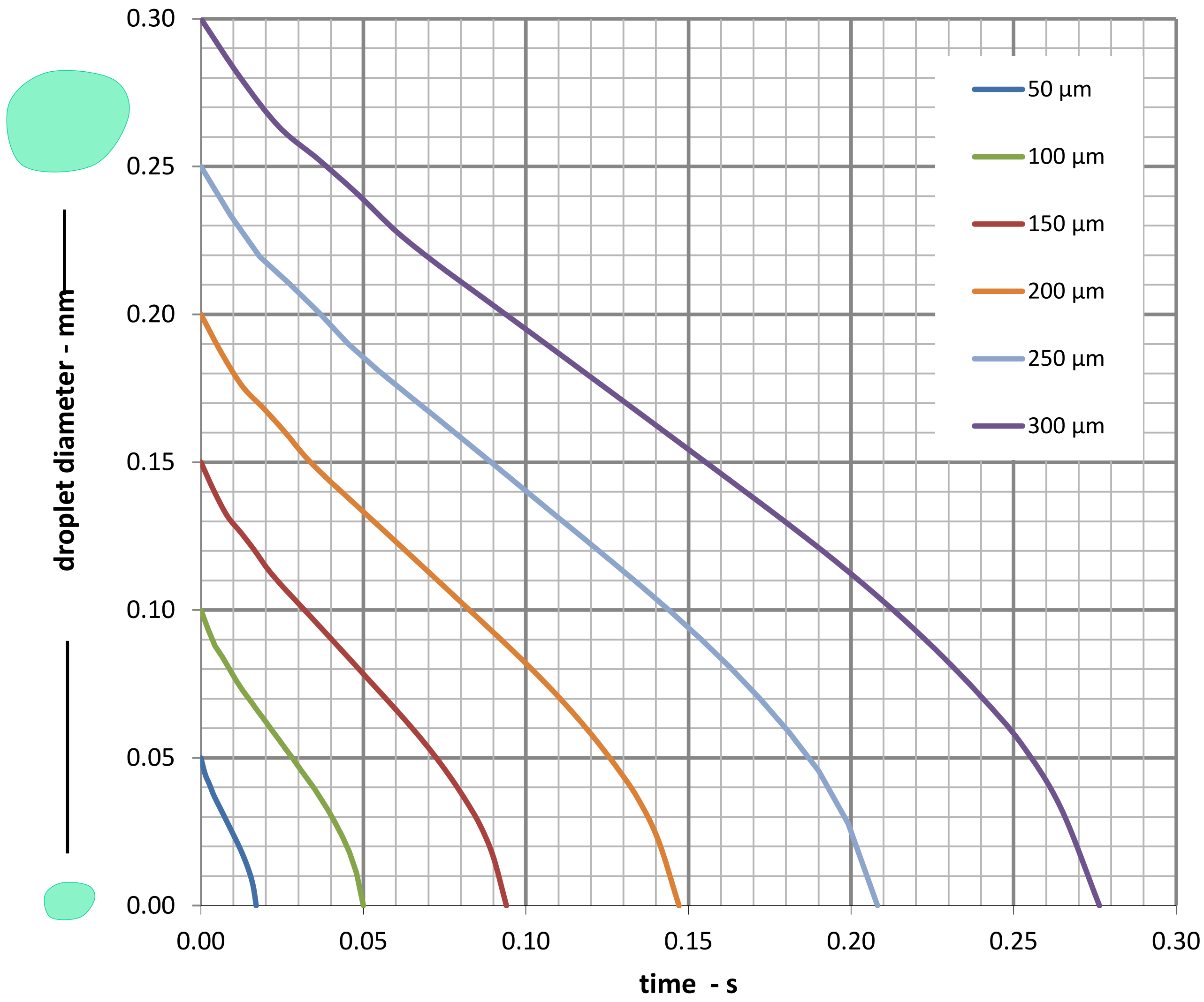
The control algorithm is simpler but several precautions must be taken in the design of the layout of the line downstream the water injection point, up to the temperature probes.

Fundamentals and basic principles of desuperheating.

1. Water evaporation requires time: evaporation time increases more than linearly with droplet diameter.
2. Smaller is the droplet diameter, more is the specific exchange surface with the superheated steam.
3. Lower is the droplet diameter and higher is the steam velocity, more easily the water droplets are dragged by the steam flow.
4. If droplets come into contact with each other or with the pipe wall, they tend to regroup in drops of larger diameter.
5. Higher is the steam velocity, higher is the heat exchange between the superheated steam and the droplet surface.

A good desuperheater must minimize the droplet size, minimize the contact of injected water with pipe wall and inject water where the steam velocity is higher.

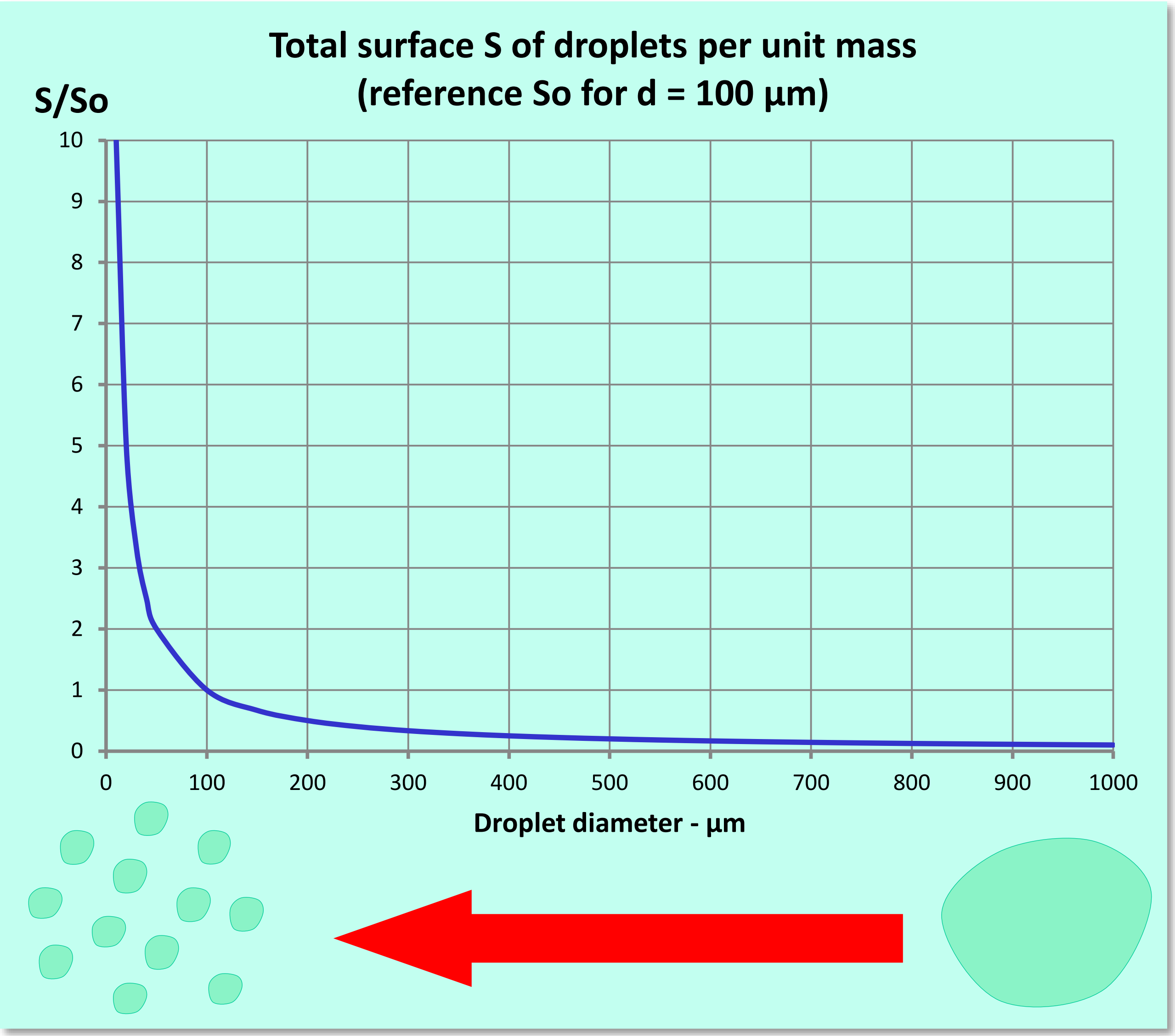
Fundamentals and basic principles of desuperheating /1



EVAPORATION TIME

...decreases more than linearly with decreasing the droplet diameter.

Fundamentals and basic principles of desuperheating /2



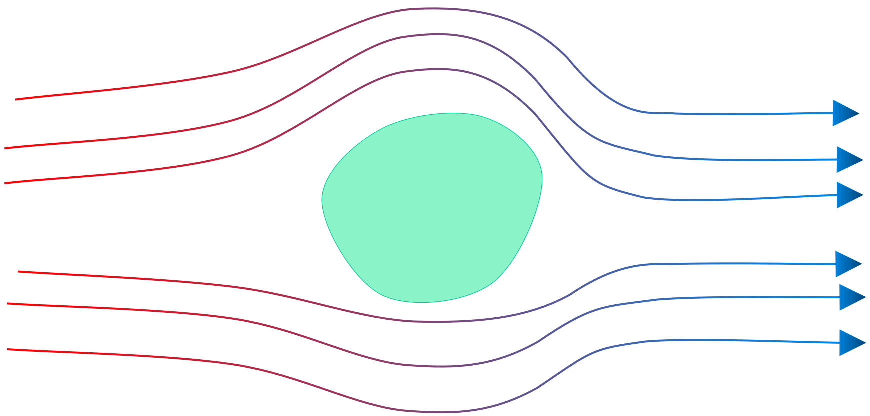
SPECIFIC EXCHANGE SURFACE

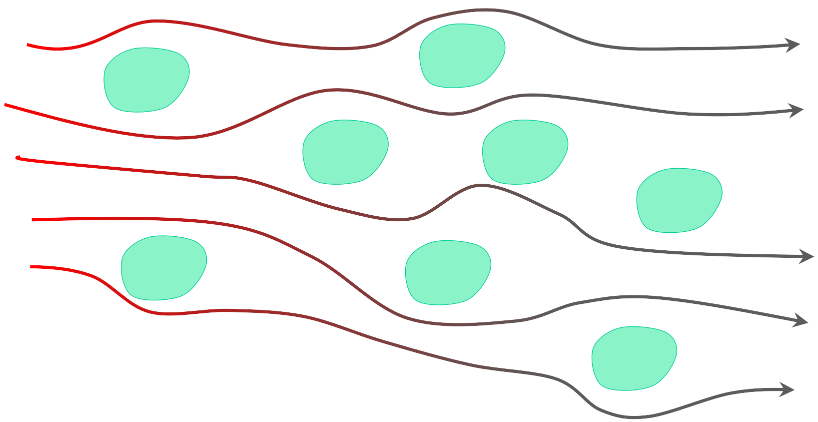
… is inversely proportional to the droplet diameter.

Fundamentals and basic principles of desuperheating /3

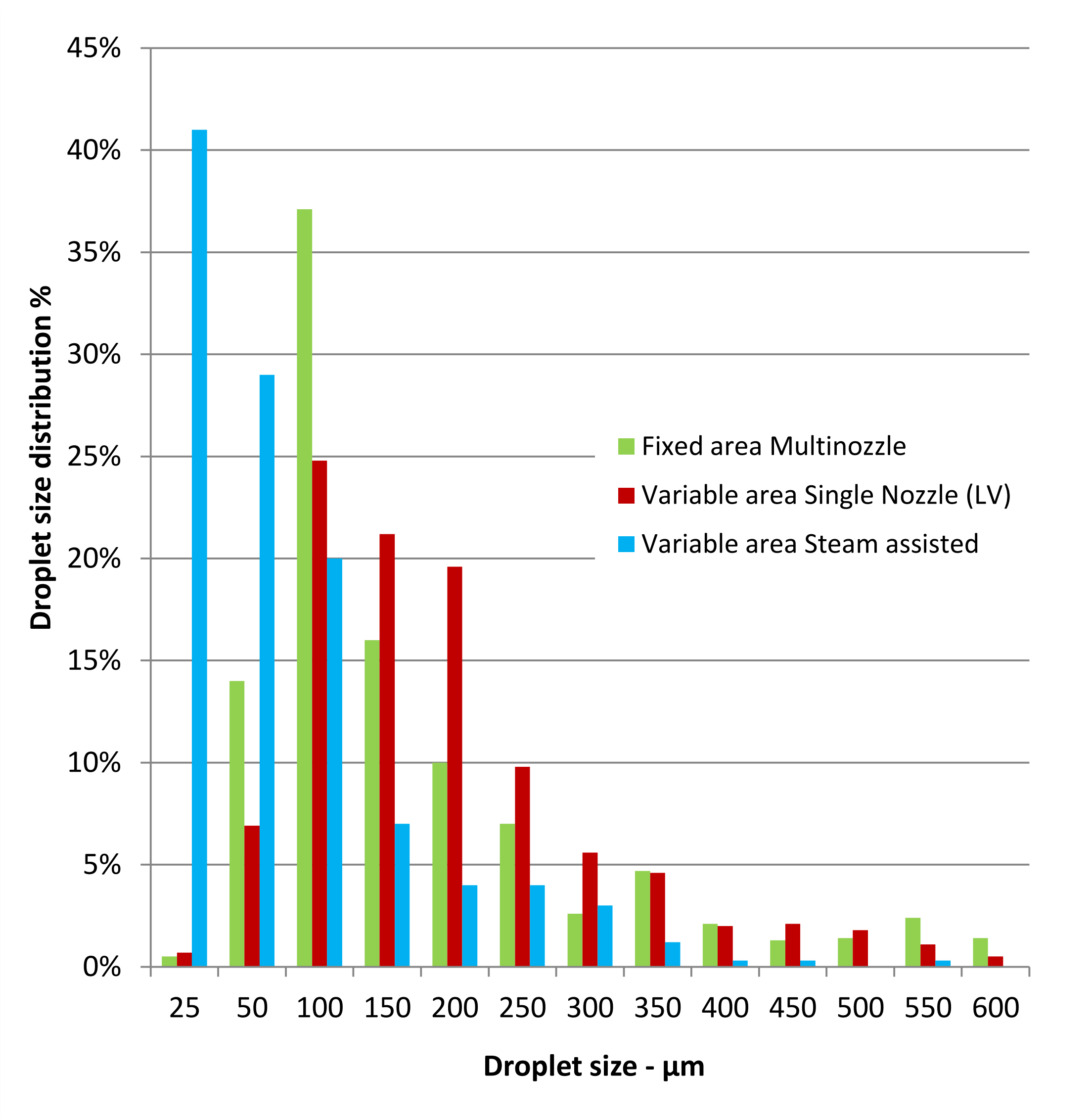
DROPLETS DRAGGING BY SUPERHEATED STEAM

... improves with the decreasing of drops diameter and the increasing of the of steam velocity





Droplets Diameter Distribution



The droplets produced by a desuperheater have diameters different from each other.

Each typology of desuperheater has different distribution of the droplets size, depending also on the nozzle size and on the applied differential pressure.

Desuperheating geometry and working principle

Nozzle Design

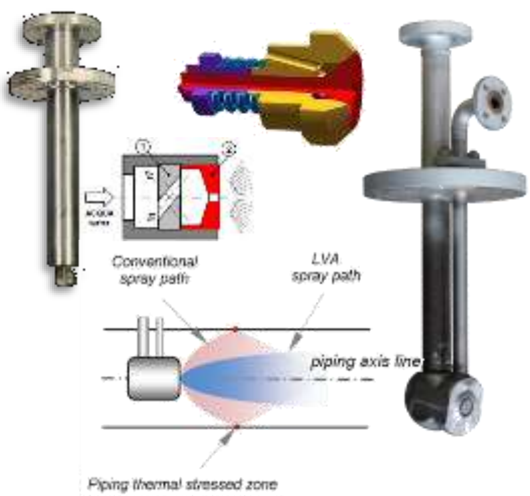
- Fixed area
- Variable area
- Steam Assisted

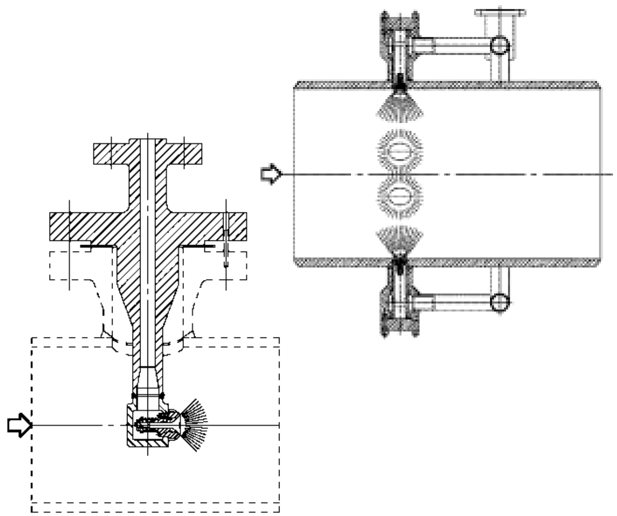
Mounting solution

- Wall mounting
- Probe mounting

Configuration

- Single Nozzle
- Multiple Nozzle





Venturi Desuperheaters

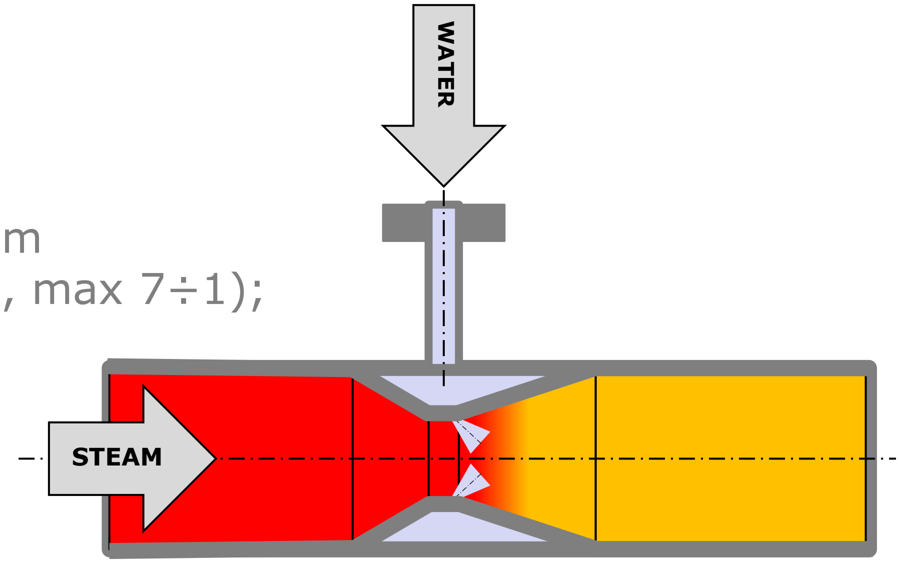
Strengths and Limitations synthesis

Main benefits:

- Good water atomizing not depending to water/steam pressure drop;
- No theoretical water/steam pressure drop limitation;
- Temperature sensor can be installed very close to the water injection point;
- Suitable for small pipe size and very low water flows;
- Compact and maintenance free design.

Main limitations:

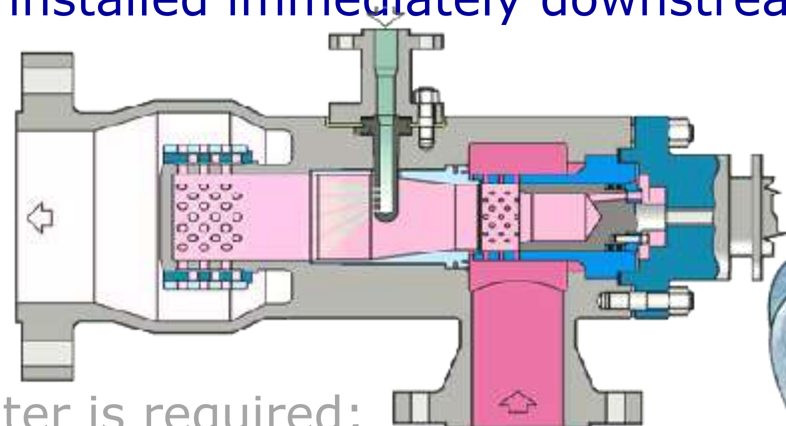
- Control valve for cooling water is required;
- Restricted turn down depending on the maximum allowable steam pressure drop (typically ≈ 3÷1, max 7÷1);
- Desuperheating performance dramatically decrease at low steam flows;
- Pressure drop on steam flow is required.

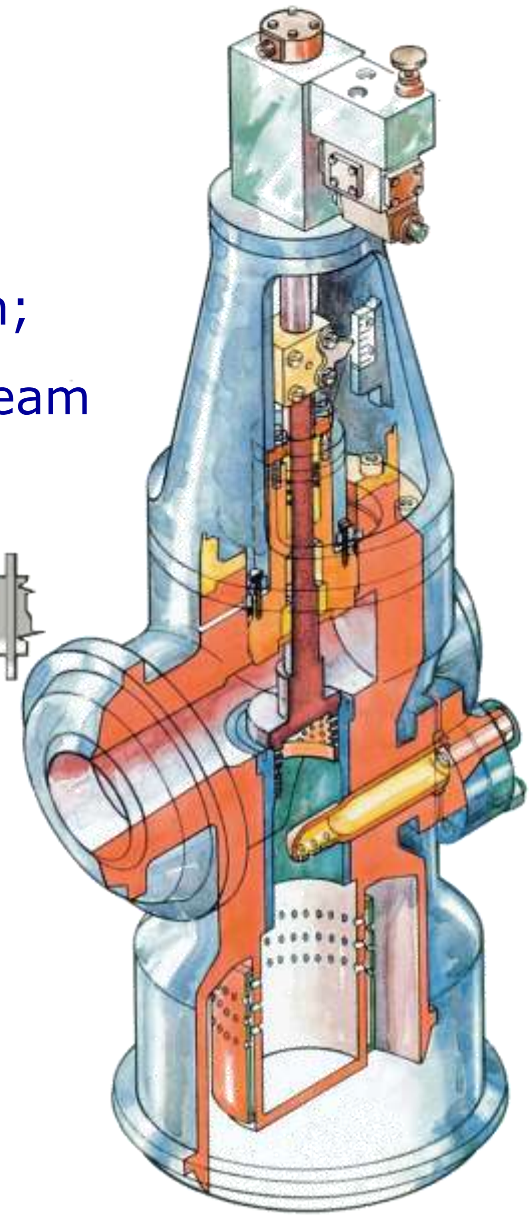


PRDS with Integrated Water Injection

Main benefits:

- Very good water atomizing in the whole range of operation;
- Temperature sensor can be installed immediately downstream of PRDS;
- High turn-down.



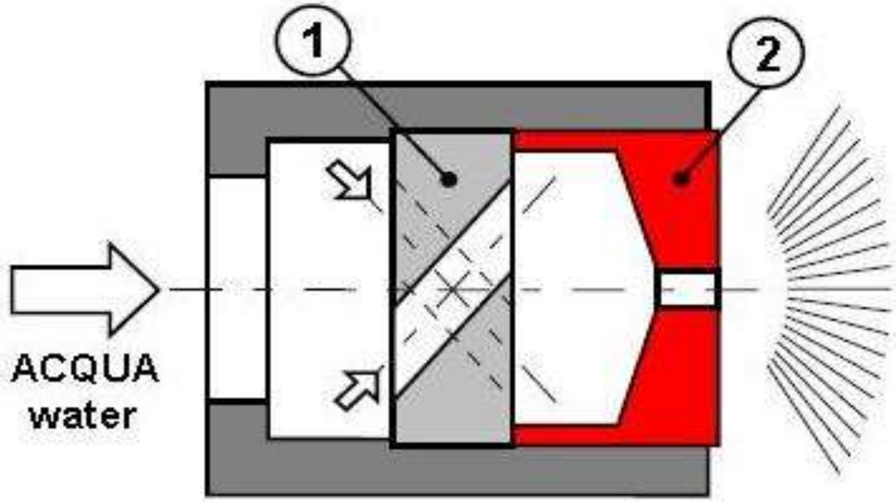


Main limitations:

- Control valve for cooling water is required;
- Continuous service with elevated pressure drops and high temperature can produce severe erosion problems;
- For very high temperature services, water injection must be accurately controlled to avoid thermal shocks on valve body.

Fixed Area Spray Nozzles Desuperheaters

Working Principle



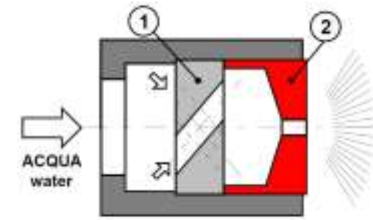
1) Turbulator: gives a swirling component to the water before the nozzle outlet

2) Nozzle: transforms pressure energy into kinetic energy

Rmax =3

Fixed Area Spray Nozzles Desuperheaters

Strengths and Limitations synthesis

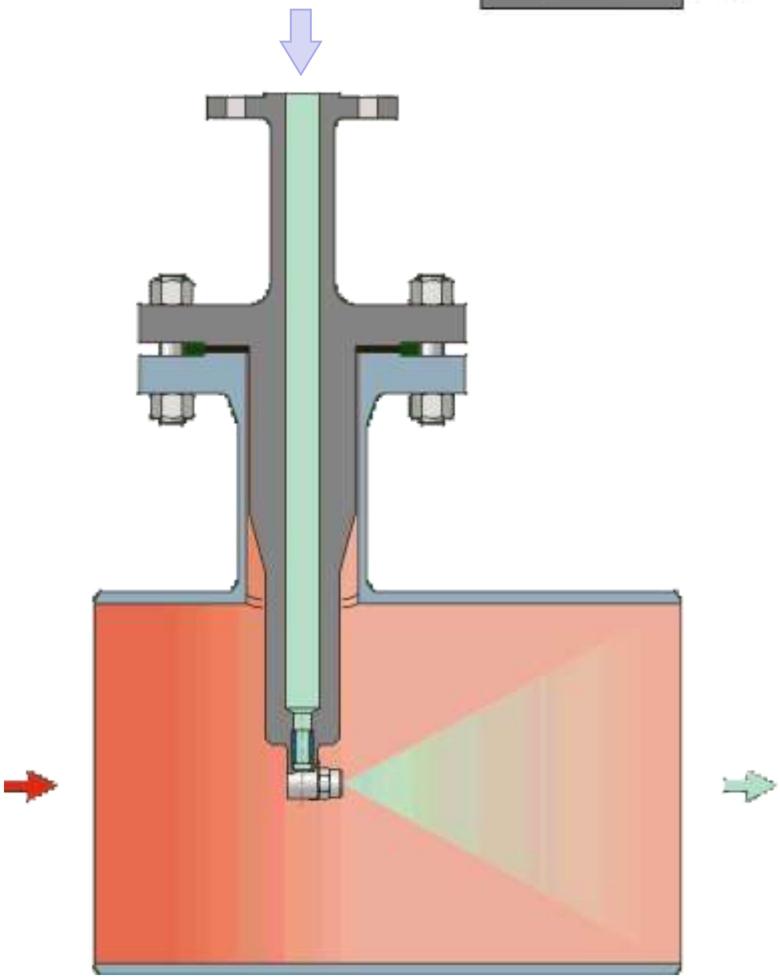


Main benefits:

- Good water atomizing within the nominal pressure drop range (0.5÷1 to 30 bar);
- Excellent atomization, using very small nozzle (Cv ≤ 0.05 gpm), even at low differential pressures (applicable for low Cv values);
- No theoretical water/steam pressure drop limitation;
- Possibility to increase total capacity (Cv) with multi nozzle systems, without nozzle size increasing.

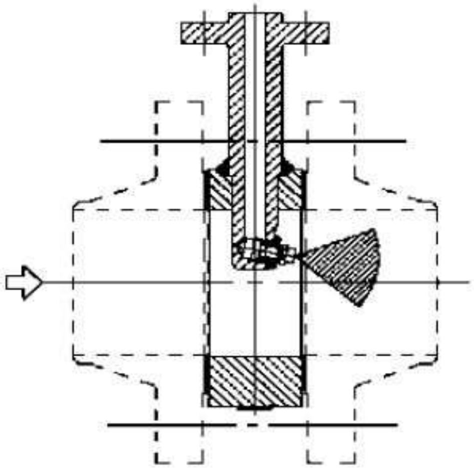
Main limitations:

- Control valve for cooling water is required;
- Spraying quality decrease when nozzle Cv increases;
- Restricted spraying rangeability up to 5÷1 max;
- Maximum spraying rangeability depends on the maximum available (water/steam) pressure drop.

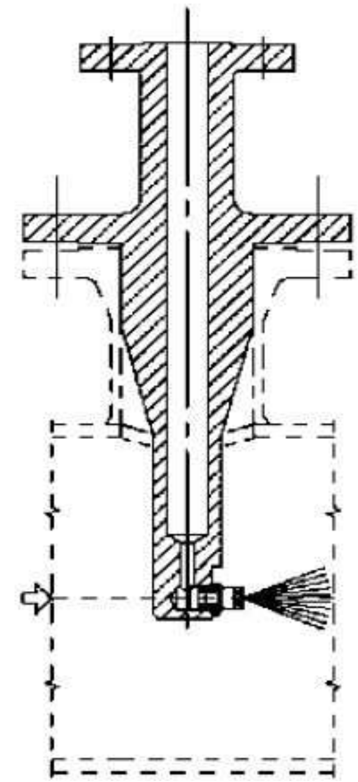


Fixed Area Spray Nozzles Desuperheaters

Single Nozzle Applications

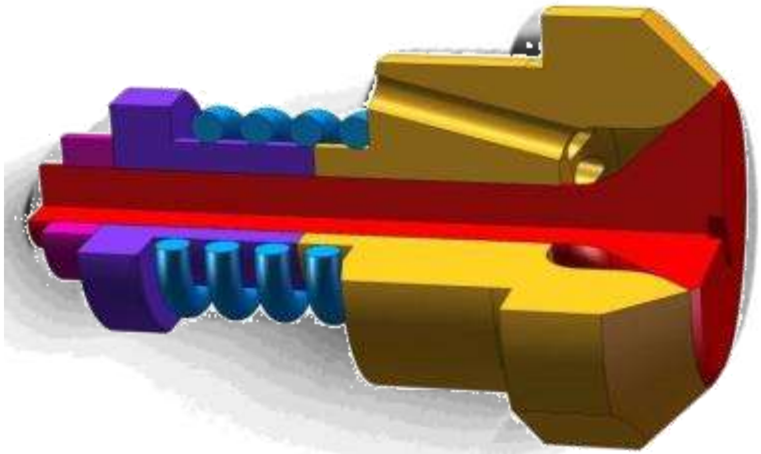


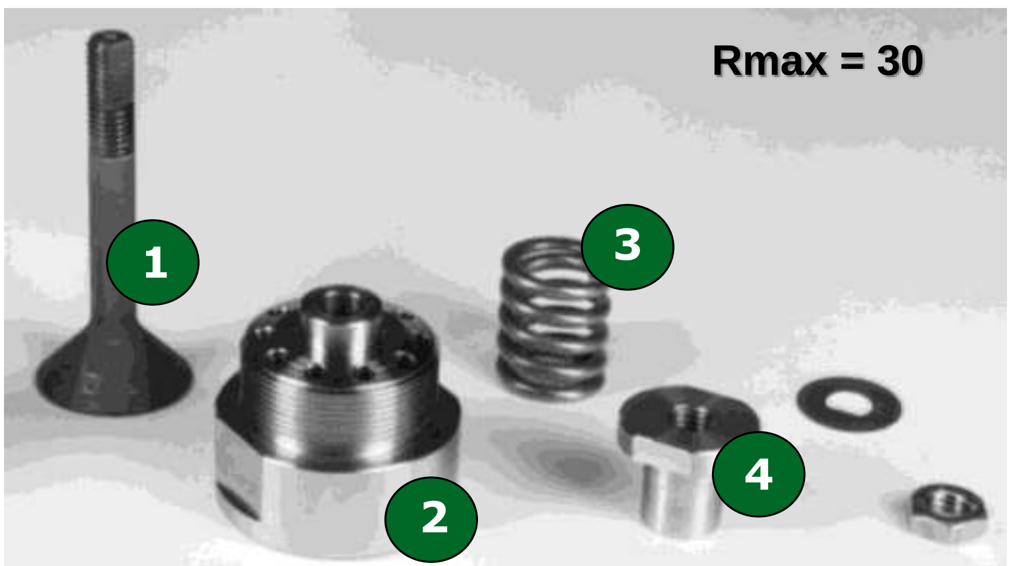
LFW 3-4531

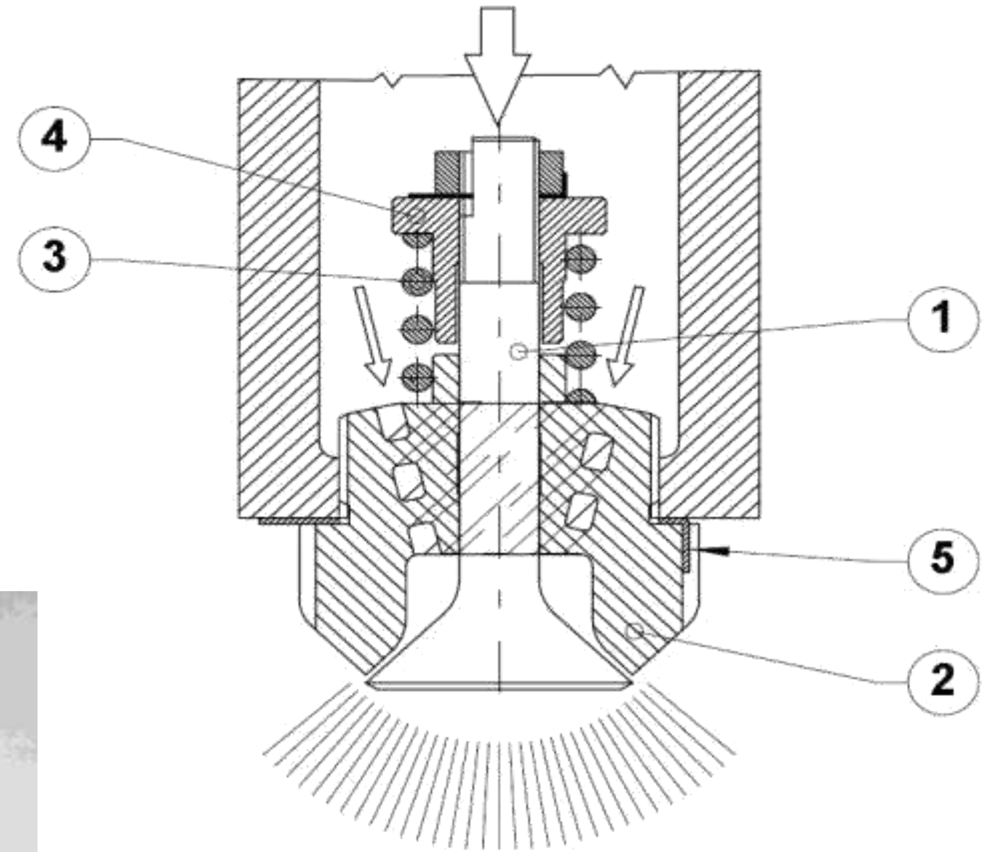


LFW 3-4511

Variable Area Spray Nozzles
Working Principle







Nozzle Components:

1) Plug
2) Body
3) Spring
4) Spring Locker
5)Washer

3-4100

Variable Area Spray Nozzle Desuperheaters

Strengths and Limitations synthesis

Main benefits:

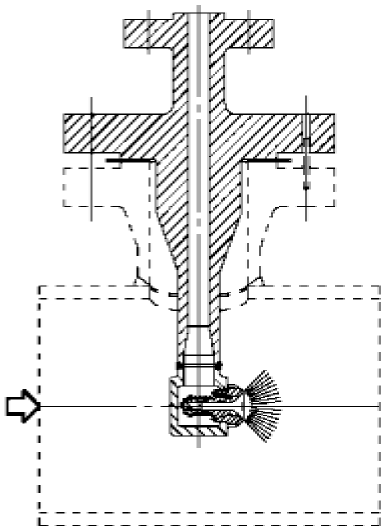
- Good water atomizing within the nominal pressure drop range (3 to 30 bar);
- Extended Spraying rangeability thanks to the variable area design allowing to reach up to 30÷1 with a single nozzle;
- Possibility to increase spraying rangeability in multi nozzle systems with different nozzle setting;
- Possibility to increase total capacity (Cv) with multi nozzle systems, without nozzle size increasing;
- Nozzle set pressure (1 to 5 bar) allows to reduce cavitation damage to cooling water control valve generating backpressure also at minimum flow;

Main limitations:

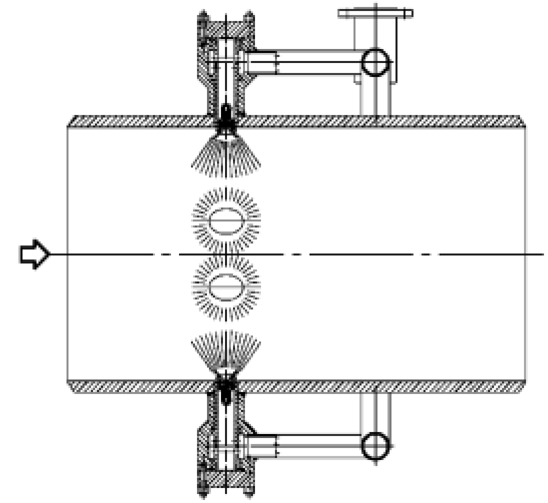
- Control valve for cooling water is required.
- Not negligible minimum steam velocity is required.

Variable Area Spray Nozzle
Applications

Single nozzle with axial oriented spray direction LV – 3-4111

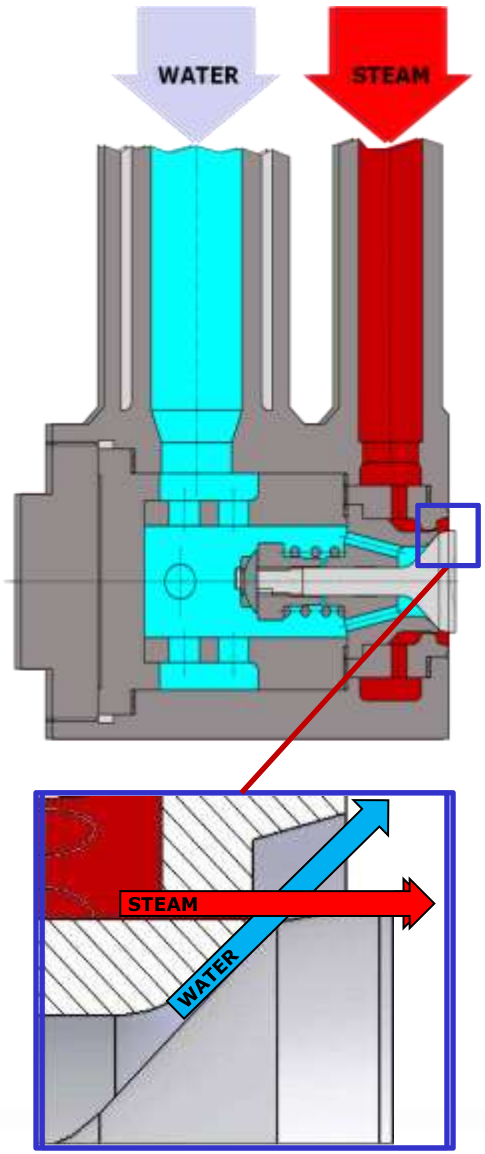


Multiple nozzle with radial oriented spray direction LVM – 3-4122

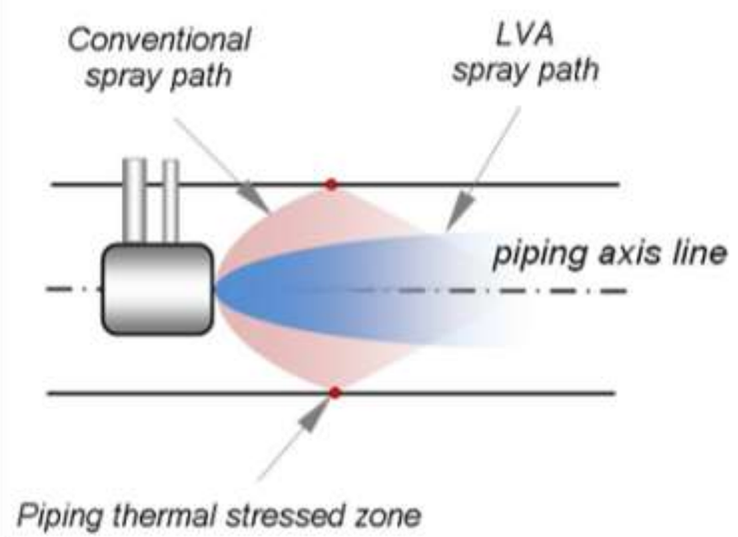


Steam Assisted Variable Area Desuperheater

Working Principle

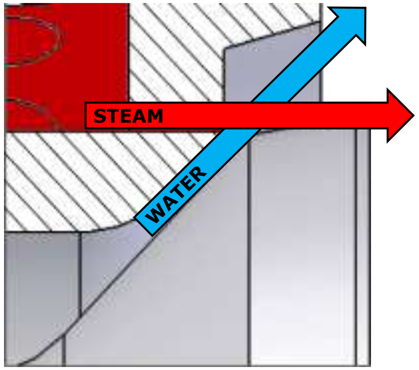


LVA - 3-4211



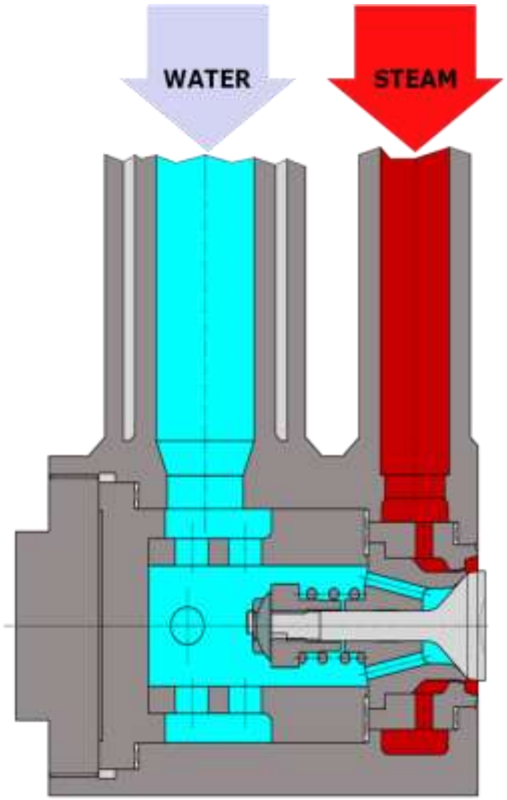
Steam Assisted Desuperheaters

Strengths and Limitations synthesis



Main benefits:

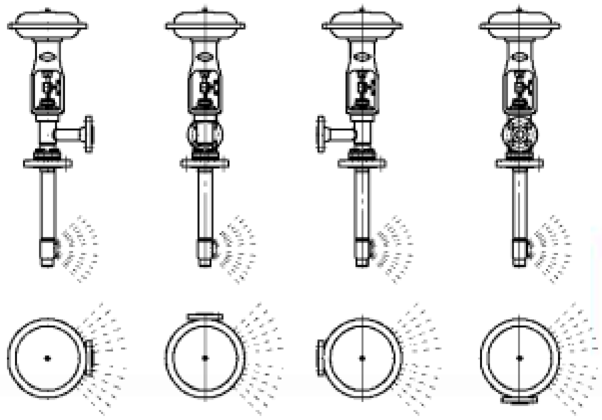
- Excellent atomization quality in the whole range of operation;
- Very high turn-down practically limited by equal to the rangeability of the water control system;
- No theoretical water/steam pressure drop limitation;
- Water jet profiling in accordance with installation layout (probe or multi-nozzle wall mounted).

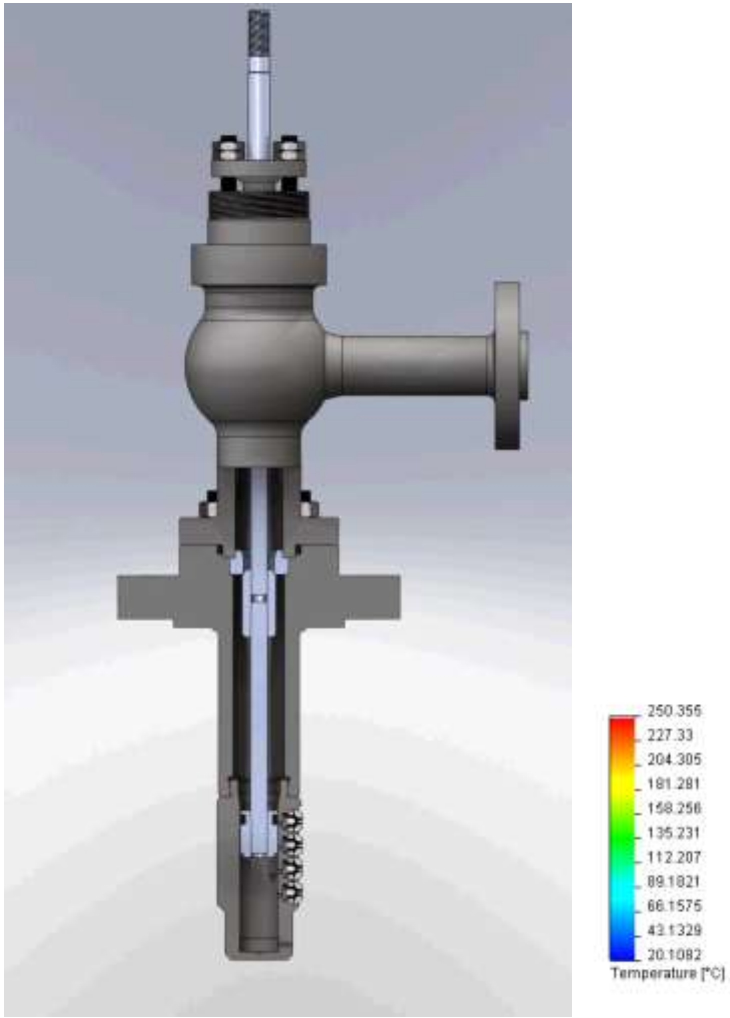


Main limitations:

- Control valve for cooling water is required;
- Additional valve for atomizing steam is required;
- Auxiliary steam with pressure significantly higher than the one of the process steam (typically two times), is required.

SpraySat 1-4442 - Multi-nozzle Desuperheater
Working Principle





Self Operated Multi-nozzle Desuperheaters

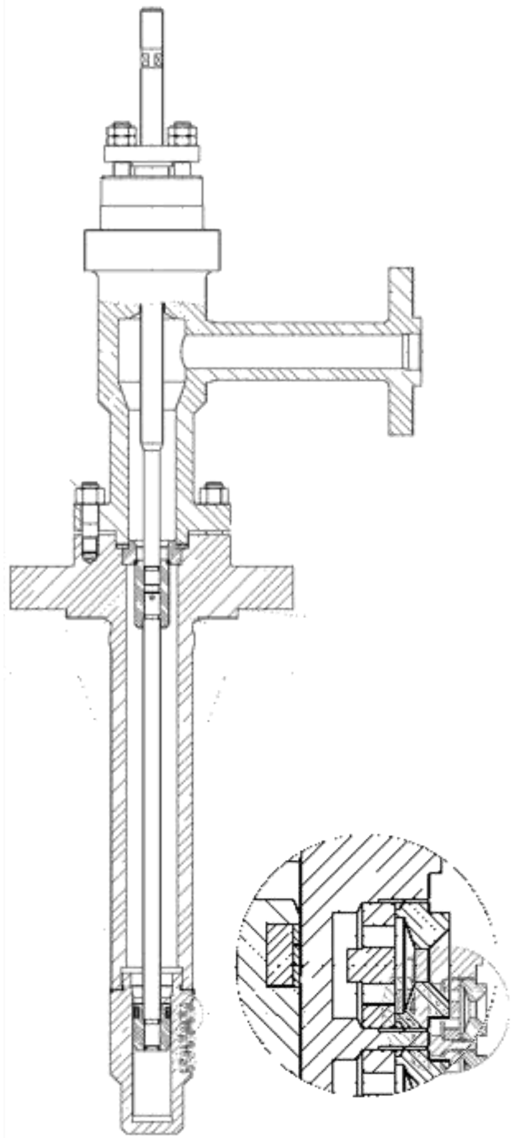
Strengths and Limitations synthesis

Main benefits:

- Good water atomizing within the nominal pressure drop range (0.5÷1 to 40-50 bar);
- Good water atomizing thanks to the constant pressure drop on all nozzles at different openings;
- High rangeability depending on number and size of spray nozzles combination allowing to reach up to 100÷1 [1];
- No control valve for cooling water is required.

Main limitations:

- Maximum water/steam pressure drop typically 50-60 bar.
- Not suitable for low dimension steam lines (< 4”).
- Not negligible minimum steam velocity for highest Cv nozzle combinations.



[1] *Maximum system turn-down also depends on minimum and maximum steam velocity (typically not more than 50÷1).*

SprayRing 1-4443 - Annular Multi-nozzle Desuperheater

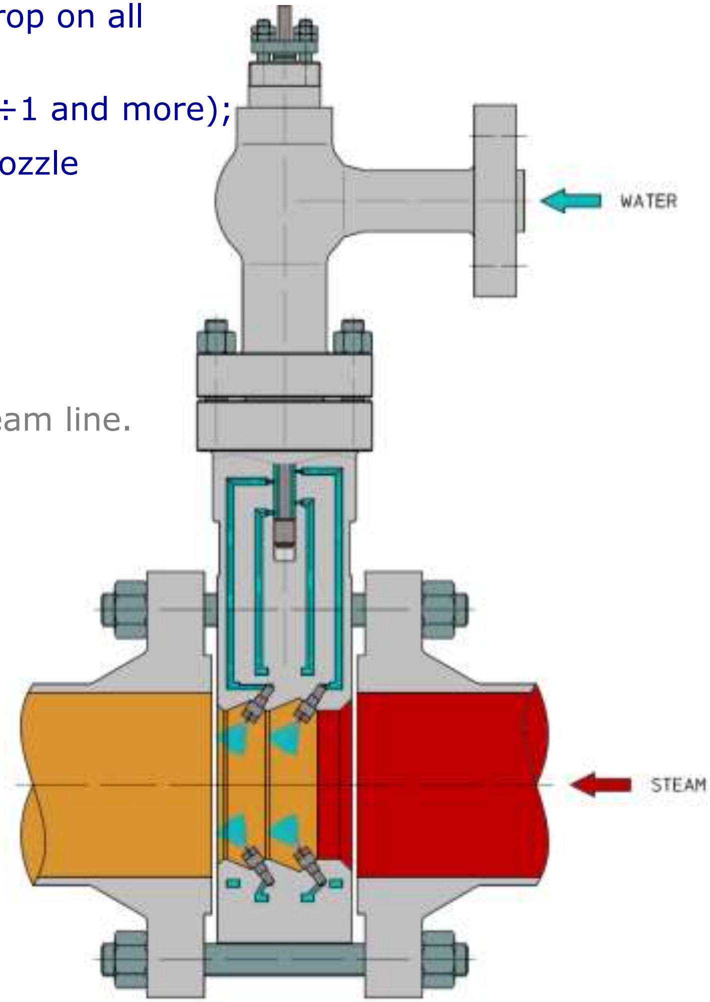
Main benefits:

- Excellent water atomizing within the nominal pressure drop range (0.5÷1 to 30 bar);
- Good water atomizing thanks to the constant pressure drop on all nozzles at different openings;
- Very high rangeability (no practical limitation: up to 200÷1 and more);
- Minimum steam velocity very low also for very high Cv nozzle combination;
- No control valve for cooling water is required.

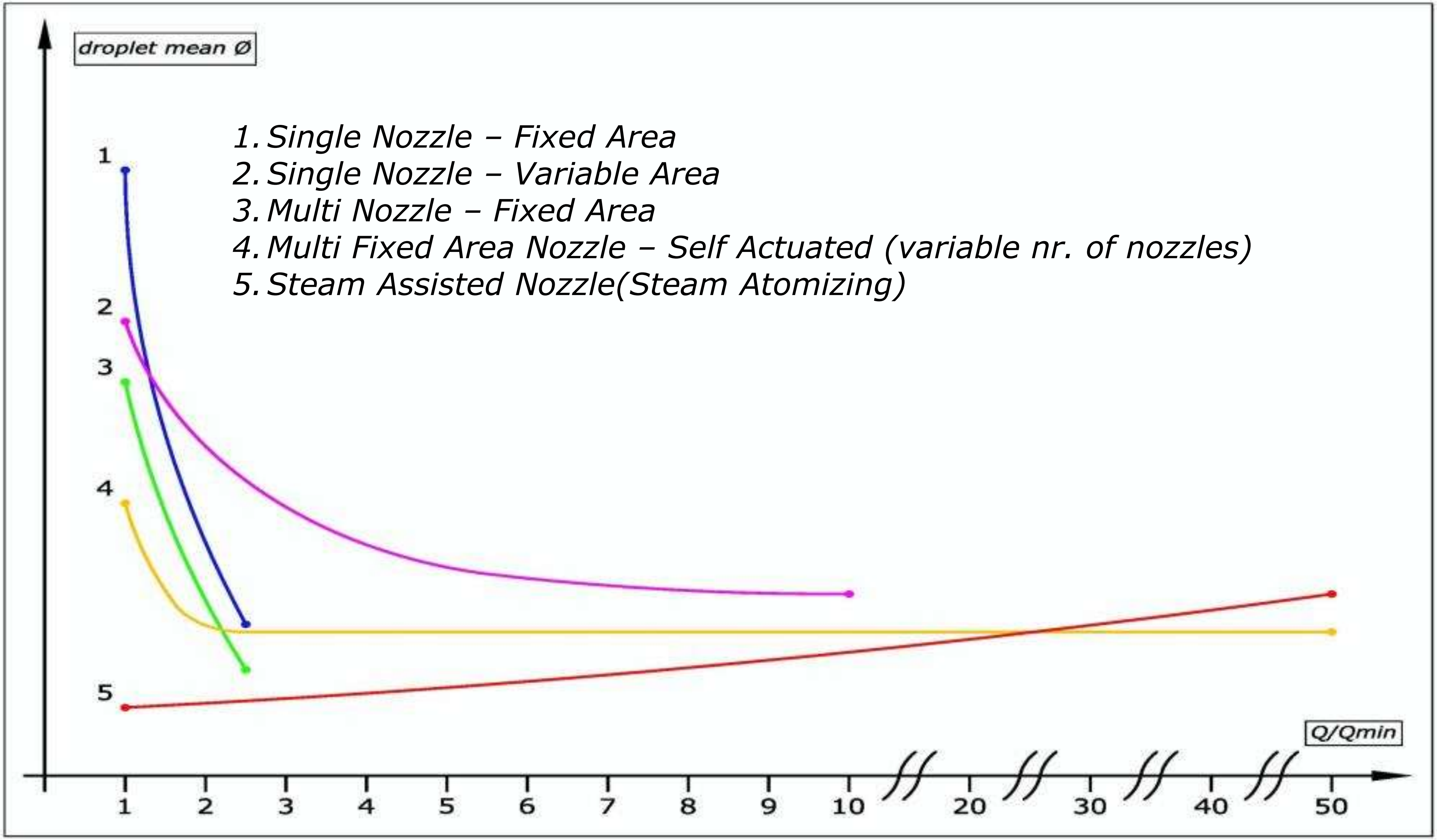
Main limitations:

- Maximum water/steam pressure drop 30 bar [1];
- It requires a line-size flanged connection on the main steam line.

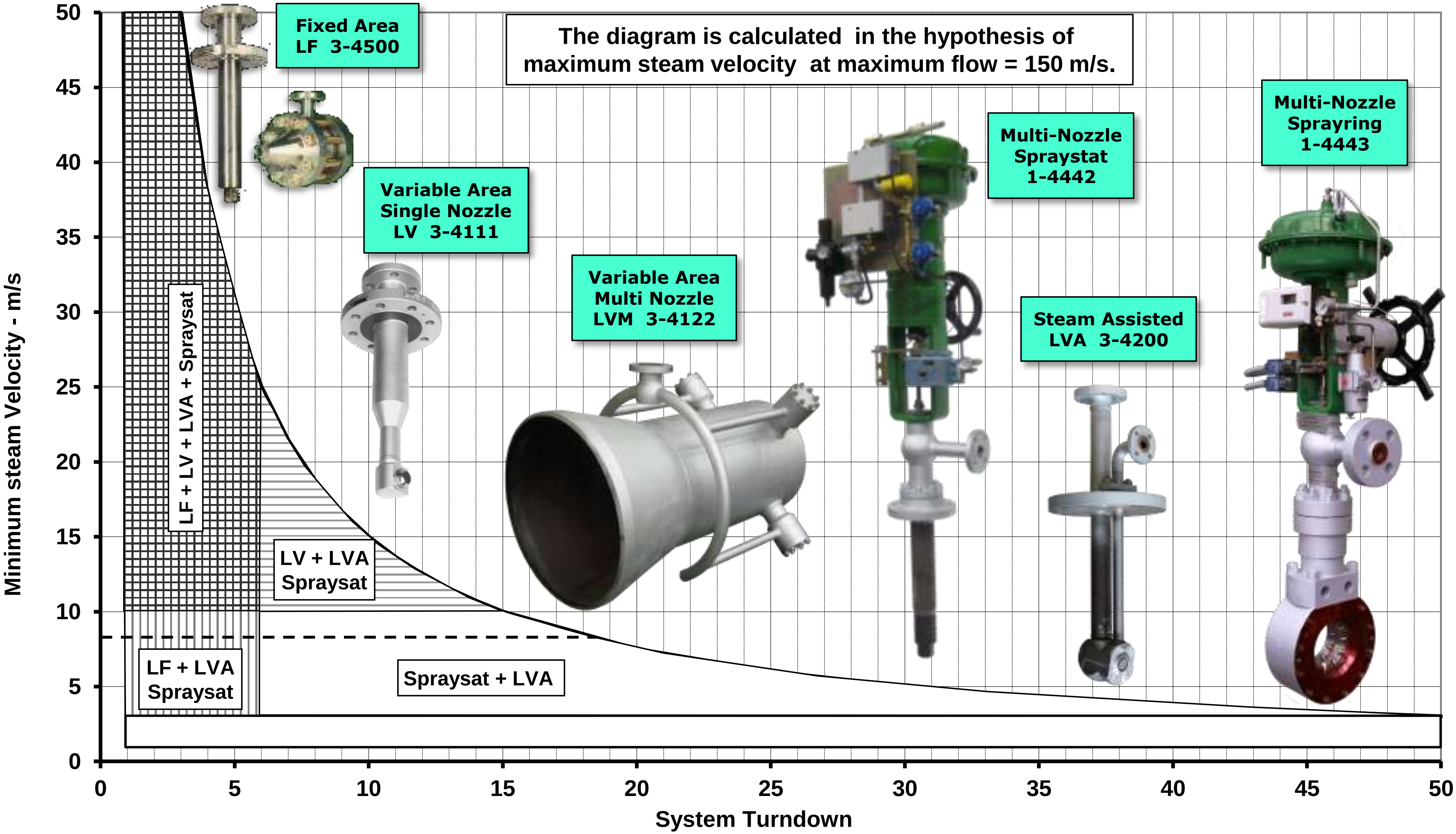
[1] *Maximum system turn-down also depends on minimum and maximum steam velocity (typically not more than 50÷1).*



Spray quality as function of load for each nozzle type



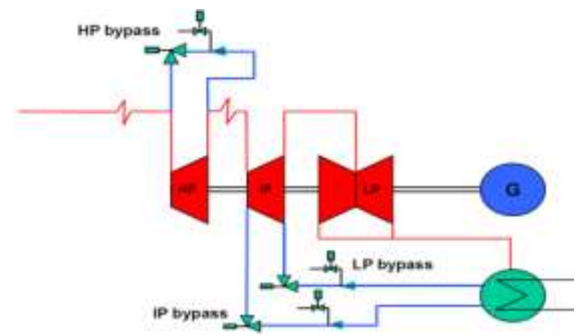
Range of Application of Desuperheaters



Steam desuperheaing applications:
Steam Turbine Bypass

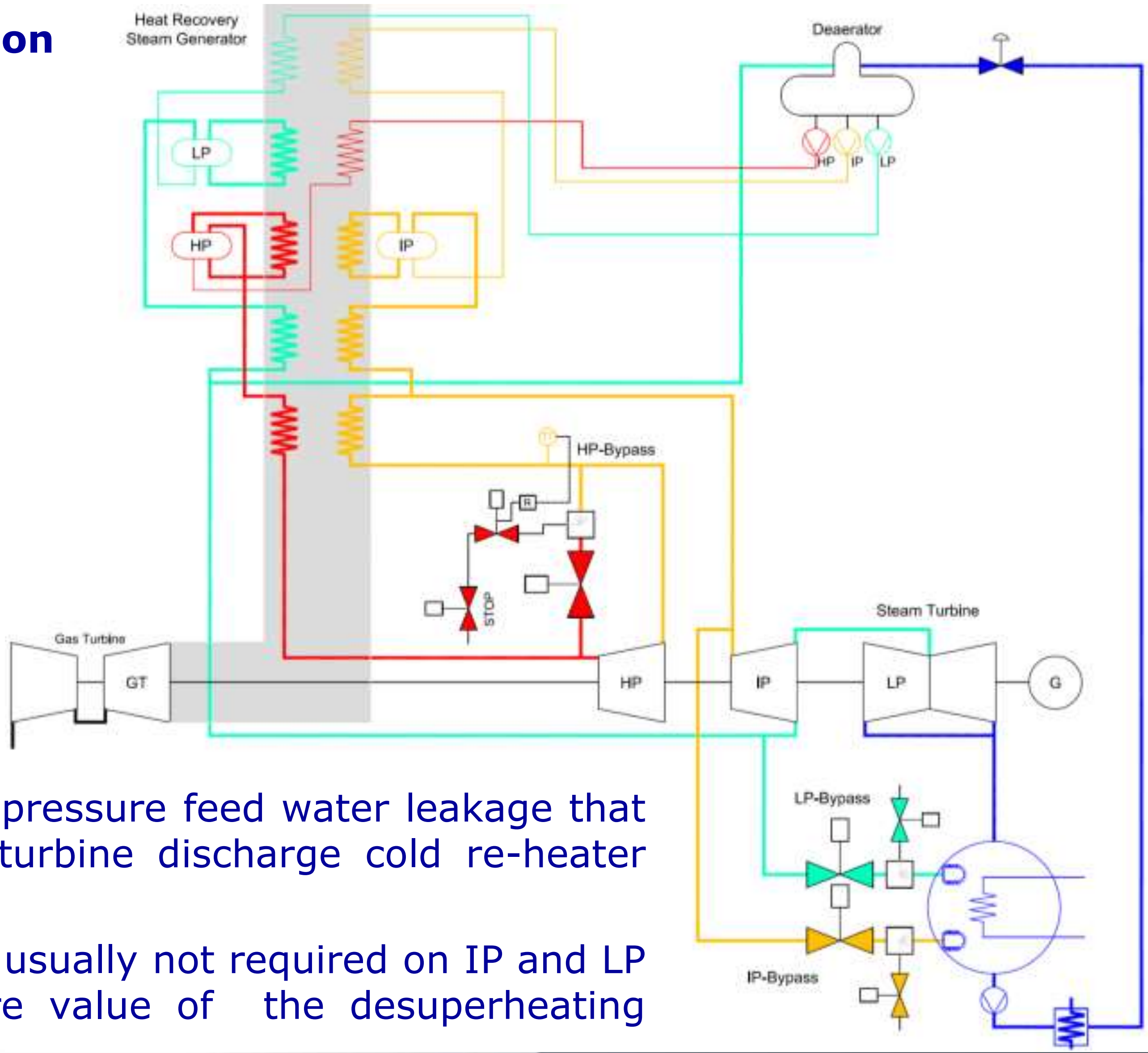
The by-pass systems allow the separation of boiler from the steam turbine during start-up, shut-down and load disturbance by allowing to:

- Avoid the intervention of the safety valves in case of turbine trip.
- Reduce fuel consumption by allowing short stops of the steam turbine while the steam generator is running at reduced load.
- Reduce start-up and reloading times.
- Reduce the consumption of treated water during the plant start-up, shut-down and turbine trip.
- Enhance operational flexibility during all transient operating modes.
- Reduce consumption of major plant components, improving lifetime.
- Maximize overhaul cycles and reduce maintenance.



Steam Turbine Bypass

Typical Three Level configuration Combined Cycle Power Plant



HP system:

a) Steam bypass control valve
b) Spray-water control valve
c) Spray-water isolation valve

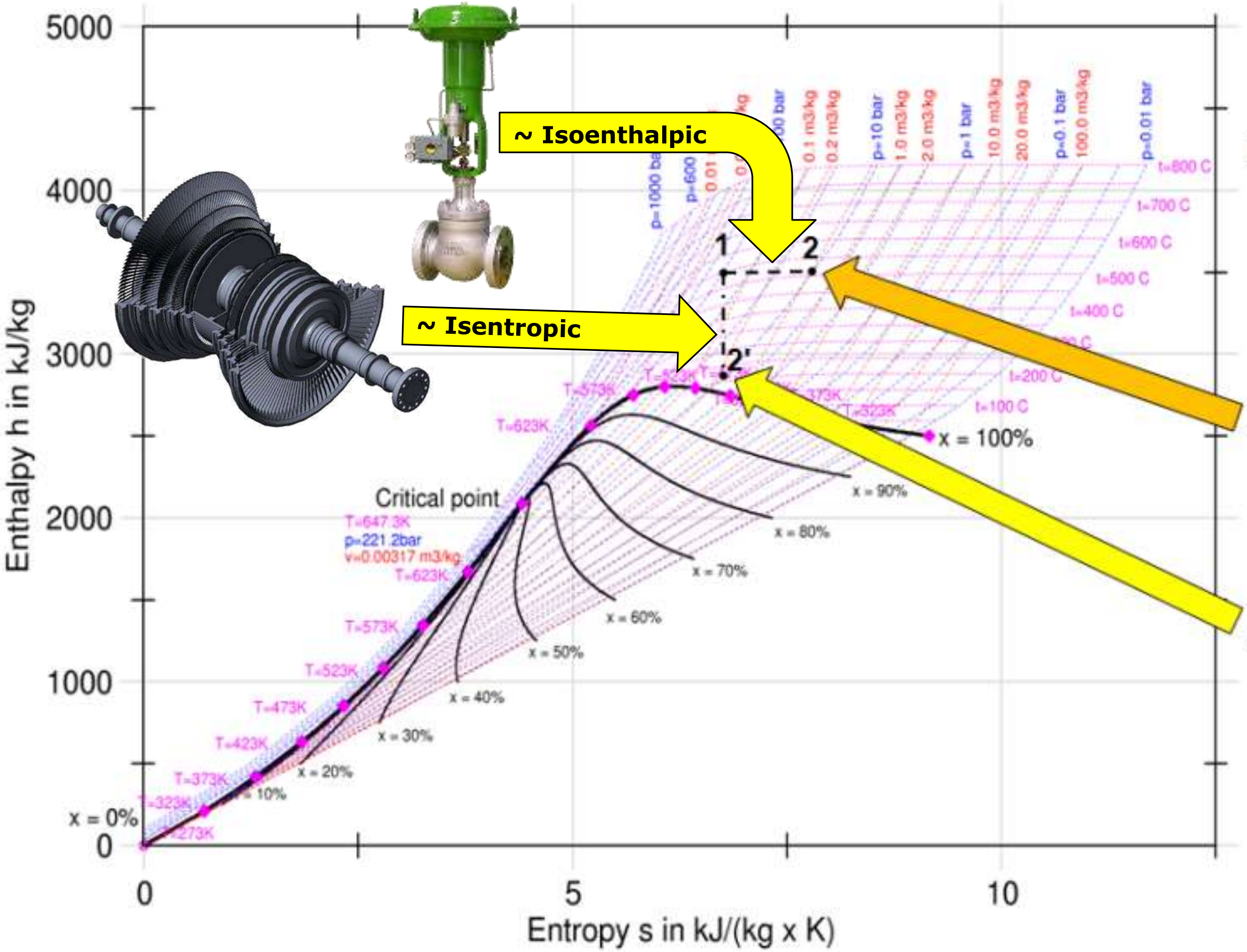
IP and LP systems:

a) Steam bypass control valve
b) Spray-water control valve

The HP bypass system spray-water line is usually provided with isolation valve to avoid high pressure feed water leakage that can produce damage on steam turbine discharge cold re-heater line.

The spray-water isolation valve is usually not required on IP and LP systems due to the low pressure value of the desuperheating water.

Steam Turbine Bypass: Isoehthalpic and Isentropic expansion



	T °C	p bar	H kJ/kg	S kJ/ kg·K
1	550	100	3500	6.8

Isoenthalpic:

	T °C	p bar	H kJ/kg
2	510	10	3500

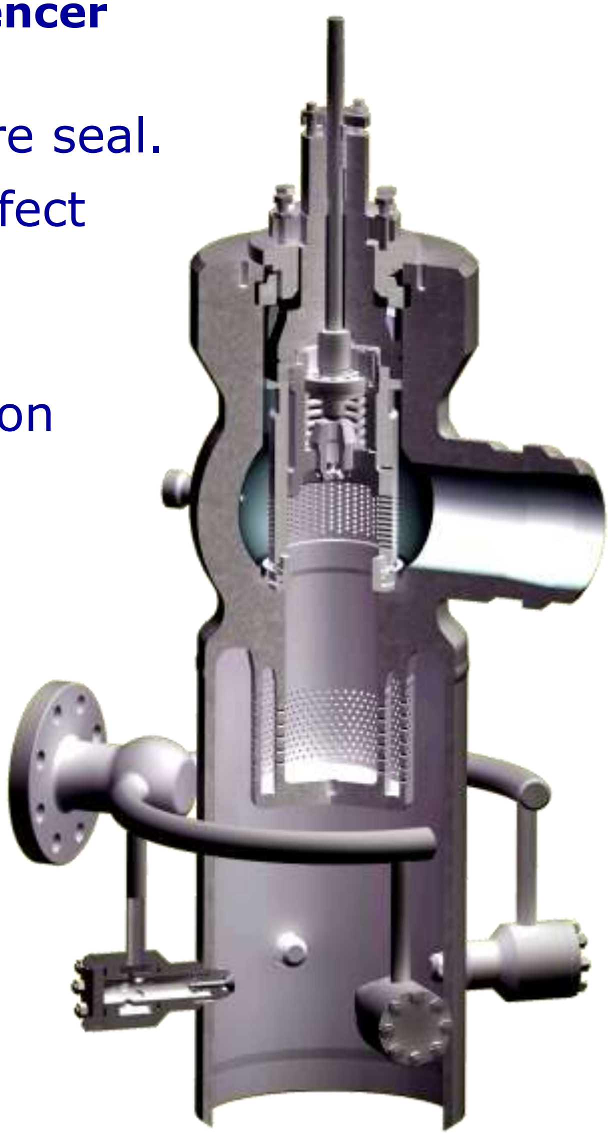
Isentropic:

	T °C	p bar		S kJ/ kg·K
2'	213	10		6.8

Pressure Reducing and Desuperheating Stations PRDS

Typical side inlet pressure reducing valve with built in silencer and downstream injected desuperheating water.

- Body bonnet connection high reliability metallic pressure seal.
- Specialty spherical body shape to reduce P/T fatigue effect (verified in accordance with TRD 301).
- Flow to close design that:
  - keeps all the main components in the upstream section that is thermally more stable and controllable.
  - allows the use of the pilot operated balanced plug solution for a perfect seal.
- Proprietary free expanding seat to body connection design to minimize thermal expansion effects.
- Low Noise design with micro-drilled cage and silencers.
- Built-in Limiphon silencer available for very low noise service.
- Built-in free expanding desuperheating water injection system.
- Compact design.



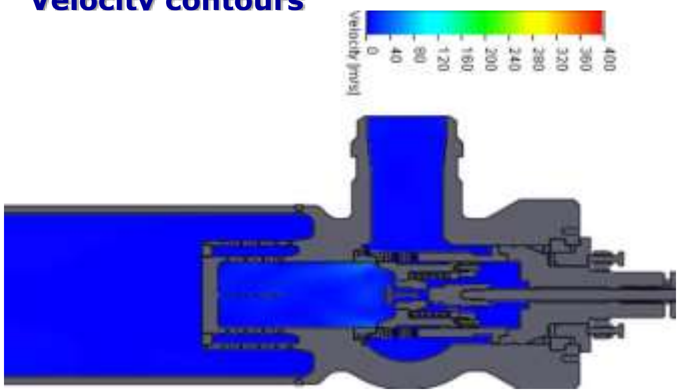
PARCOL 1-5700 PRDS

PRDS: built-in multistep silencer

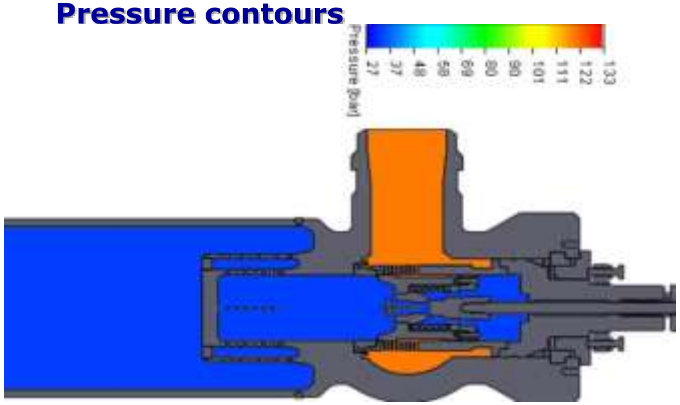
Built-in silencer has the function to:

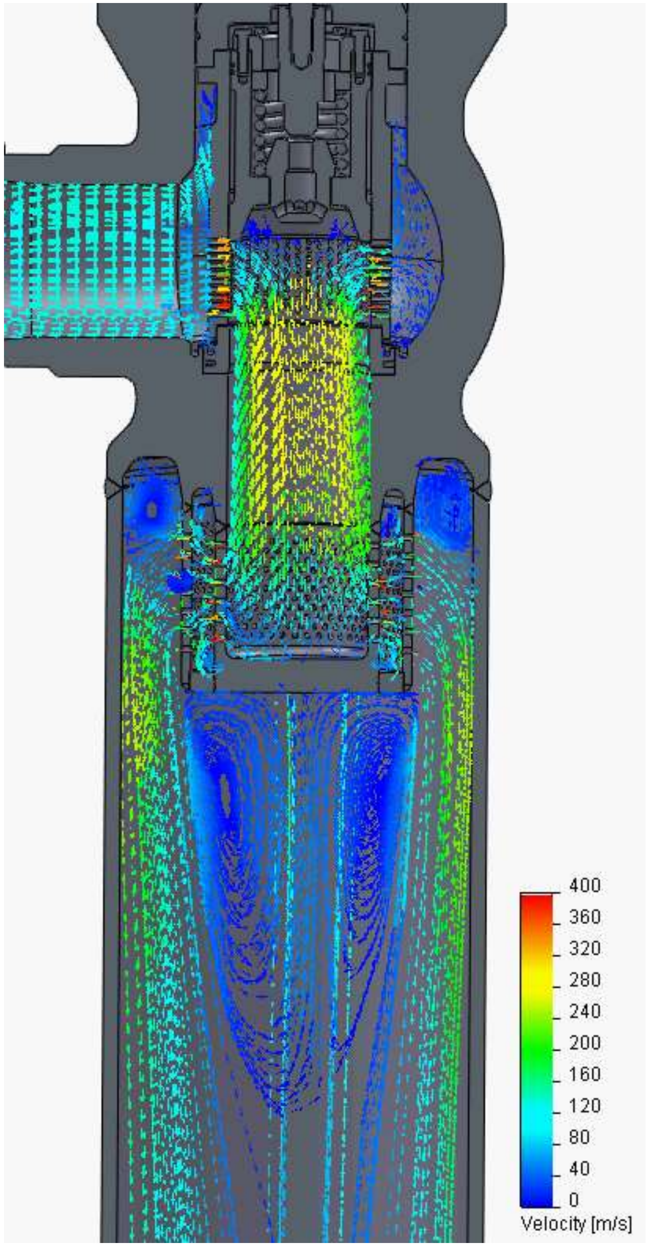
- **Generate a suitable backpressure** in order to:
  - **reduce noise generated** by the first stage at medium and high loads.
  - **moderate the steam velocity** across the seat to prevent noise generation and vibrations.
- **Reduce the downstream transmission of the noise** generated by first stage and seat.
- **Produce a suitable velocity distribution** at valve outlet to optimize downstream injected water evaporation.

Velocity contours



Pressure contours

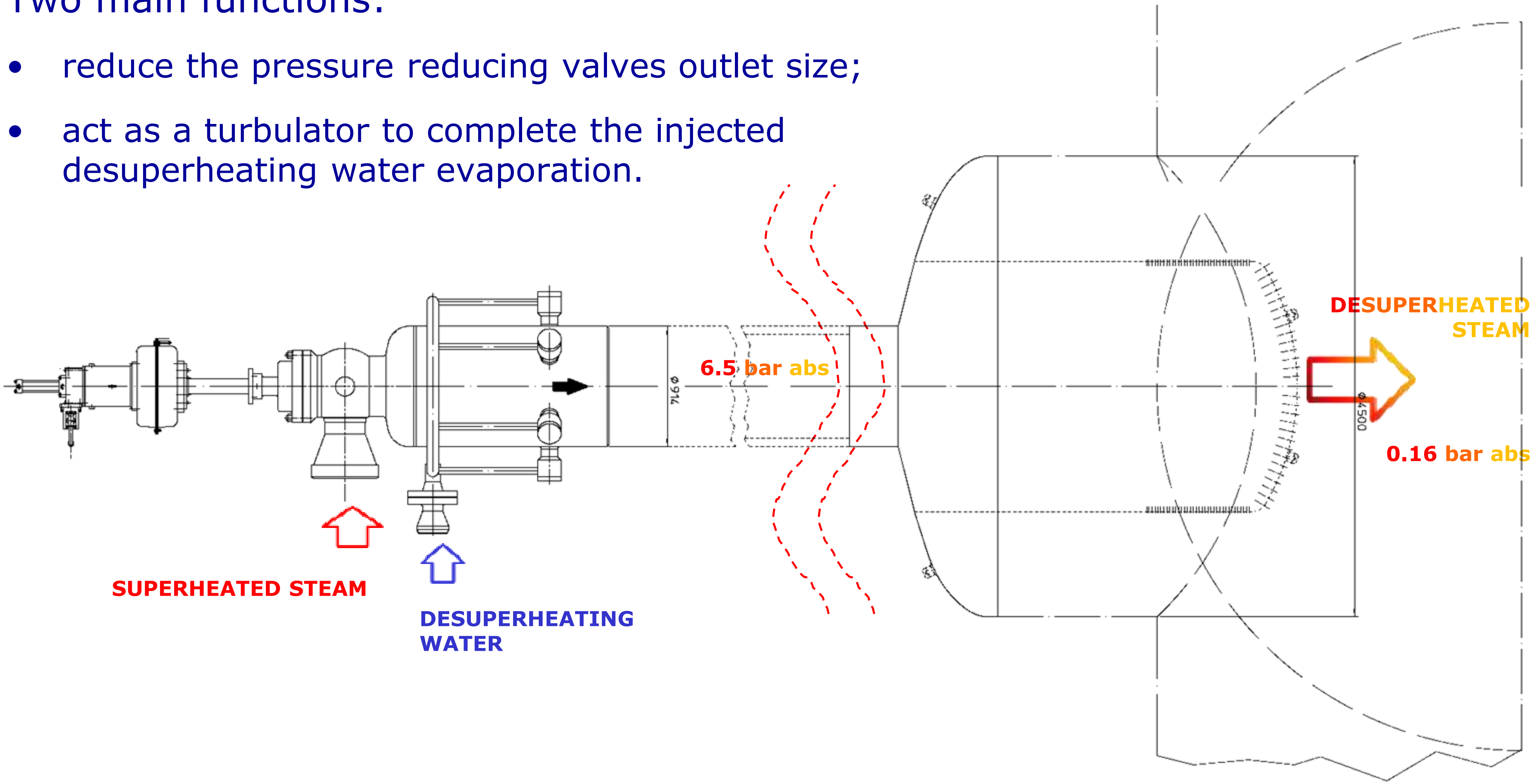




DUMPER to Condenser

Two main functions:

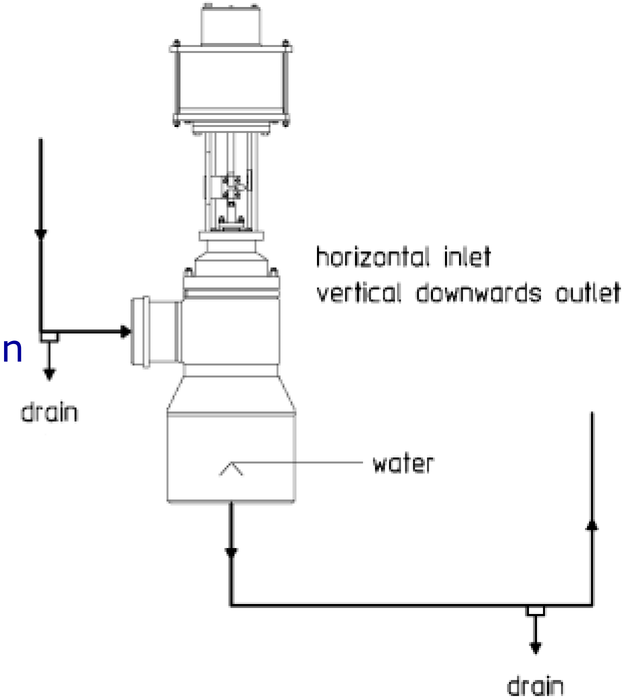
- reduce the pressure reducing valves outlet size;
- act as a turbulator to complete the injected desuperheating water evaporation.

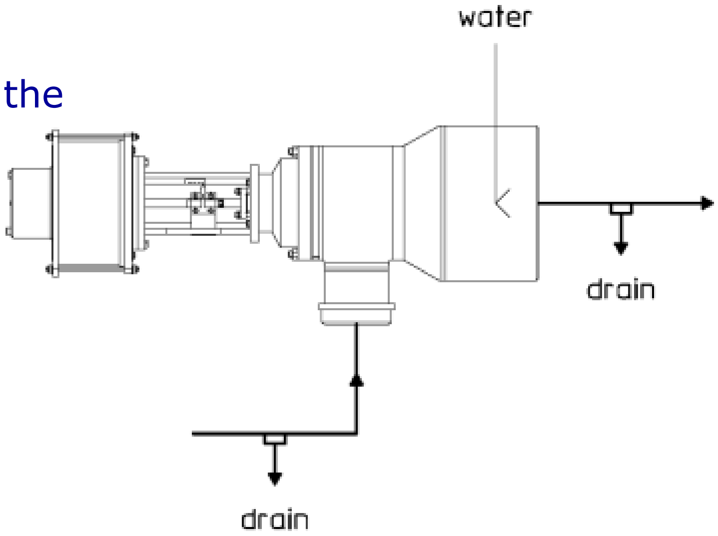


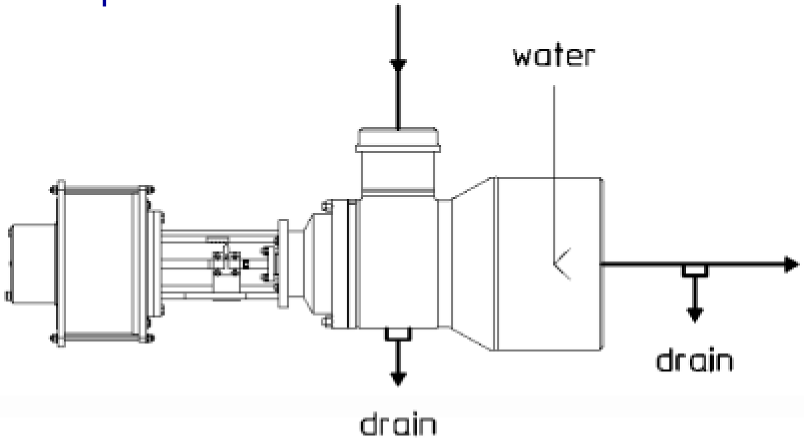
Installation

Condensate Drainage

- Upstream and downstream piping must be equipped with appropriate condensate draining systems.
- For PRDS, according to pressure reducing valve orientation, upstream condensate draining connection can be provided on upstream piping or on valve body.
- Except for self draining lines (typically to condenser) when enthalpic calculation control system is installed, condensate drain system downstream water injection must be sized taking in account for not evaporated water to avoid:
    - dangerous accumulations that may cause thermal shocks, water hammer and erosions.
    - disturbances to detection system of controlled temperature, for the presence of free water.







Installation

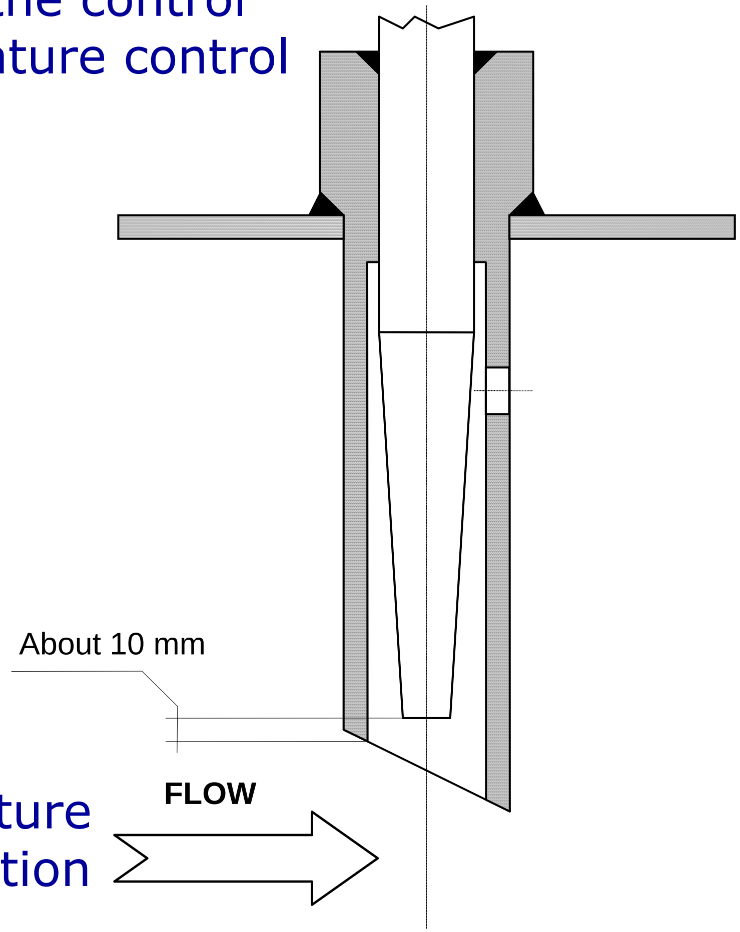
Temperature Probes Installation and Protection

Temperature sensor is the basic element for closing the control loop in all desuperheating systems based on temperature control principle (closed loop applications).

Main parameters to be taken in consideration are:

- Distance from injection point as function of:
  - Desuperheater type
  - Piping configuration
  - Process parameters

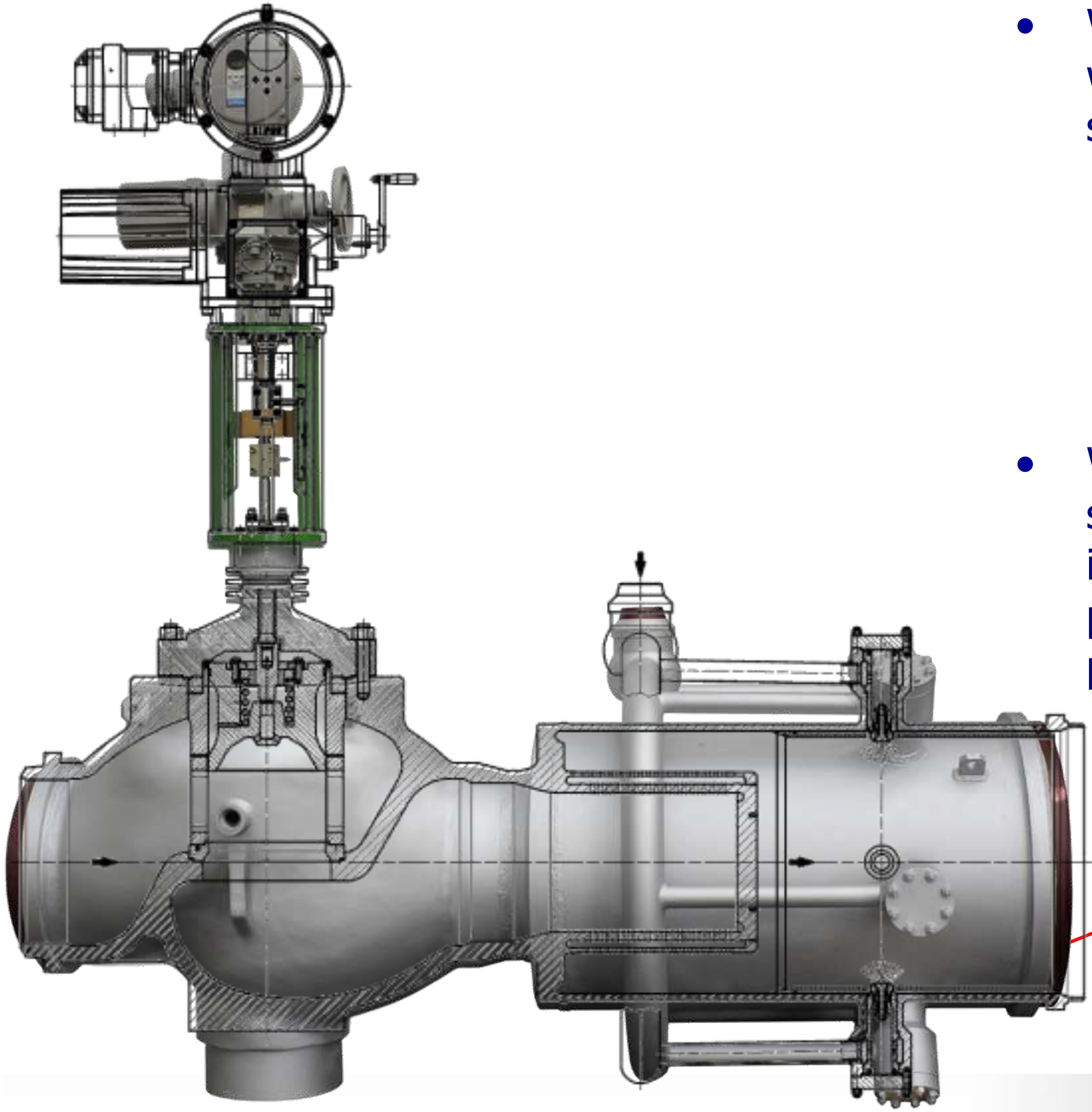
- Temperature probe positioning



For all critical application and when a stable temperature control is required, the installation of a sensor protection is suggested.

Installation

Internal Pipe Wall Protection to avoid damages for thermal fatigue



- Water dripping and/or water jet impact with pipe wall, can cause the inside pipe surface to crack due to thermal shock.

⇩

- When the difference between the superheated steam temperature and the injected water is exceeding 250 °C, a protective jacket (steam liner) for pipe wall protection is recommended.

Internal Protective Jacket

Desuperheater Selection

Main Parameters Affecting the Choice

- Superheated steam flow
- Steam pressure and temperature
- Percentage of injected water vs. steam
- Difference of required final temperature from saturation
- Required System Turndown
- Minimum and maximum steam velocity at injection point
- Minimum and maximum water-steam pressure drop
- Steam line dimensions
- Upstream and downstream piping layout
- … … …
- Etc, etc.

Process and geometrical parameters influence on desuperheating efficiency

Process Parameter	Influence
1. Water to steam pressure drop	+
2. Nozzle dimension	–
3. Steam velocity	+
4. Steam pressure	+
5. Desuperheating water temperature [1]	+
6. Water differential temperature to saturation [2]	–
7. Percentage of desuperheating water to be injected vs. steam	–
8. Pipe diameter (with same steam velocity)	+

[1] Higher water temperature reduces surface tension helping the fragmentation to small droplets.
[2] Higher differential to saturation temperature increases time for water heating up to boiling temperature.

Thank you for your attention