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SPRAY WATER ATOMIZATION AND DESUPERHEATING OF STEAM

The efficiency and selection of an SCV over a PRV with a separate desuperheater depend to a large degree on the way the water gets injected. There are many circumstances in steam plant engineering in which water drops exist temporarily within a superheated flow. It is important to know the possible lifetime of drops, especially if they could hit parts of the turbine, elbows, diffuser plates, condenser dump tubes or other impingement-sensitive parts.

This condition occurs when cooling water is added to the superheated steam flow for desuperheating, also called attemperation. A dispersion of small drops in a gas phase is generally called a liquid spray, and depending on the droplet size (diameter d) we can distinguish between

HP spray droplets	d= 0.5-100	µm
LP spray droplets	d= 20-400	µm
Erosion by impingement	d= 60-2000	µm

Real wet steam differs considerably from two-phase systems known from equilibrium thermodynamics.

Atomization of a liquid can be achieved by using a number of different nozzle designs. In the following we will define some important parameters for proper atomization.

In order to achieve atomization, the water has to leave the nozzle with a relatively high velocity. The water sheet in form of a thin film leaving the nozzle forms rotation-symmetrical waves and oscillates until disintegration. At high flow rates the water sheet breaks-up due to axisymmetric amplification of aerodynamic surface perturbations. The steam flow turbulence supports this process.

Once the radial components of velocity are restrained by the liquid's surface tension only the jet disintegrates. The disintegration results in a spray pattern of many different droplet sizes with diameters spread over a wide range.

A typical spray nozzle for steam conditioning valves may produce a droplet size distribution approximating the log-normal law. Another popular and well-fitting distribution is the one from Rosin-Rammler.

Such a size distribution curve gives an accurate description of the spray pattern. The characterization of a spray is usually made in terms of the Sauter Mean Diameter (SMD).

A droplet velocity distribution chart is of further interest for the calculation of the evaporation time and length.

A droplet stability criterion allows the engineer to determine the maximum drop size which can temporarily exist for given steam flow conditions without breaking immediately apart.

The **stability of drops** depends mainly on the ratio of aerodynamic pressure forces trying to deform it and the surface tension forces trying to make its shape spherical. This ratio is known as the Weber number (We). At low We numbers the drops remain almost spherical. Above a critical We number fragmentation takes place in a time range of 1 to 3 msec.

It can be observed that the droplet diameter produced by a spray nozzle increases nearly linearly with the increasing of the nozzle outlet diameter. The droplet diameter will also increase with decreasing density of the carrier fluid.

Higher steam velocities reduce the max. possible drop size at the injection point due to oscillation and friction.

The performance of spray nozzles is strongly influenced by surface tension, density and viscosity of the **cooling water**.

° The flow through a nozzle varies roughly with the square root of the water **density**.

° The **viscosity** influences the droplet size, the resulting spray pattern, the flow rate and has an impact on the formation of natural instabilities in the water sheet through variations in the Reynolds number.

° The **surface tension** represents the resisting force to increase the liquid surface area.

The **steam** pressure and temperature (and thus the density) have also a significant effect on the atomization and evaporation process. The spray angle and droplet size vary as a function of the gas density.

Preheating and Evaporation of Drops

The temperature within a drop is determined by heat conduction to or from the drop surface, where the temperature is influenced by the carrier steam conditions. Under certain ideal conditions cavitation boiling may occur in the drop (called flashing) and result virtually in an explosion and fine fragmentation of the drops.

As soon as we inject water into a hot steam flow, heat transfer takes place. The evaporation process involves simultaneously heat and mass transfer.

First, the drops need to be heated-up to the saturation temperature. During this preheat process the transferred heat is transformed into drop enthalpy. After arriving at the saturation temperature the heat for evaporation is transferred to the droplet surface by convection and conduction from the steam. The heat flux is transformed into latent heat of evaporation which is a function of the pressure and temperature. Vapor is transferred back into the steam flow by convection and diffusion. The smaller the initial droplet size, the shorter the heat-up and evaporation time which in turn reduce the evaporation length. The heat transfer coefficient, droplet Reynolds number, Nusselt number (convective heat transfer), drop surface tension and viscosity are important factors in these calculations.
A complete analysis of the **mechanics in steam and droplet mixtures** has further to consider

° Droplet drag forces and related drag coefficients
° Coagulation and bounce-off effects of drops
° Droplet impact, deposition and rebounding
° Droplet deformation and break-up due to resonance, velocity Gradients, turbulence, shock waves, impingement, and
° Breakup patterns and forms.

Today there are commonly two general methods used for modeling of two-phase spray flow conditions occurring in the outlet section of steam conditioning valves and desuperheaters:

1. The **Euler method** for an interpenetrating continua approach, and
2. The **Lagrange model** for a dispersed phase.

The Euler method applies the continuum formulation of conservation for the liquid and gas phase in a fix defined reference frame. The Lagrangian moving-frame approach considers the motion and transport of discrete liquid particles through a flow field. The interphase laws of the latter method describe the droplet behavior more accurately and provide better information on the particle phase, the drop history, bouncing-off and other boundary effects. The water droplet trajectories are calculated by integrating the differential equations for particle momentum, particle energy and mass transfer. Both phases, steam and water, are coupled by standard correlations to account for momentum, mass and heat transfer.

A prediction of the evaporation length for a certain spray includes the investigation of a possible liquid film along the pipe wall and resulting secondary atomization effects due to flow turbulence and velocity differences between steam and water film.

Water Injection Nozzle Design

From the above it becomes obvious that the design of the water nozzle, the resulting initial droplet size, the injection point, valve outlet geometry and the fluid conditions are the governing circumstances for successful and trouble free desuperheating.

The fluid condition can generally not be influenced by the valve designer, but he is in control of the mechanical design and the aerodynamic geometry which provide for an optimum result.

The spray water flow path is a crucial element in an SCV. The internal water proportioning mechanism in a combined valve must be designed with a specific relationship to the steam plug characteristic and the water/steam conditions and allow for a sufficient atomization pressure over the entire range of operation. The water proportioning and the nozzle geometry are usually customized to account for varying steam and water conditions.

A swirl section and a subsequent acceleration chamber in the nozzle are important features. The swirler generates a momentum which distributes the water evenly at the nozzle outlet, stabilizes the flow sheet and increases the velocity. The acceleration chamber further increases the water velocity and as a result the relative velocity between water drops and carrier steam which is an important criteria in the desuperheating process. The outlet gap of the water nozzle should be large enough to let minor impurities through but small enough to produce a fine film.

The mean droplet size has a big influence on the total evaporation time. Drops should be as small as possible and evenly dispersed across the flow area. A bigger number of fine drops automatically increase the total drop/steam contact surface which enhances the heat exchange.

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