© 2015 IJSRSET | Volume 1 | Issue 2 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

De-superheating for controlling accurate steam temperature in high pressure and temperature boiler

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ABSTRACT

In power industries, steam is used to perform mechanical work, such as driving a turbine, and also as a heat transfer fluid. Both functions are accomplished with steam properties at opposite ends —dry superheated steam at high end, while de-superheated steam near its saturation point at the low end. Introduction of De-superheater can effectively improve the thermal efficiency of heat transfer processes by allowing the usage of steam at its saturation point, to control unintentional superheat from reducing the pressure of steam, to protect the boiler equipment and piping from high temperatures and pressures.

Keywords: De-superheated, Spray water flow, welding parameters.

I. INTRODUCTION

De-superheating is the process of reducing the temperature of the superheated steam to its saturation point. The de-superheater is used to reduce the temperature of steam generated by high pressure/temperature boilers to the level required in process operation. The primary function of a de-superheater is to lower the temperature of superheated steam & vapour.

Principle of operation

All de-superheater operate on the same principle. Water (usually condensate), is introduced into the process line and thus comes into direct contact with the superheated steam. That is, the process of adding water to steam to lower its temperature is known as de-superheating and the device used is called as de-superheater. Evaporation of the water reduces the steam temperature. The outlet steam temperature is controlled by the quantity of water that is evaporated. This minimizes the time of the suspension of the water particles in the steam so that all the water is evaporated and none falls to the inside walls of the pipe work.

II. METHODS AND MATERIAL

Choosing the most appropriate material for the construction of the de-superheater can increase life and ultimately reduce cost. For designing de-superheater in range of temperatures less than 800°F, carbon steel externals and stainless steel internals are sufficient. Whereas in temperature range above 800°F it may get converted from carbon steel to graphite, so the Chromium-molybdenum alloys are recommended for temperatures in the range of 800-1200°F. The chrome-molybdenum components should not be welded to stainless steel components. If Chrome-molybdenum is treated with Stainless steel it becomes sensitized and susceptible to corrosion after heat treating. Hence when temperatures exceed 1200°F, de-superheater must be fabricated entirely of stainless steel. 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. The material comparison in their corresponding temperature range is shown clearly in table 1.

Table 1 Material Selection Range

S. No	Design Temperature	External Material	Internal Material
1.	Up to 800^{o}F	Carbon Steel	Stainless Steel
2.	801^{o}–950^{o}F	$1^{1}{}_{/4}$cr,$1_{/2}$mo	$1^{1}{}_{/4}$cr,$1_{/2}$mo
3.	951^{o}-1200^{o}F	$2^{1}{}_{/4}$cr,1mo	$2^{1}{}_{/4}$cr,1mo
4.	1200^{o}-1500^{o} F	Stainless Steel	Stainless Steel

A. Construction

The Venturi type de-superheater has the simplest construction. It consists of either a ring that is clamped in between two line flanges, or a pipe with either flanged or welded ends. A water injection venturi is located concentrically within the ring or pipe, with the water supply line entering the ring/pipe at right angle and welded to the venturi throat. The throat has a drilled hole to pass the required de-superheating water with minimum pressure drop. This is the only type where we have a pressure drop through the unit. It is capable of cooling to within 10^{o}F of saturation and a greater turndown can be obtained. The de-superheating head contains the high pressure steam nozzle and the cooling water orifice. In the Steam nozzle the water is broken down to fine droplets improving performance and obtaining greater turndown ratios. The water is supplied at the water injection venturi throat where it becomes atomized by the accelerated steam flow. In addition, the water inlet on the venturi de-superheater has a special thermal sleeve to minimize thermal stresses. The layout of the Venturi type de-superheater is shown in figure 1.

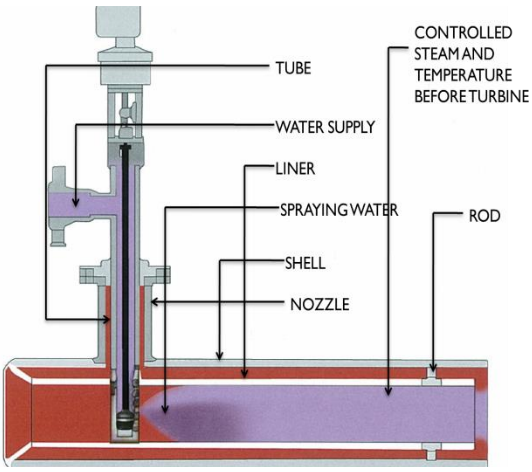

Figure 1: Venturi type de-superheater

B. Installation

The venturi type de-superheater is installed directly in steam line. Orientation may be in either horizontal or vertical up position. A pressure reducing valve is installed in the upstream of the de-superheater. For controlling temperature down to 10 degrees F superheat, the minimum distance of the temperature sensing element should be 30ft Downstream of the de-superheater. Elbows may be inserted in between the de-superheater and the sensor. Straight pipe before the first elbow should be equal to 10% of the maximum steam line velocity. If the residual amount of superheat is substantial enough, the distance of the sensor may be less than 30ft. The sensing element itself should be completely immersed in the steam line.

C. Process Parameters

Temperature Set point

The downstream temperature set point should not be too close to the saturation temperature of the primary steam. Injection of spray water, especially in larger pipelines, can result in uneven distribution of the steam's temperature. If the de-superheating spray water has not been properly injected, regions of superheated steam can surround a core of much cooler steam. This situation occurs when the set point is near saturation. If there is conversion steam flow to water, droplets will cling to the temperature-sensing element as the hotter steam passes. This results in a false temperature reading of the steam saturation. The temperature controller reading will increase and the controller will decrease the spray water flow continuously to get the correct temperature. The pipe drain system protects against unexpected over spraying or water fallout situations.

Spray water Pressure

The amount of pressure differential between the spray water and the steam is very important for both water atomization and the range ability between maximum and minimum water flows.

The maximum pressure differential, along with spray water temperature and spray nozzle design, directly affects atomization to the smallest droplet size, The smaller the droplet, the more rapid the vaporization.

Spray water Temperature

If the temperature of the spray water is in its critical state, it leads to rapid vaporization and conversion into steam. Hotter water vaporizes faster than cooler water for two reasons.

The hotter water is closer to its saturation temperature so it requires less heat input from surrounding steam, and therefore, less time to vaporize.

The reduction in evaporation is more favorable than water flow increase.

Minimum Steam Velocity

One of the most critical aspects of Water vaporization involves minimum Steam velocity.

For vaporization to occur completely, 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 influence the velocity that is required.

The minimum steam velocity must be approximately 30 feet per second or greater.

Pipeline Size

The size of the pipeline is also important in relationship to the amount of required spray water. The large amounts of spray water in the Small pipelines can lead to water accumulation on the pipe wall and subsequent fallout.

De-superheating steam in large pipelines can be challenging because establishing a mixture of steam and injected water is difficult. This mixing leads to inaccurate temperature measurements and subsequently, Poor temperature control.

Steam Pipe Liner

Liners are used to protect the steam pipes against water accumulation and thermal shock at the point where spray water 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.

A liner can improve system performance as well as protect against cracking of the main pressure-retaining pipes. Also, the liner’s condition should be checked regularly.

D. Working

The first stage of de-superheating occurs in the internal diffuser. A portion of the steam is accelerated in the internal nozzle and the velocity is used to atomize the incoming water. The cooling water is injected into the diffuser through a number of small jets, which helps to atomize the water further.

In the second stage of de-superheating, a saturated mist or fog emerges from the internal diffuser into the main diffuser where it mixes with the remainder of the steam. Thus, there is a region of turbulence where the second stage of de-superheating occurs. This mechanism minimize cooling water contact with the sidewalls, combining maximum de-superheating effectiveness with minimum pipe wear

Turndown ratio - Turndown is used to describe the range of flow rates over which the de-superheater will operate. The inlet pressure, temperature or flow rate will cause a variation in the cooling water requirement. There are two types of turndown ratio they are

Steam turndown ratio - This reflects the range of steam flow rates that the device can effectively de-superheat.

Cooling water turndown ratio - This reflects the range of cooling flow rates that can be used. Even it directly affects the steam turndown ratio, the relationship depends on the temperatures of the superheated steam, the cooling water and the resulting de-superheated steam.

The steam flow turndown ratio does vary depending on the actual conditions. The cooling water turndown for most plant applications is 20:1 which is possible depending on the actual operating conditions. The cooling water turndowns beyond 20:1 are also possible but the cooling water booster pump is needed to achieve it.

When installed vertically, better mixing occurs which can result in an improved turndown ratio of over 5:1. The main problem is that there is not enough vertical space to install the de-superheater, as it will be several meters long.

A modification to the standard venturi type de-superheater is the attemperator de-superheater. This uses the same method of injecting the coolant into the superheated steam, but does not utilize the venturi shaped mixing section.

The term attemperator is used to refer to a de-superheater that is installed after a boiler or superheater to give accurate control over temperature and pressure.

Figure 2 shows the working of the venturi type de-superheater.

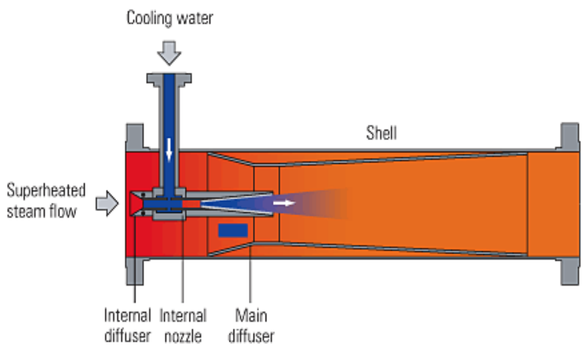

Figure 2: Working of venturi type de-superheater

Attemperator nozzle

Figure 3: Attemperator nozzle

Primary atomization is the breakdown of water into droplets by the attemperator nozzles.

They provide good primary atomization as water flow decreases. Because of reduction in differential pressure that is characteristic of reduced flow.

All droplets created by mechanical atomizers are not of the same diameter. The size and shape of the droplets varies with injection velocity and nozzle geometry.

Secondary atomization refers to the break-up of large droplets by the dynamic force of the steam flow. The forces acting on a droplet must be greater than the viscous forces holding the droplet together.

To achieve good secondary atomization, the water spray should be injected perpendicular to the steam flow, not parallel to it.

The small droplets produced by secondary atomization boil and evaporate. The time to complete the evaporative process depends on the total surface area of the water volume and is proportional to the square of the droplet diameter.

Any droplets that do not evaporate before reaching the temperature sensor may wet the sensor and make it difficult to control steam temperature as intended.

Inadequate design of the attemperator system can result in poor temperature control and poor atomization. It also causes **damaging to headers and tubes.**

The primary design requirements for a proper attemperation system are,

- Control final steam temperature accurately
- Provide high turndown capacity/range ability (50:1) of spray-water flow to maximize efficiency.
- Accommodate thermal quenching of mechanical parts.

III. WELDING PARAMETERS

Table 2 Problems and Remedies

SNO	PROBLEMS	REMEDIES
1.	(Precipitation)chromium carbide along the grain boundaries **loss of corrosion** resistance	Solution: Heat treatment 1025°c-1100°c air cooler(air, water penetration)
2.	Stress corrosion cracking, high concentration in	Protect from halogen family environment(Halog

	the weld heat affected cone	en- Cl, H, Sulphate family chloride)
3.	**Knife line attack**, **inter granular corrosion** attack occurs in an arrow plane in the area immediately to the **adjacent to the weld mend**	Use: extra low carbon electrode (0.03%) (or) use stabilizing element niobium, tantalum& titanium
4.	High Hardness & Toughness	Use: skipping layer run

Table 3 Optimization of gas and TIG welding for stainless steel

SNO	NATURE	SS
1.	Type of flame	Neutral or Slightly oxidized
2.	Type of technique	Back hand technique
3.	Angle of torch	400-600
4.	Nozzle diameter	More diameter
5.	Velocity of flame	Low soft velocity flame
6.	Flux used	Borax, NaCo3, NaCl2
7.	Type of inert gas	Argon+He+o_2
8.	Electrode composition	Tn, Zr
9.	Type of Electrode	E308, E309, E347, Corrosion resistance, E316, E317, E330, high temperature, straight, E410, E430

Table 4 Optimization of arc welding for stainless steel

SNO	NATURE	SS
1.	Polarity	DCRP
2.	Feed	Weaving
3.	Run	Skipping run
4.	Arc length	Longer arc
5.	Edge preparation	More angle
6.	Root gap	More
7.	Electrode dia	6mm
8.	Pre-Heating	Less preheating

Design calculation

Enthalpy in process = Enthalpy out process

$$\dot{m}_{cw}\, h_{cw} + \dot{m}_s\, h_s = \dot{m}_s\, h_d + \dot{m}_{cw} + h_d$$

$$\dot{m}_s\, h_s - \dot{m}_s\, h_d = \dot{m}_{av}\, h_d - \dot{m}_{cw}\, h_{cw}$$

$$\dot{m}_s\,(h_s - h_d) = \dot{m}_{cw}\,(h_d - h_{cw})$$

$$\dot{m}_{cw} = \frac{\dot{m}_s(hs - hd)}{(h_d - h_{cw})} \quad \ldots\ldots\ldots..(1)$$

Where,

$\dot{m}_{cw}$ -Mass flow rate of cooling water (kg / hr)

$\dot{m}_s$-M ass flow rate of superheated steam (kg / hr)

h_s- Enthalpy at superheated condition (kJ/kg)

h_d - Enthalpy at de-superheated condition (kJ/kg)

h_{cw} -Enthalpy of cooling water at inlet Condition (kJ/kg)

STEAM

Pressure = 10 bar

Temperature = 300 ^{o}c

Mass flow rate ($\dot{m}$) = 10,000kg/hr

COOLING WATER

Pressure = 15 bar

Temperature = 150 ^{o}c

REQUIRED STEAM CONDITION

Pressure = 10 bar

Temperature = saturated temperature + 5 ^{o}c

Then,

$\dot{m}_s$ = 10,000 kg / hr

h_s = 300 ^{o}c at 10 bar pressure

= 3052 kJ / kg (from steam table)

h_{cw} = 4.2 kJ /Kg ^{o}c

= 4.2 * 150 ^{o}c

= 630 kJ / kg

T = 180 ^{o}c at 10 bar (from steam table)

The required de-superheated condition,

T_{sat} = (180^{o}c+5^{o}c) = 185 ^{o}c

h_g = 2778 kJ /kg

h_{sup} = 2829 kJ /kg

T_{sup} = 200^{o}c

Then ,

$$h_d = h_g + (h - h_g) * \frac{Tsat^{-T}}{(Tsup-T)}$$

$$h_d = 2778 + \left[(2829 - 2778) * \frac{185 - 180}{200-180}\right]$$

$$h_d = 2778 + [(51*5)/20]$$

$$\mathbf{h_d = 2791\ kJ/kg}$$

sub in eqn no (1)

$$\dot{m}_{cw} = \frac{\dot{m}_s(hs - hd)}{(h_d - h_{cw})}$$

$$= \frac{1000 * (3052 - 2791)}{2791 - 630}$$

$$\mathbf{\dot{m}_{cw} = 1208\ kg/hr}$$

Therefore de-superheated steam supplied at the rate of,

$$= \dot{m}_s + \dot{m}_{cw}$$

$$= 10000 + 1208$$

$$= 11208\ kg / hr$$

Thus the requirement for 10000 kg / hr of de-superheated steam the initial superheated steam flow rate can be determined by this simple proportional method

$$\frac{10000}{11208} = \frac{\dot{m}_s}{10000}$$

$$\mathbf{\dot{m}_s = 8923\ kg/hr}$$

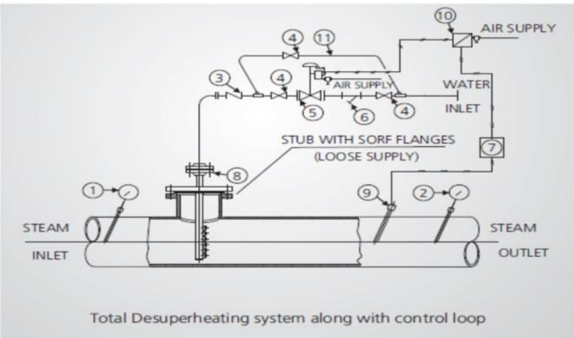

Figure 4 : Total de-superheating system along with control loop

IV.CONCLUSION

For Getting the best performance Engineers must give careful consideration to the maximum allowable working pressure (MAWP) and design temperature of the unit.

The de-superheater should be placed as close as possible to the point of steam usage area, not to the point of steam generation. A shorter distance will ensure that the de-superheated steam is delivered at the specified conditions

The temperature sensor must be installed far enough downstream to **allow the vaporized water to fully mix with the superheated steam.**

The de-superheater can achieve increased turndown when the unit is **oriented vertically** with **flow in the upward direction**. The Minimum velocity is about 30% lower so with such an orientation the turndown is increased by about 30%.

Applications

- Suitable for most general plant applications, except where high turndowns on steam flow rate are required.
- The Thermal liners increases steam velocity and turbulence, which helps to keep water droplets in suspension.
- The de-superheaters are used in Thermal Power Plants and All process plants like Fertilizers, Petrochemical, Refineries, Pharmaceuticals, Sugar, Pulp, Paper, Steel etc.

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