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DESUPERHEATING FOR ACCURATE STEAM TEMPERATURE CONTROL

THE SEEMINGLY SIMPLE PRACTICE OF ADDING WATER TO STEAM TO LOWER ITS TEMPERATURE IS ACTUALLY QUITE COMPLEX. THE AUTHOR PROVIDES GUIDELINES TO HELP OPERATORS UNDERSTAND HOW TO CONTROL THE DESUPERHEATING PROCESS.

BY JOEL W. KUNKLER

In the process and power industries, steam is used both to perform mechanical work, such as driving a turbine, and as a heat transfer fluid. Unfortunately, both functions are accomplished best with steam properties at opposite ends of a spectrum—dry superheated steam is at the high end, while desuperheated steam near its saturation point is at the low end. Going from the high end of the spectrum to the low end involves steam conditioning, a process typically misunderstood and often overlooked.

What complicates steam conditioning is temperature control, or desuperheating. This seemingly simple practice of adding water to steam to lower its temperature is actually quite complex because desuperheating leads to a temporary, two-stage, liquid-vapor flow with potential control difficulties.

The three general process reasons for desuperheating steam are:

- to improve thermal efficiency of heat transfer processes by using steam near saturation
- to control unintentional superheat from reducing the pressure of steam
- to protect downstream equipment and piping from elevated temperatures and pressures.

The goal of steam desuperheating is to reduce the temperature setpoint at the shortest possible piping distance and elapsed time while avoiding damage from two-phase flow. A number of critical installation and application parameters influence whether or not this goal is reached.

Temperature Setpoint

The downstream temperature setpoint should not be too close to the saturation temperature of the primary steam. This is because as the saturation temperature is approached, the steam flow almost always exhibits two-phase characteristics. Injection of spraywater, especially in larger pipelines, can result in uneven distribution of the steam's temperature. For example, if the desuperheating spraywater has not been properly injected, regions of superheated steam can surround a core of much cooler steam.

This situation is compounded when the setpoint is near saturation. If some steam flow is converting to water, droplets will cling to the temperature-sensing element as the hotter steam passes. This results not only in a false temperature reading of the steam saturation, but also a cycling of the desuperheating system. The temperature controller reading will increase and the controller will decrease the spraywater flow continuously while hunting for the correct temperature.

The general rule is that you should have a setpoint greater than 10° F above saturation when using feedback control based on a downstream temperature sensor. If a setpoint of less than 10° F is absolutely necessary, a feed-forward control strategy must be used. This requires a simple algorithm in the plant's distributed control system to calculate the spraywater required to reach the temperature needed based on the conditions of entering steam and spraywater. Also note that a sufficient pipe drain system should be part of any desuperheating station to protect against unexpected overspraying or water fallout situations.

Spraywater Pressure

The amount of pressure differential between the spraywater and the steam is very important for both water atomization and the rangeability between maximum and minimum water flows. The maximum pressure differential, along with spraywater temperature and spray nozzle design, directly affects atomization to the smallest droplet size: the smaller the droplet, the more rapid the vaporization. Additionally, the greater the pressure differential, the greater the spray nozzle's rangeability to reach lower water flow situations through continued acceptable differential levels.

Spraywater pressure ideally is 150 to 1,000 psid greater than the steam pressure. Although desuperheating devices can operate at much lower differentials, a

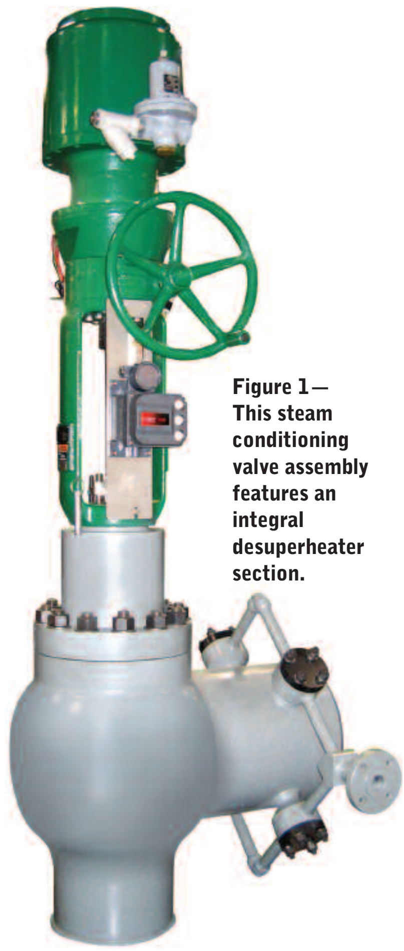

Figure 1—This steam conditioning valve assembly features an integral desuperheater section.

direct correlation exists between differentials and vaporization speed performance as well as ability to obtain controllable low-flow levels. One cautionary note: when considering high pressure differentials, the spraywater control valve may need cavitation protection.

Spraywater Temperature

The temperature of the spraywater is critical to rapid vaporization and conversion into steam. Hotter water vaporizes faster than cooler water for two reasons. First, the hotter water is closer to its saturation temperature so it requires less heat input from surrounding steam, and therefore, less time to vaporize. Note that an increase in the amount of "hot" spraywater is required compared to "cold" water and the reduction in evaporation is more favorable than water flow increase.

The second, more subtle reason for using hotter water is that at higher temperatures, hot water atomizes into smaller droplets due to less surface tension. As a rule, water is deemed hot at approximately 180° F and greater. The higher above 180° F, the better the atomization.

Note also with caution that potential flashing issues exist both in the spraywater control valve and at the nozzle. Flashing of the spray water as it exits the nozzle is beneficial. However, flashing upstream, in either the valve or just before the nozzle, drastically inhibits performance and may damage both pieces of equipment.

Initial and Final Steam Superheat

The initial amount of superheat reduction needed determines the amount of spraywater flow. The greater the amount of spraywater, the longer it takes for complete vaporization. Equally important, however, is the converse: the desired amount of final superheat. As mentioned above, controlling to a setpoint barely above saturation makes the vaporization process more difficult.

Minimum Steam Velocity

One of the most critical aspects of water vaporization involves minimum steam velocity. For vaporization to occur, water droplets must remain suspended in the steam flow until they can completely evaporate.

The type of spray nozzle and the turbulence of the steam flow influences what velocity is required. In a traditional desuperheater-only configuration, the minimum steam velocity must be approximately 30 feet per second or greater. However, lower velocities of approximately 10 feet per second are possible when special desuperheater constructions assist in mixing.

The optimum situation, however, is to have steam pressure reduction occurring immediately upstream of the desuperheater. Such a situation occurs when a combined function device—such as a steam conditioning or turbine bypass valve or a separate pressure-reducing valve located within approximately three to five pipe diameters—is used. Either arrangement can keep water droplets suspended in average velocities as low as approximately five feet per second because of the turbulence in the steam flow.

Maximum Steam Velocity

Concern about the effect steam velocity has on desuperheating comes from the fact that the faster the velocity, the faster two-phase flow moves in the pipe and the greater the distance required to completely convert the flow to steam. High velocity can be beneficial because its greater overall turbulence enhances the mixing. However, weight the value turbulence against the sheer momentum of the steam, which causes longer distances/time for the spraywater to vaporize. Most steam piping velocity guidelines suggest a maximum velocity of 200 to 250 feet per second to minimize turbulence-induced vibration.

Pipeline Size

Also important is the size of the pipeline in relationship to the amount of required spraywater. Large amounts of spraywater in small pipelines can lead to water impingement on the pipe wall and subsequent fallout. Still, desuperheating steam in large pipelines can be challenging because establishing a homogeneous mixture of steam and injected water is difficult. This mixing

Figure 2—A desuperheater that injects spraywater in the outlet of its venture section assures excellent mixing and rapid atomization.

Figure 3—This desuperheater has multiple, fixed-geometry spray nozzles for applications with nearly constant loads.

challenge leads to inaccurate temperature measurements and subsequently, poor temperature control.

Installation Orientation

Orientation of the desuperheater also can affect the speed of vaporization. Installations in which spraywater is injected into a horizontal pipe are most common and are used as the baseline. Installations in a vertical flow-up pipe perform slightly better because of the positive effect gravity has on the injected water droplets—a longer residence time enhances vaporization. Conversely, however, installations in a vertical flow-down pipe perform slightly worse than horizontal because of the negative effect of gravity—reducing residence time.

Turndown

Turndown is often misunderstood. To a user, the term "turndown" refers to the ratio of the maximum to minimum steam flow a desuperheater can control. However, this view fails to recognize the importance of variations in both steam and spraywater pressures, temperatures and flows that occur at various operating times.

The correct method for determining turndown is to view it in terms of the spraywater nozzle's control rangeability. The driving consideration for temperature control is the nozzle's ability to create an adequately formed, conical-shaped spray pattern. In turn, that pattern must be comprised of droplet size and shape easily converted and maintained over a range of conditions. The spray nozzle's ability to perform defines the range between controllable maximum and minimum spraywater flow, which in turn determines what can be accomplished given a certain set of conditions.

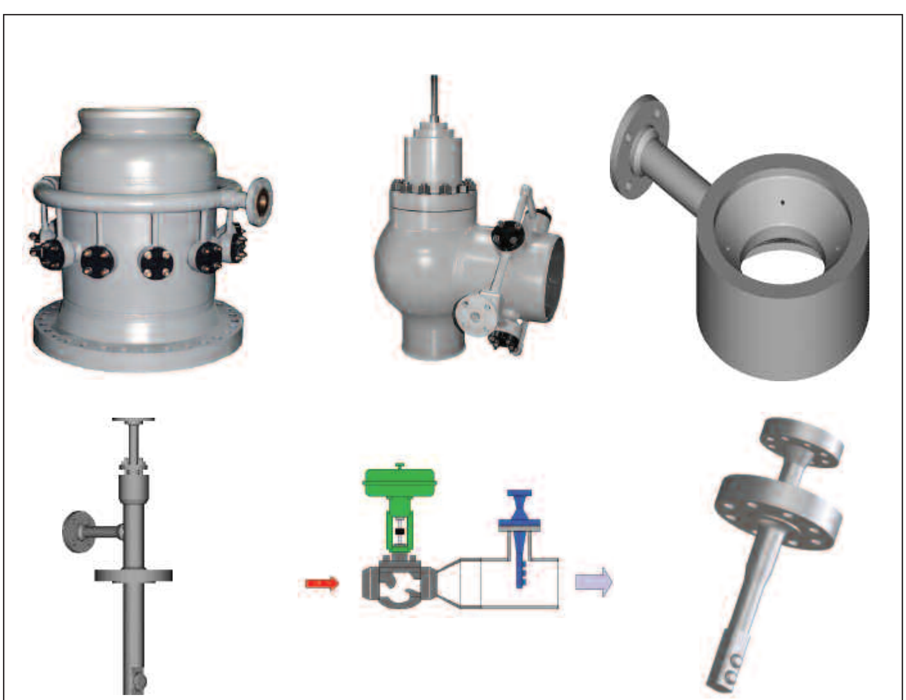

Figure 4—Types of desuperheating devices

Strainers

If the spraywater may include particulates such as weld slag, dirt or other debris or if the spray nozzle has a very small orifice, the use of in-line spraywater strainers is mandatory. These strainers protect the spray nozzle from becoming clogged by debris, which can decrease capacity as well as distort the spray pattern droplet size.

Steam Pipe Liner

Liners are used to protect the steam pipes against water impingement and thermal shock at the point where spraywater is injected. These pipe liners are usually high-grade chrome-molybdenum, which has a greater resistance to cyclic thermal stress than carbon or lower alloy steels.

In the past, liners were commonly used because nozzle design technology was not as sophisticated and because we had less understanding of the thermodynamic issues involved in desuperheating. A problem with liners, however, is that if spraywater comes in contact with them, they ultimately disintegrate and are released downstream with the potential for serious damage.

Often, more careful consideration of installation factors can replace the need for such a device. However, when no alternative is available and the potential for spraywater fallout is too great, a liner can improve system performance significantly as well as protect against cracking of the main pressure-retaining pipes. However, the increased velocity must be factored

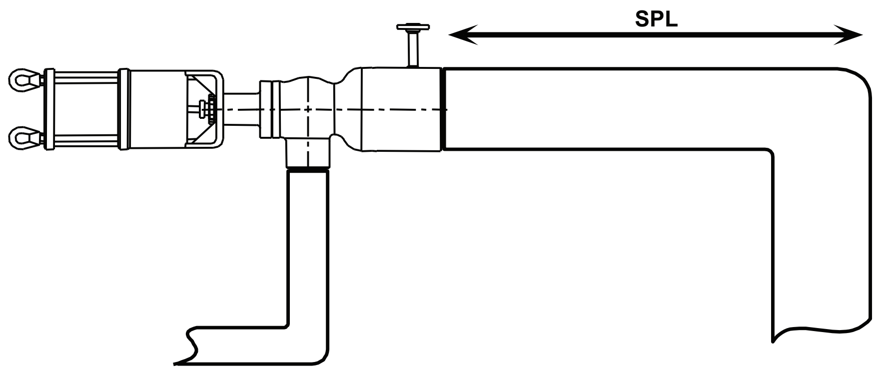

Figure 5 – Straight Pipe Length (SPL): assumes 80% vaporization and thermal mixing; calculated by thermodynamics of system; and without obstruction typically over the first 10 to 40 feet.

into the calculation for straight pipe distance and temperature sensor location. The desuperheater supplier must know liner dimensions to avoid installation problems. Also, the liner's condition should be checked regularly.

Straight Pipe Run Requirement

The correct distance for uninterrupted pipe after a desuperheater can be determined only after careful consideration of all influencing factors. This distance should not contain elbows, valves or other steam flow obstructions. If the straight pipe is not long enough, non-vaporized water droplets will contact the first elbow pipe wall and fall out of the steam. This unevaporated water will lessen the effect of the injected spraywater, resulting in higher temperatures and requiring the addition of more water. This will lead to spraywater falling out of suspension. Furthermore, the portion of the elbow pipe wall hit by the spraywater will erode.

In addition to no obstructions in the straight pipe distance, there should be no piping tees or branches. This is because the water in the steam flow cannot be divided equally between multiple flow paths before the temperature sensor. Modeling, testing and field experience suggest that at least 80 to 90% of spraywater droplets should be evaporated before the first obstruction. After that point, elbows tend to enhance the vaporization of the remaining droplets through increasing turbulence in the flow stream.

Distance to Temperature Sensor

Equally important is how far the point of spraywater injection is from the location of the temperature-sensing device. The remaining 10 to 20% suspended spraywater must be vaporized completely before it encounters this sensor. Water that remains in suspension causes inaccurate temperature readings from droplets that form on the sensor.

Beyond the Guidelines

It's important that all the factors that impact steam conditioning be considered before applying the separate guidelines. For example, some recommendations are made based almost solely on velocity such as the fact that higher steam velocity causes greater turbulence, faster mixing and requires shorter downstream distances. While greater turbulence is beneficial, the residence time required by the water droplets cannot be ignored.

Water droplet size is sometimes promoted as an absolute criterion. In fact, spraywater nozzle technology has evolved to the point that some nozzle manufacturers publish droplet size. However, droplet size is also influenced by spray water pressure and temperature (e.g., hotter water at larger pressure drops provides smaller droplets than cooler water without much pressure drop.)

Instead of relying on general rules of thumb, it's best to use a prediction method that takes into account all factors, including water temperature, steam velocity, percentage of spraywater and the amount of superheat in determining straight pipe run length and sensor location. VM

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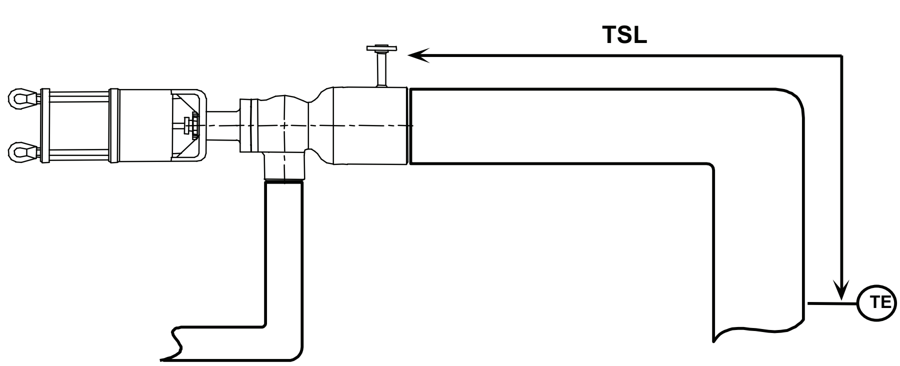

Figure 6 – Distance to Temperature Sensor (TSL): assumes complete vaporization and thermal mixing; calculated by thermodynamics of system; and very condition specific—can vary from 40 to 100 feet depending on mass and velocity considerations.