

STEAM CONDITIONING FOR THE SUGAR INDUSTRY

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Abstract

Steam conditioning (desuperheating) is an essential and critical part of sugar production, particularly with reference to the processing of expressed juice where critical steam temperatures are most necessary to ensure final quality. Desuperheating is a simple process that is not widely understood in principle and is much abused in its practical application and operation.

The purpose of this paper is to:

- explain briefly the basic physical principle of steam desuperheating
- discuss the various types of equipment available and highlight their relevant advantages and disadvantages
- highlight specific applications in the South African sugar industry over the past 30 years
- highlight typical operational problems that have arisen and how they were overcome.

This paper places users in a better position to select, operate and maintain suitable equipment on a 'total life cycle' cost basis that will suit their specific application.

Keywords: superheat, system turndown, final temperature, water quality, life cycle cost

Introduction

This paper considers steam 'conditioning' in a wide sense to include pressure reduction of initially superheated steam and desuperheating to produce steam with the lowest available final steam temperature that can be controlled consistently. This process is essential to the processing of expressed juice, where critical steam temperature is necessary to ensure final quality.

Reasons for desuperheating:

- minimised sucrose destruction (undetermined loss)
- improved heat transfer efficiency to metal surfaces (tubular or plate)
- greater enthalpy available therefore less use of steam
- lower temperature results in use of less exotic materials.

Definitions

Superheated steam is an excellent source of energy, but for certain applications saturated steam, or steam with little superheat, can do the job best. Therefore, if steam is delivered in a highly superheated state, the temperature must be reduced to an acceptable value. This is desuperheated steam.

Superheat

Before exploring ways to remove extra heat, it is necessary to obtain a clear picture of what the term 'superheat' means. When steam is produced from water, its temperature is similar to that of the water. There is a fixed relationship between steam temperature and pressure under saturation conditions. Saturated steam can only gain energy by removing it from direct contact with the water and adding more heat, as in a boiler superheater. This is superheated steam.

When steam is generated at a temperature that is too high, it may have to be desuperheated, regardless of how the extra heat was supplied originally. The most economical way is the direct-contact method of cooling by water injection. When cool water mixes with extremely hot steam it attracts energy from the steam and vaporises. The result is an increased volume of steam, at a lower temperature. Figure 1(b) illustrates the method of calculating the amount of cooling water required for steady flow desuperheating at a constant pressure. The distance from the point of water injection, to the temperature sensing device is critical. The shorter the distance allowed, the more efficient the desuperheater.

Amount of injection water required

Assume it is necessary to lower superheat of steam from 315 to 260°C at a constant pressure of 2 070 Kpa. Disregarding radiation losses, total heat entering desuperheater equals total heat leaving.

Thus, $4\,545 \text{ kg/hr} \times 3\,059 \text{ kJ/kg} + M \text{ kg/hr} \times 456 \text{ kJ/kg} = (4\,545 + M) \text{ kg/h} \times 2910 \text{ kJ/kg}$, where M is the mass of cooling or injection water. Solving $M = 277 \text{ kg/h}$, and the amount of steam leaving the desuperheater at the new temperature is then $4\,545 + 277 = 4\,822 \text{ kg/h}$.

True steam temperature

True steam temperature is the true state of the steam leaving the desuperheater, i.e. the temperature after all injected water has been evaporated. If steam and water exist together in a pipeline without being completely mixed, a temperature-sensing element will not give a true reading. Consider what happens when water is injected into a steam line. Downstream from the point of injection, a number of thermometers are installed at an arbitrary distance apart. Under most flow conditions, thermometers nearest the desuperheater will not give similar readings. The distance from the desuperheater, beyond which successive readings agree (excluding heat lost through insulation), is the closest point at which a valid temperature measurement can be made.

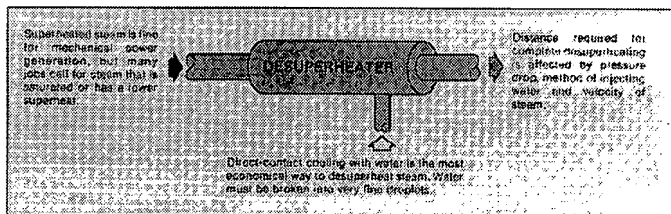


Figure 1a

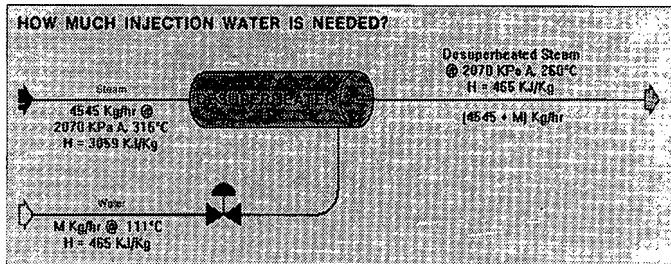


Figure 1b

Figure 1. Desuperheating process.

Function of a desuperheater

The function of a desuperheater is to speed heat transfer between steam and water so that true temperature conditions occur within the shortest distance. If water could be separated into very fine droplets, the surface area exposed to steam would be great, and evaporation would be aided. If particle sizes of water were infinitely small, true temperature distance would be infinitely short. However, water cannot be separated into infinitely small particles. The term 'atomisation', commonly used in desuperheater parlance, means separating water into small particle sizes.

There are a number of ways to produce small droplet size. These include variable and fixed orifice nozzles and steam atomising nozzles. Each will be discussed in detail later. Another important way to achieve efficient desuperheating is to subject both steam and water to a pressure drop. Velocity change and resulting turbulence is extremely effective. Required downstream distance for valid temperature measurement is greatly reduced. When a pressure drop can be tolerated, the method of injecting water (droplet size) becomes less critical.

The distance for complete desuperheating is also affected by steam velocity. Even very low flows are turbulent when the critical Reynold number is exceeded. The Reynold number is a factor used to determine whether flow will be turbulent or viscous, and is based on mean velocity, pipe diameter, specific gravity of the fluid and absolute viscosity. The higher the velocity, the shorter the distance needed for mixing. This is true even though it appears that contact time of water with steam is reduced. As flow becomes increasingly turbulent, random movement of entrained water increases so that the actual path of an individual particle of entrained moisture will be longer.

Coefficients of heat transfer

The coefficient increases with higher velocities. The net effect is to shorten the distance for mixing. If velocity is carried high enough, it may be possible to reach a point where still higher

velocity is detrimental. Certainly this point, if it exists, is well above velocities used in good piping design. Theoretically, it is possible to attain sonic velocities (speed of sound - Mach 1) before problems occur.

The final steam temperature is the most important consideration. The closer it is to saturation, the slower the evaporation of water. Generally, desuperheaters should be able to control this to within 5°C of saturation.

In actual test data for an application served by a mechanical type desuperheater with built-in steam trap. Steam flow is 136 364 kg/h at 3 793 kPa g and 454°C, and desired final steam temperature is 274°C (25°C of superheat). The total cooling water required is 22 727 kg/h. Steam flow varies from zero to 136 364 kg/h and back to zero in 22 seconds. Final temperature must be controlled to within 14°C above or below the desired 274°C. Extremely rapid load swings require a two-element control. The cooling water valve position is controlled by the influence of steam flow and final temperature. The steam temperature is to be measured at five different points.

At loads above 30% of design flow the theoretical amount of water required to reduce steam temperature agrees with the actual quantity of water injected. In these flow ranges water is not discharged from the steam trap, so atomization efficiency is excellent. Efficiency decreases at loads below 30%. The theoretical amount of water required to reach final temperature is therefore exceeded. Under extreme conditions, more water may discharge from the trap than is absorbed in the steam. At very light loads, a large increase in water flow is required for significant changes in final steam temperature.

Five points of measurement show how the steam temperature increases progressively downstream from the desuperheater. Measuring elements closest to the desuperheater contact extremely small particles of moisture that have not been completely vaporized and superheated by steam, therefore these readings are low and do not measure the true state of the steam.

Desuperheater performance

Desuperheater performance is evaluated on final steam temperature control. When evaluating desuperheaters it should be noted that the reading of one temperature bulb or indicating thermometer is not conclusive, although apparent performance may be excellent.

Types of desuperheaters

Mechanical atomising desuperheater (Figure 2)

Mechanical atomising desuperheaters have good spray characteristics and are used where the load is relatively steady. The mechanical atomizing units consist of a main tube and spray nozzle. Cooling water flows through the main tube to the nozzle, which must be designed to meet a specific set of conditions. Nozzle design optimises the cooling water particle size so that rapid absorption can take place. By controlling the pressure drop

of the spray nozzle and maintaining reasonably high header velocities, reliable temperature control is obtained.

The mechanical-atomizing desuperheater can be used when flow turndown requirements are not too high, in the order of two or three to one. Final temperature can be maintained to within $\pm 8^{\circ}\text{C}$ of set point down to 11°C above saturation.

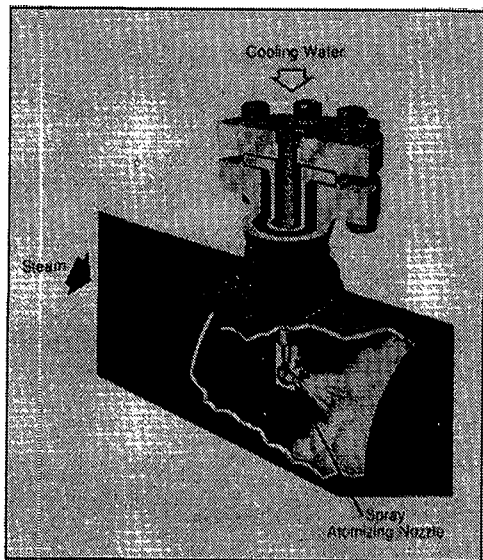


Figure 2a

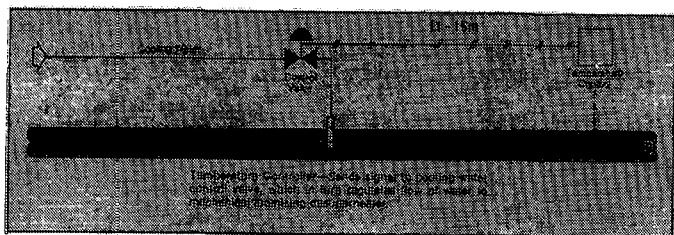


Figure 2b

Figure 2. Mechanical atomizing desuperheater.

Steam atomising desuperheater (Figure 3)

These were developed to obtain a more uniform spray under varying load conditions and where no pressure drop in the steam header can be tolerated.

A number of present-day designs operate on basically the same principle. Steam and water are brought separately into a spray head. The spray head has a series of nozzles arranged in a circle, sized to suit quantity and pressure drop. Cooling water enters the center of the spray head and then through a number of radial holes in the nozzle. Atomizing steam from a higher pressure source is introduced through steam ports at right angle to the radial cooling water holes, thereby blasting each of the cooling water jets.

The cooling water is projected at high velocity with small droplet size into the steam header, where it is distributed and vaporized. The natural expansion of atomizing steam and the resultant pattern of discharge has the water particles surrounded by a sheath of steam that enables the desuperheating process to be rapid. The atomizing steam is constantly flowing when the desuperheater is in use, and the atomizing process is therefore

fully effected at all loads down to the lowest rate of injection of cooling water. This completely offsets the decreasing benefit obtained from the mixing and carrying capacity of the main steam in the header as its flow reduces. This characteristic is the reverse of most other types of spray desuperheaters.

Steam atomising desuperheaters are capable of maintaining the final steam temperature to within $\pm 5,5^{\circ}\text{C}$ of set point even when this is no more than 8°C above saturation temperature at all loads from maximum flow down to 15% of maximum flow.

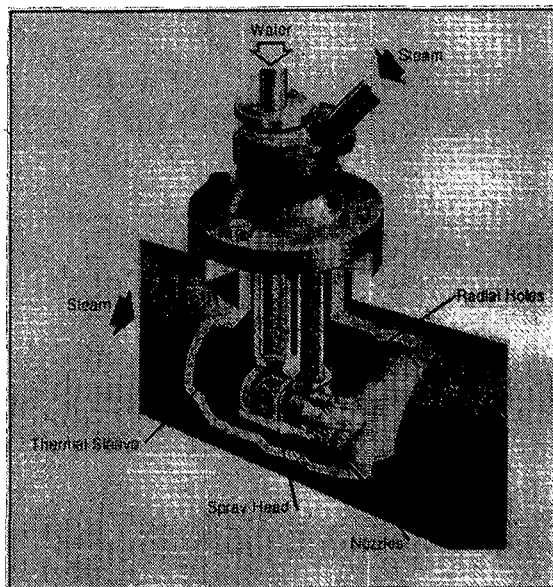


Figure 3a

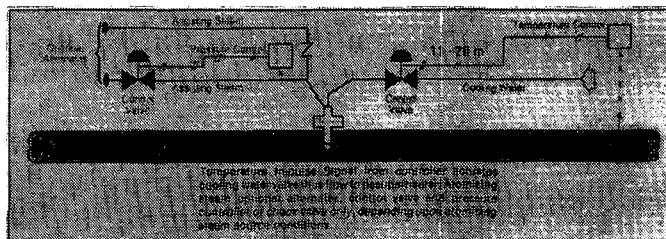


Figure 3b

Figure 3. Steam atomising desuperheater.

Multiple nozzle spray (MNS) desuperheater (Figure 4)

The MNS desuperheater has been developed to offer optimum performance and rangeability in a variable spray tube design. The MNS desuperheater fills the performance gap between limited capability of a simple mechanical spray type desuperheater and the unlimited capability of the variable orifice desuperheater (VOD).

Many applications require turndowns in excess of that offered by a simple mechanical spray desuperheater but do not necessarily warrant the expense or require the additional refinements offered by the variable orifice desuperheater. Many of these intermediate duties can be met with a steam atomizing type desuperheater, but atomizing steam is often not available. The MNS desuperheater has been designed for these applications. This desuperheater automatically controls the cooling medium with the ability to modulate and shutoff. A separate cooling medium control valve is not required.

The cooling medium is admitted to the nozzle tube assembly through the branch in the mounting head. It reaches the lower portion of the nozzle tube assembly via balancing ports in the plug. With the plug seated on the end cap, no cooling medium can reach the discharge nozzles. As the plug is lifted by the actuator, under the dictates of the temperature control loop, cooling medium makes a flow reversal at the seat. It then is throttled by the lower piston ring at the slots just behind the discharge nozzle plate.

The cooling medium passes through a specially designed, swirl discharge nozzle. A major portion of the energy available from the differential pressure between the cooling medium and the main header is expended within the nozzle, which intensifies mechanical atomization. The resulting soft, misty spray has a very low exit velocity. This promotes rapid absorption and optimum desuperheater efficiency, even at very low flow rates.

The spray from the first discharge nozzle is quickly dispersed within one metre from the point of discharge. As the plug continues to modulate open, a swirling interaction of the various discharge nozzle sprays maintains a narrow, cone shaped pattern. This keeps the water particles in the center of the header where the line turbulence is the greatest.

Temperature control can be maintained within 5,5°C of saturation with the ability to hold set point within a tolerance of $\pm 2,3^\circ\text{C}$.

Variable orifice desuperheater (VOD) (Figure 5)

The VOD unit consists of a housing with a self-regulating orifice. This orifice is made up of a circular seat with a flow plug maintained in concentric position by a plug guide. Cooling water enters the orifice chamber and is uniformly distributed around the periphery. The amount is controlled by a diaphragm-operated valve actuated by a temperature controller.

The force of steam through the desuperheater raises the plug, each flow rate giving it a different position. Pressure drop is typically constant at 20-35 kPa for all flows.

Cooling water enters at the seat of the orifice where steam velocity is highest. With the plug held in concentric position, incoming steam flows uniformly around the 360 degree periphery where cooling water enters. Pressure drop of steam passing

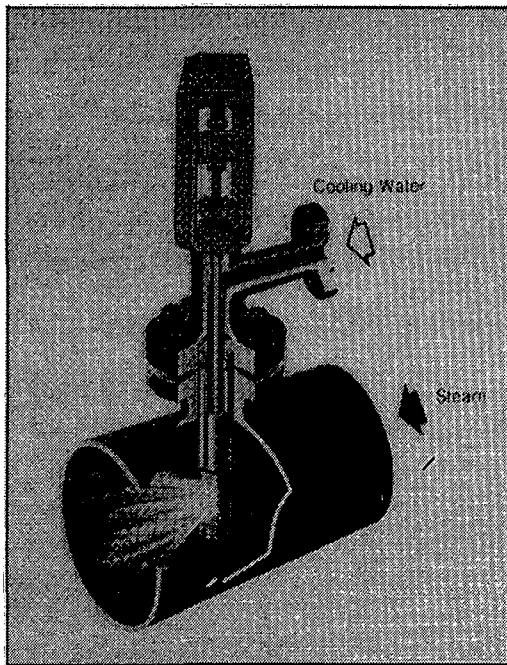


Figure 4a

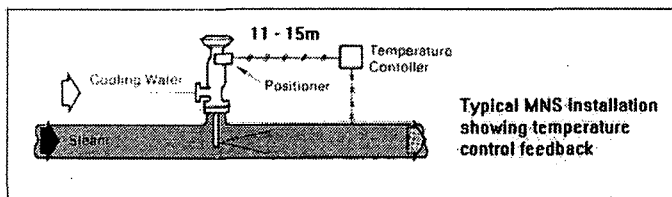


Figure 4b

Figure 4. Multiple nozzle spray desuperheater.

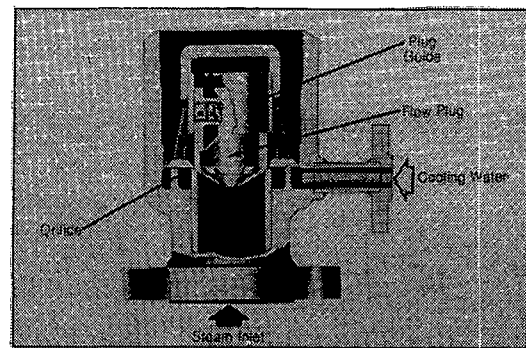


Figure 5a

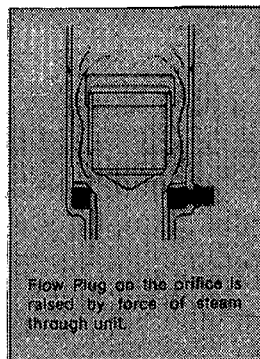


Figure 5b

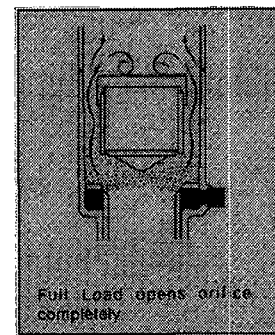


Figure 5c

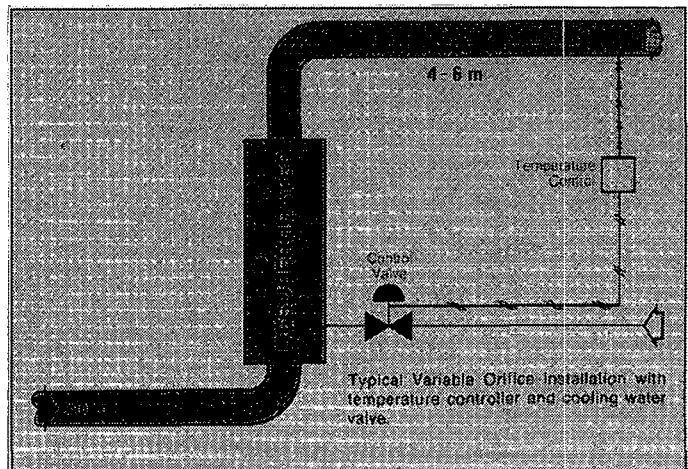


Figure 5d

Figure 5. Variable orifice desuperheater.

through annular restriction between plug and ring creates an aspirating effect that also helps draw in cooling water. Result is high turbulence over the full range of flow. Cooling water and steam are instantly brought together in an intimate mixture for complete vaporization. Since the unit is always mounted vertically, any water that is not immediately absorbed remains in suspension until it has been completely dissipated.

VODs hold final temperature within $\pm 2,3^{\circ}\text{C}$. The temperature controller should be a standard type having both proportional and reset features. Final temperature may be as low as $5,5^{\circ}\text{C}$ above saturation. Turndown is only limited by the rangeability of the coolant control valve. Therefore 100:1 system turndown can easily be achieved while holding steam temperature constant within six metres downstream from the outlet.

Pressure reducing and desuperheating station (PRDS)
(Figure 6)

The PRDS was developed from the VOD, which is the most efficient form of desuperheating. This valve can be installed in place of a separate pressure reducing valve and desuperheater. It has an expanded outlet that accommodates the change in steam specific volume, thus keeping outlet velocity reasonable.

Steam pressure is reduced through the single seat balanced throttle plug control valve. A balancing piston is situated below the throttle plug to reduce forces on the plug and consequently the actuator size required for positioning.

Immediately adjacent to the seat is a water annulus into which cooling water is admitted.

The plug is connected to the valve actuator, which receives a signal from the pressure controller and is responsive to changes in downstream pressure. The actuator positions the valve to regulate the flow of steam and downstream pressure. Pressure reduction is achieved between the seat and contoured section of the plug. As the throttling occurs steam velocity increases, which results in a low pressure zone immediately following the seat and an extremely turbulent flow path as steam seeks to recover its normal flow pattern.

By introducing the cooling water at the seat, use is made of the low pressure zone for immediate separation of cooling water into fine particles and, in the ensuing turbulence, the steam and water are intimately mixed within a very short distance of the water injection point.

As the amount of pressure reduction is the same, regardless of the valve opening, similar conditions of turbulence will exist under all load conditions, and therefore similar conditions for desuperheating will also be present. This enables the unit to deal with widely fluctuating load conditions.

The PRDS controls steam pressure and temperature from 100% down to only 2% of full load. Steam pressure can be held within $\pm 14 \text{ kPa g}$ and temperature to within $\pm 2,3^{\circ}\text{C}$ of the required setting. Final steam temperature can be controlled to within $5,5^{\circ}\text{C}$ above the saturation temperature.

Overall, the combined PRDS option is the most cost effective, space saving, efficient solution for typical sugar mill applications. Southern African mills with PRDS installations include Malelane, Komatiport, Umfolozi, Maidstone, Simunye, Triangle and Hippo Valley, as well as Illovo Sugar Ltd Byproducts, Sezela. There are numerous other sugar mill installations of similar nature internationally, and the type of equipment described is also used extensively in the petrochemical, power generation, paper and mining industries in South Africa.

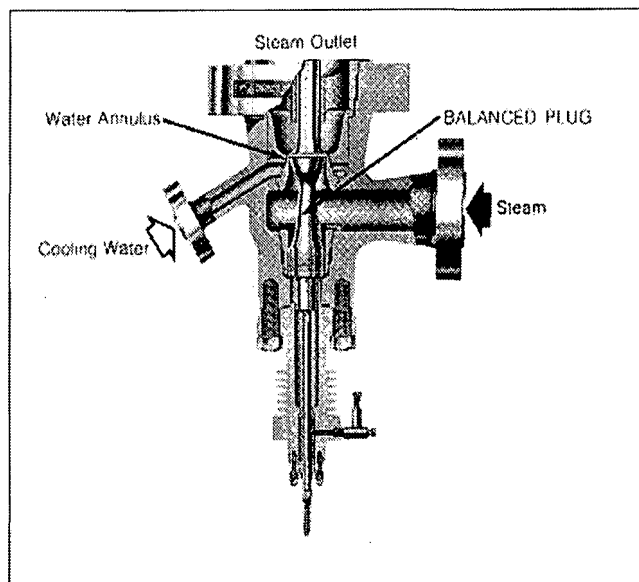


Figure 6a

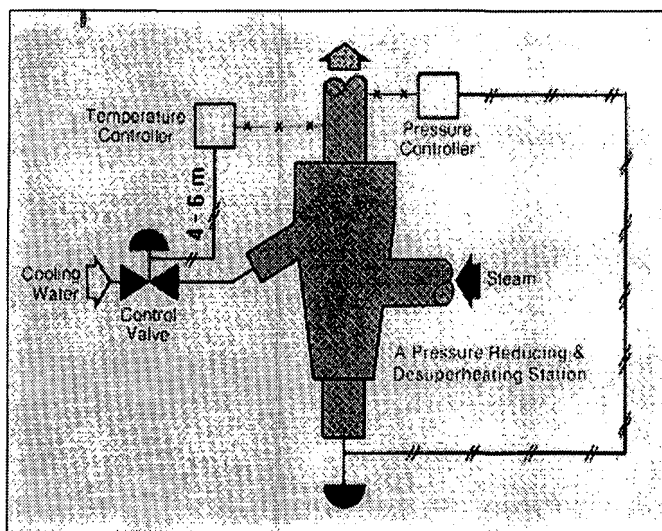


Figure 6b

Figure 6. Pressure reducing and desuperheating station.

Desuperheater selection guide

For process functions requiring temperature reduction with control and efficiency to meet the process parameters, selection of the best type of desuperheater is essential, and many factors have to be considered. Many years of experience and success in the field of direct contact desuperheating has resulted in a step-by-step selector (Appendix 2). Selection by this means will insure efficient system performance using proven equipment at the lowest possible cost.

Guidelines on water quality for use with desuperheaters

Because of the risk of contamination of the superheated vapour and the possibility of oxygen corrosion taking place, a high degree of purity is required in the coolant used in contact type desuperheaters. Any particles contained in the coolant will be left behind when the coolant vaporises, and could cause problems in the downstream system.

Oxygen present in the coolant will be liberated when the coolant is evaporated and could give rise to oxygen corrosion in the desuperheater and downstream pipework.

Caution should also be applied to any other ingredients in the coolant that could attack the structure of the desuperheater and the downstream system when present in a concentrated form. High concentrations of chloride or chlorine may well cause corrosion fatigue cracking or stress corrosion cracking of the desuperheater. The conjoint action of sustained tensile stress, even when well below the yield stress, and chemical attack, even in a seemingly mild environment, can cause cracking.

Cooling water specification

Condensate is normally recommended as a coolant for desuperheating purposes, or de-aerated water containing no more than five parts per million of dissolved solids such as sodium, chloride, sulphate and silica.

Noise levels

The desuperheating process itself does not generate noise and the cooling water requirements usually result in a control valve that operates well below the required 85d BA, which is currently the accepted norm. However, the pressure reducing part of the steam cycle can generate unacceptable noise levels if incorrect selections are made. The PRDS solution has the advantage that introduction of the spray water into the throat area of the valve has a significant noise reducing effect.

It is usual to insulate the PRDS type of equipment with up to 125 mm of thermal/acoustic lagging. Care must be taken with inlet and outlet piping designs to ensure they do not generate excessive noise, and correct piping schedules must be used.

Life cycle costing of desuperheating installations

Current practice with many purchasers of desuperheaters is to evaluate bids on 'capital cost' only. However, it is important to ensure that evaluation is carried out on 'total life cycle cost' to ensure that all aspects of costing are taken into account.

In many cases a higher initial cost installation may have the lowest cost over the life span of the equipment, and relative costs from different suppliers will vary. It is therefore important that offers be compared by taking into account the respective value of all aspects of the life cycle costs.

Definition

Life cycle cost is the total cost to the organisation for ownership and acquisition of the product over its full life. This typically includes:

Capital cost of equipment. This is the cost of the desuperheater and its associated water control valve and, in typical sugar mill applications, would also involve a pressure reducing valve. A combined pressure reducing and desuperheating station (PRDS) is an ideal solution to this problem as it combines the best type of desuperheating technology with a pressure reducing function. The combined functions significantly reduce the cost and amount of associated pipework and also save space. This solution should be the first choice.

Capital cost of associated items. This is the cost of interconnecting pipework, isolating and non-return valves, drain lines and steam traps. Good piping design requires the inclusion of these items to ensure good start-up and operation of the plant, and minimum damage to and erosion of pipes and fittings. Suitably designed and selected instrumentation for control of temperature and pressure must be catered for and costed. Access platforms and stairs or cat ladders will often be necessary, and should be included in the budget costing.

Installation costs. Installation of different types of desuperheaters can vary considerably according to size and relative positioning in the piping system. Expensive crane time may be necessary, which could add significantly to total overall costs.

Maintenance costs. Depending on design and material selection of different types of desuperheaters, costs of spare parts and possible necessity of supervision by qualified experts can vary significantly. Some manufactures can offer equipment guarantees extending to five years or more.

Running costs. Desuperheaters do not incur running costs as such, but it should be borne in mind that those which provide a temperature close to saturation will provide final steam with the highest amount of heat available, and total steam usage would therefore be reduced. It is possible to quantify this and, as steam usage is a continuing and long term parameter, minimising steam usage will provide a saving in costs.

Product retirement and phase out costs. When equipment has reached the end of its operating life span, it has to be removed and disposed of. With certain equipment this can be an expensive operation. Typically, with desuperheaters which are relatively small in size and do not have any contaminating consequences, this cost is insignificant.

Typical problems with desuperheater installations

Operating off design parameters

Different designs of desuperheaters can tolerate operating off design parameters better than others (see Appendix 2). Typical problems that arise:

- Failure of desuperheaters and water valve trims.
- Cracking of discharge piping.
- Erosion of discharge piping (in particular sharp bends).
- Inability of drainage to cope with excessive amounts of water.

Quality of spray water

- Excessive amounts of suspended solids being deposited on moving parts and eventually causing seizing.
- Excessive levels of chemicals such as chlorides causing corrosion fatigue failure.

Incorrect positioning of temperature sensing element

- When the sensing element is too close to the desuperheater it cannot detect an accurate final steam temperature and excessive water can be injected into the system.
- 'Hunting' of the water control value function can also be caused, as the control signal is constantly changing.

Poor piping layout and design

- Cracking of pipes.
- Erosion of bends.
- Excessive noise generation (essentially due to inadequate pipe schedules and inadequate insulation).

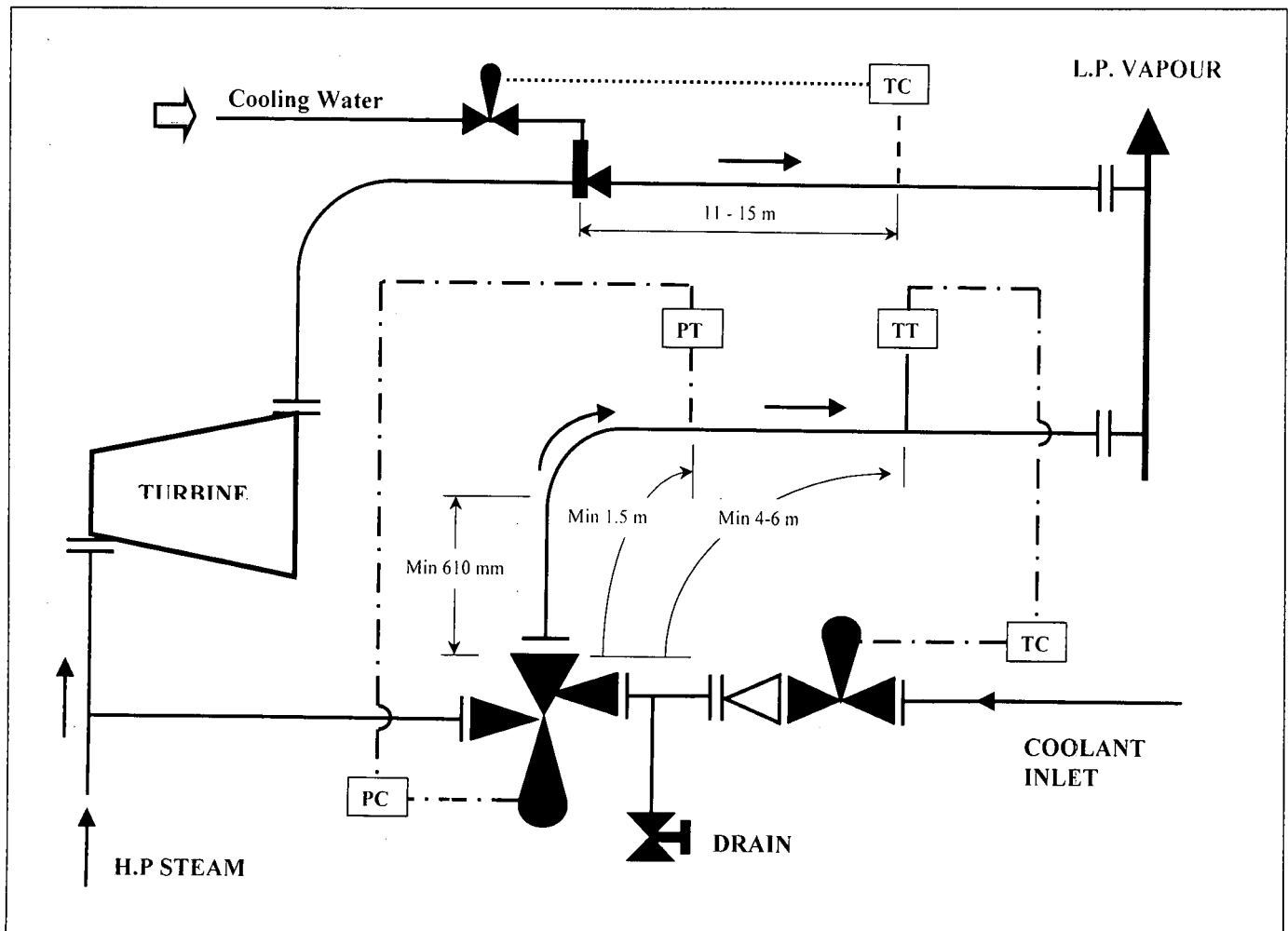
Acknowledgements

Thanks are due to Mr Paul Haitas for document scanning and preparation of computer disc presentation, and Mrs G Morais for typing and presentation.

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APPENDIX 1
Typical sugar mill steam schematic.



APPENDIX 2
Desuperheater selection guide.

DESUPERHEATING ONLY	REQUIRED INSTALLATION DATA			DESUPERHEATER SELECTION		
Steam flow turndown required less than 1,25 : 1	Control required $\pm 8,5^{\circ}\text{C}$ with minimum set point sat 11°C	Coolant available with superior pressure 7.5 bar	Steam velocity at minimum flow 30 m/s with liner if necessary	Select MSD		
Steam flow turndown required less than 16:1	Control required $\pm 5,5^{\circ}\text{C}$ with minimum set point sat $+ 8^{\circ}\text{C}$	Coolant available with superior pressure 3 bar	Atomising vapour available with superior pressure 5.5 bar	Steam velocity at minimum flow 7,5 m/s with liner if necessary	Select SA35	
Steam flow turndown required less than 40:1	Control required $\pm 5,5^{\circ}\text{C}$ with minimum set point sat $+8^{\circ}\text{C}$	Coolant available with superior pressure between 5 and 35 bar	Steam velocity at minimum flow 12,5 m/s with liner if necessary	Select MNSD		
Steam flow turndown required less than 100:1	Control required $\pm 2,5^{\circ}\text{C}$ with minimum set point sat $+5^{\circ}\text{C}$	Coolant available with superior pressure 1,5 Bar	Steam velocity at minimum flow 7,5 m/s	Select VOD		
PRESSURE REDUCING AND DESUPERHEATING			All steam entering the unit to be simultaneously pressure reduced and desuperheated	Select PRDS		
Steam flow turndown required up to 100:1	Control required $\pm 2,5^{\circ}\text{C}$ with pressure reduction of vapour and with minimum set point sat $+5^{\circ}\text{C}$ of reduced pressure vapour	Coolant available with superior pressure of 2 bar above reduced pressure or 2 bar above $\frac{1}{2}$ the inlet pressure, whichever is the greater	Part of pressure reduced (LP) steam to be diverted ahead of desuperheating stage or LP steam from alternative source to be desuperheated	Select pressure reducing valve and separate desuperheater		
		Coolant available with superior pressure 1.5 bar above reduced steam pressure				