In typical process plants, there is a high demand for saturated steam. However, process steam is usually superheated, or heated to a temperature above saturation. The amount by which the superheated temperature exceeds the saturated temperature is known as the degree of superheat. Desuperheaters are used to bring the outlet degree of superheat closer to that of saturation. From very simple mechanical designs to highly complex and flexible systems, the range of desuperheater capabilities is vast. Desuperheated steam is more efficient in the transfer of thermal energy. It may also allow the use of thinner pipes, lighter flanges or less-expensive materials.

Regardless of the process, there is a desuperheater available to accommodate most requirements. With numerous styles and models available, evaluation of the actual needs of the process is crucial to ensure selection of the right equipment. Specifying conditions less stringent than the actual operating conditions will result in a unit that cannot handle all operating cases. Similarly, over-specifying the thermal load or process requirements is detrimental to efficient operation and will increase the price tag of both the desuperheater and its controls.

Evaluating the requirements
Turndown capability, pressure drop and outlet superheat play lead roles in desuperheater design and selection. In general, no single parameter is more important than the other – some processes demand steep turndown capability, while others rule out significant pressure drop or outlet superheat. For the optimum design, it is imperative for engineers to understand the nature of these parameters and their potential to influence a process.

Turndown represents the variability of the steam flowrate. Certain processes have a constant steam flow, so turndown is not an important design factor. Other applications, including power generation and food processing, require large disparities in steam flow. As a general rule, higher turndown requirements call for more complex and more expensive desuperheaters.

Turndown is calculated by dividing the outlet velocity of the maximum steam flow by the outlet velocity of the minimum recommended steam flow. As the density of the outlet steam does not change with flowrate, turndown can also be calculated by dividing the maximum mass flowrate by the minimum mass flowrate. All symbols are defined in the nomenclature table.

\[ Tr = \frac{V_{\text{maximum}}}{V_{\text{minimum}}} \quad (1) \]

\[ Tr = \frac{m_{\text{maximum}}}{m_{\text{minimum}}} \quad (2) \]

Pressure drop varies from negligible in some units to very high in others. Most users prefer to keep desuperheater pressure drop to a minimum; and for low-pressure systems, it is vital. Sophisticated systems can actually adjust the desuperheater performance based on actual pressure drop at all times.

Generally, for moderate pressure systems, a 5-10 psi drop is considered reasonable. From an operations standpoint, moderate pressure drop will also reduce the outlet temperature somewhat. However, the reduced temperature is usually not low enough to make any significant difference to downstream equipment.

It is important to bear in mind that from a design standpoint, pressure drop and turndown are at odds. For example, a high velocity desuperheater with a 10-in dia. will have a better turndown but higher pressure drop than a 12-in unit with lower velocity. When the allowable pressure drop is lower than 5 psi, it is likely that certain desuperheater...
styles will be unable to meet substantial turndown ratios. The potential to reduce the degree of outlet superheat is limited by the capability of the control system. Nearly all desuperheaters are used to reduce steam (or gas) temperature as close to saturation as possible. Most desuperheater styles are actually capable of achieving saturation, or close to it. The caveat is that these units must be controlled precisely to prevent flooding of the whole system. The limitation of the control system is its sensitivity range. Consider a system with a controlled outlet temperature set at 5°F above saturation, where the controls are designed to maintain ±5°F. As the temperature falls below the setpoint, the controls will continue to pump cooling water into the stream. Only when the temperature falls to saturation will the controls decrease the cooling water flow. Due to the delays inherent in the control system, cooling water will continue to flow at the design rate for a short time. In that small amount of time, the saturated steam will be allowed to condense. Condensing vapor creates a vacuum, which sucks in more vapor, which continues to condense. The control is lost, downstream equipment may be damaged, and downstream processes may be severely affected.

Many desuperheater manufacturers have opted to not guarantee desuperheating lower than 10°F above saturation. Controls for this situation are reasonably priced, and downstream processes do not suffer much from the small amount of superheat. Manufacturers who package their desuperheaters with controls are more likely to guarantee lower outlet superheat, as they are fully in control of the system parameters. Units that produce less outlet superheat are typically more expensive than those that produce more superheat.

Desuperheater styles
Most desuperheaters reduce the temperature of superheated process steam by introducing finely atomized cooling water droplets into the steam flow. As the droplets evaporate, sensible heat from the superheated steam is converted into latent heat of vaporization. Required cooling water flow is determined from a rearrangement of the energy balance equation.

\[ m_o = m_i \frac{(h_i - h_o)}{(h_i - h_c)} \]  

A further reward of these desuperheaters is the addition of the evaporated cooling water to the total outlet steam flow. Figures 1-6 illustrate the cooling mechanism and temperature gradient for typical configurations that utilize cooling water.

The simplest designs are known collectively as mechanical-atomizing desuperheaters (Figure 1). The basic principle of operation is to desuperheat steam by injecting water through a spray nozzle, breaking the water stream into a fine mist. The difference between various mechanical-atomizing units directly corresponds to the style of spray nozzle used by the manufacturer. Mechanical atomizing desuperheaters handle relatively low turndown requirements, usually in the range of 2:1-5:1. Although there is little to no pressure drop induced in the steam, the required water pressure is typically much higher than the steam operating pressure – often up to 50 psi greater. Another major limitation of this style of desuperheater is that the minimum outlet superheat will not drop below 20°F (11°C) above saturation. However, with its simple and inexpensive design, this workhorse of a desuperheater should not be overlooked.

When high-pressure water is unavailable for a mechanical-atomizing desuperheater, venturi desuperheaters are a good choice. Required water pressure is ≤5 psi over the steam pressure. In this configuration, water is piped right into the venturi nozzle, which does all the work of atomizing the water without moving parts or smaller orifices that are subject to clogging or eroding. Two levels of venturi desuperheaters are available. Single-venturi (partial-venturi) desuperheaters (Figure 2) simply incorporate a venturi nozzle and achieve slight improvements in turndown ratio and outlet superheat, when compared to the performance of mechanical atomizing units. However, double-venturi (full-venturi) designs (Figure 3) incorporate a venturi nozzle inside a venturi body to increase turndown up to 10:1 and decrease the outlet temperature to 10°F (5.6°C) of superheat. Venturi units are more expensive than mechanical atomizing ones.
and some induce a higher pressure drop in the steam than do the mechanical atomizing versions. But when compared to the mechanical atomizing style, occasionally the increased turndown and lower outlet superheat of a venturi desuperheater offset such drawbacks.

When high turndown is required and high-pressure steam is available, steam atomizing desuperheaters (Figure 4) present a viable solution. A steam-atomizing nozzle allows a small amount of steam (about 1-2 mass% of the main steam flow) to enter the nozzle upstream of the cooling water. The atomizing steam breaks up the cooling water without expensive spray nozzles or venturi cones. Cooling-water requirements change slightly with the addition of atomizing steam.

\[
m_w = m_n (h_i - h_n) - m_s (h_o - h_s)\]

The atomizing steam pressure typically must be 1.5-2.0 times higher than the main steam pressure, but the steam can be conveniently piped from upstream of the closest pressure reducing valve in the main steam line. Similar to venturi units, minimum outlet temperature is 10°F above saturation. But unlike venturi desuperheaters, steam-atomizing units engender negligible pressure drop. Turndown ratios can reach an impressive 50:1, and the simple construction makes these units surprisingly inexpensive.

When atomizing steam is not available, but a high turndown is required, a multiple-nozzle design (Figure 5) is appropriate. The method of operation is essentially the same as a mechanical atomizing style. But with multiple spray nozzles, the orifices on the nozzles can often be opened or closed to optimize the cooling water velocity for low turndown operation. Therefore, outlet superheat and turndown similar to that of steam-atomizing units can be achieved. The main drawback of the multiple nozzle type, compared to the steam-atomizing variety, is the large pressure drop induced by the spray nozzles. Also, these units are comparatively expensive. For very high turndown requirements, up to 100:1, the complex variable-orifice (Figure 6) style warrants consideration. As steam flow changes, a self-regulating orifice controls the water flow for optimum performance. As with double venturi, steam-atomizing and multiple nozzle styles, minimum outlet superheat is 10°F. Pressure drop is low, due to the constant regulation of the orifice, but price is justifiably high for this carefully engineered desuperheater.

For the most stringent applications, a steam conditioning valve or a pressure reducing desuperheating system may be the best option. This customized package combines a pressure reducing station, desuperheater and controls, achieving results comparable to those of the variable orifice. The major benefit of these systems over the variable orifice is that the outlet pressure is continually controlled. As the system monitors pressure drop through the desuperheater, it adjusts the performance of the pressure reducing valve. Since any style of desuperheater can be specified in the package, prices vary. There is another desuperheater that differs basically from the others already discussed. Surface-absorption units (Figure 7) do not inject water into the steam flow. Instead, the steam is forced through wetted packing, to minimize water carryover, which is important for certain processes in the food industry. An important advantage of surface-absorption units is that the outlet temperatures can reach saturation. The major disadvantages are high cost and large pressure drop induced by the wetted packing.

**Selecting Materials**

Choosing the most appropriate materials of construction can prolong useful life and ultimately reduce costs. Table 1 summarizes the recommended external and internal materials for various temperature regimes.

For design temperatures less than 800°F, carbon steel externals and stainless steel internals are sufficient. However, prolonged exposure to temperatures above 800°F may convert the carbide phase of carbon steel to graphite, severely compromising the integrity of the metal. Chromium-molybdenum alloys are recommended for temperatures in the range of 800-1200°F. It is important to keep in mind that chrome-molybdenum components should not be welded to stainless steel components. Whereas chrome-moly must be heat treated, stainless steel becomes sensitized and susceptible to corrosion after heat treating.
When temperatures exceed 1200°F, desuperheaters are most commonly fabricated entirely of stainless steel. However, stainless steel has a high thermal expansion coefficient, which can cause stress at nozzles or welds. Special alloys can be used as an alternative, but the high cost usually prohibits their acceptance.

**Getting the best performance**

Engineers must give careful consideration to the maximum allowable working pressure (MAWP) and design temperature of the unit. Most plants have nominal guidelines for calculating these values (20% higher than the operating pressure and temperature), but many times a reduction of 10 psi or 20°F will allow use of lighter flanges. The cost of heavy flanges adds up quickly, especially on small desuperheaters. Although the principle of operation is very straightforward, a desuperheater is not a standalone piece of equipment, and suitable controls are vital for efficient operation. Desuperheater control systems can either be integral to the unit or added to an inline type of desuperheater. Integrally controlled units are far more versatile than in-line configurations and are capable of manipulating highly variable systems. However, integrally controlled systems carry a high price tag, which is attributable to their advanced design and engineering. If a process does not require varying steam conditions, a separately controlled in-line desuperheater may be sufficient, without such strains on the budget. When installing a complete system, locate the water and atomizing steam controls as close to the desuperheater as possible. By minimizing the volume of fluid between the controls and desuperheater, this strategic placement allows a change in setpoint to occur quickly. Likewise, the desuperheater should be placed as close as possible to the point of steam use, not the point of steam generation. A shorter distance will ensure that the desuperheated steam is delivered at the specified conditions. However, the temperature sensor must be installed far enough downstream to allow the vaporized water to fully mix with the superheated steam. This distance is calculated based on the required outlet superheat. Minimum outlet superheat requires the maximum downstream length. For instance, an outlet superheat of 10°F requires 30 ft downstream of the desuperheater for complete mixing. Cooling water should ideally be brought as close to its boiling point as possible. Injecting subcooled water does not substantially improve thermal efficiency because the sensible heat that must be absorbed by sub-cooled water is relatively small in comparison to the latent heat of vaporization (averaging 970-1,000 Btu/lb for medium pressure steam).

In fact, highly subcooled water, 100°F or more below the saturation temperature, may actually have a negative impact. If the steam velocity is low or the flow pattern is not sufficiently turbulent, there is a good chance the subcooled water will fall out of suspension before it has a chance to vaporize. In such situations, manufacturers may add a steam-assist feature around the cooling-water inlet pipe. This allows a small amount of superheated steam to circulate around the water inlet, warming the water before it exits the nozzle. Any water droplets that hit the downstream pipe are warmer than they would be without the thermal sleeve, thus reducing thermal shock to the pipe and downstream erosion from water runoff. In lieu of a steam-assist feature, manufacturers may opt to include a thermal liner, as it also reduces thermal shock and downstream erosion. This cylindrical shield is placed inside of the desuperheater and downstream piping. While the liner itself may erode or develop

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**Table 1. Desuperheater Material Selection**

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Carbon steel</th>
<th>Stainless steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 800°F</td>
<td>1/4 Chromium - 1/2 Molybdenum</td>
<td>1/4 Chromium - 1/2 Molybdenum</td>
</tr>
<tr>
<td>801-950°F</td>
<td>1/4 Chromium - 1/2 Molybdenum</td>
<td>1/4 Chromium - 1/2 Molybdenum</td>
</tr>
<tr>
<td>951-1,200°F</td>
<td>1/4 Chromium - 1 Molybdenum</td>
<td>1/4 Chromium - 1 Molybdenum</td>
</tr>
<tr>
<td>1,200-1,500°F</td>
<td>Stainless steel</td>
<td>Stainless steel</td>
</tr>
</tbody>
</table>

**Table 2. Relative Costs and Benefits for Each Desuperheater Style**

<table>
<thead>
<tr>
<th>Style</th>
<th>Tundown ratio</th>
<th>Pressure drop</th>
<th>Outlet superheat</th>
<th>Relative cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical atomizing</td>
<td>2:1 to 5:1</td>
<td>low</td>
<td>20°F</td>
<td>low</td>
</tr>
<tr>
<td>Single venturi</td>
<td>2:1</td>
<td>negligible</td>
<td>20°F</td>
<td>low</td>
</tr>
<tr>
<td>Double venturi</td>
<td>10:1</td>
<td>moderate</td>
<td>10°F</td>
<td>moderate</td>
</tr>
<tr>
<td>Steam atomizing</td>
<td>50:1</td>
<td>negligible</td>
<td>10°F</td>
<td>moderate</td>
</tr>
<tr>
<td>Multiple nozzle</td>
<td>50:1</td>
<td>high</td>
<td>10°F</td>
<td>moderate to high</td>
</tr>
<tr>
<td>Variable orifice</td>
<td>100:1</td>
<td>low</td>
<td>10°F</td>
<td>high</td>
</tr>
<tr>
<td>Customized steam conditioning valve</td>
<td>up to 100:1</td>
<td>self-regulating</td>
<td>10°F</td>
<td>very high</td>
</tr>
<tr>
<td>Surface absorption</td>
<td>unlimited</td>
<td>high</td>
<td>saturated</td>
<td>high</td>
</tr>
</tbody>
</table>
cracks, the structural integrity of the pipe is preserved. Thermal liners also increase steam velocity and turbulence, which helps to keep water droplets in suspension. However, this additional benefit is not their primary use. In fact, difficult installation and replacement makes thermal liners less attractive in cases where a steam-assist feature will do the job.

Cooling water pressure also pays an important role in certain styles. The mechanical-atomizing, multiple nozzle, variable orifice, and surface absorption styles all require the cooling water pressure to be much higher than the main steam pressure – sometimes up to 50 psi higher. This differential is required to prevent the water from dropping out of suspension. Adherence to straight pipe lengths recommended by the desuperheater manufacturer is very important, both upstream and downstream of the desuperheater. Straight length upstream allows the steam to settle into a flow pattern that is conducive to uniform spray-water distribution. Straight length downstream ensures sufficient time for the water droplets to fully evaporate. One rule of thumb suggests a length in feet equivalent to one tenth of the downstream velocity.

\[ V = \frac{m}{A} \]  

(5)

Elbows may be installed downstream of the required straight length and upstream of the temperature sensor. Elbows actually increase turbulence and encourage more thorough mixing. However, never install elbows within the specified straight downstream length, as the un-evaporated-water droplets will fall out of suspension, preventing full desuperheating and encouraging premature erosion of the elbow wall.

To help optimize performance, a strainer should be installed upstream of the water control valve. This will reduce small particles that may clog or erode nozzle orifices. This is particularly important for desuperheaters with non-replaceable water nozzles.

Careful consideration should also be given to the space available for installation. Many desuperheater styles can achieve increased turndown when the unit is oriented vertically with flow in the upward direction. As the steam and water are countered by gravity, the water is less likely to fall out of suspension. Minimum velocity is about 30% lower with such an orientation, thus increasing turndown by about 30%.

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