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Understanding steam quality and its vital role

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Steve Bishop discusses the important role of steam quality in decontamination and tackles some key questions, including: how can we solve the 'trilemma' of service resilience, improved quality and decarbonisation challenges?

Steam is a vital element of sterile services and one that is all too often taken for granted. It is the predominant (indeed default) sterilisation media for many applications, yet often seen as a mere "utility" that is surely always delivered as required under all circumstances.

Yet sometimes, the signs are right before us that all may not be as it should be with this critically important element in our 'sterilisation armoury'. Corrosion rates on re-useable instruments, increased processing times (or even reprocessing) for sterilisation loads, repeated daily validation test failures on steam sterilisers, wet loads after processing, requirement for increased drying times and intermittent load failures due to temperature shortfall; these can all be indicative of problems with steam quality.

This raises some important issues and questions, including: why is steam used in sterilisation? How do we define 'steam quality'? How should we measure and assess this? What is the impact of not having a sufficient quality of steam? What's the difference between steam quality and the grade of steam we use ? What aspects of our steam system/plant or their use can adversely impact steam quality? What are the practical steps we can take to mitigate the risks involved? How can we solve the 'trilemma' of service resilience, improved quality and decarbonisation challenges?

Delegates at the recent Decontamination and Sterilisation Conference 2024 in Birmingham were provided with some valuable insights into these issues thanks to our team from Spirax Sarco Group. We'd like to share some of these within this article and hope it may empower you to meet these challenges head on – or maybe even embrace them with renewed confidence.

Why is steam used in sterilisation?

HTM01-01 Part C (1.4) directly references steam as being the preferred sterilant due to its superior sterilising qualities. So let's just unpick that for a minute, in order to understand why it might be considered "superior", or indeed proven to be so.

Steam is a unique heat transfer fluid – indeed it has often been called "the energy fluid" due to the very particular characteristics and properties that it has. Steam is a vapour – moving from one place to another as a result of pressure differential. This also means it has great capabilities when it comes to penetration of any sterilisation load – allowing ready ingress across a huge range of equipment materials and profiles, ensuring complete and consistent item sterilisation.

Steam, of course, is also hot and these higher temperatures (typically between 120-140°C) are critically important when it comes to ensuring the destruction of a wide range of potentially harmful microorganisms, including heat-resistant bacterial spores. In order to do so, it is vital that temperatures are maintained for the required duration of the process, while the high total heat energy content in steam is also vital.

Steam sterilisation is also a quick and versatile process when compared to many other sterilisation methods and does not leave behind any chemical residues or other bi-products on the equipment being processed – a major benefit for increasingly busy decontamination and sterilisation departments, where additional processing may cause surgical delays. With proven reliability and performance over time, alongside cost-effectiveness when viewed against other methods, it is clear that steam will remain a vital element of decontamination for some time. However, we will only be able to utilise these unique characteristics of steam if it is delivered to the process in accordance with the right quality standard.

What exactly is steam quality?

Naturally, we should challenge ourselves and other stakeholders to consider "what is steam quality?", as well as seeking answers to "how should we assess and measure this?" and "is there a difference between 'steam grades' and 'steam quality'?"

Let's start by answering the easy questions first...Steam grade is most certainly a different consideration than that of steam quality. Various 'grades of steam' can be raised/produced and these are largely dependant upon the water source from which the steam has been produced and the risks in relation to any remaining physical debris within the steam itself. We usually categorise four key grades of steam in common use: *plant steam,* ▶

filtered steam, which (as the name implies) has additionally been filtered in some manner to remove physical debris down to a defined size; *clean steam* (with which many readers should be familiar); and, finally, *pure steam* which is raised in a similar process to clean steam, but using a water source meeting WFI (water for injection) quality.

Steam quality is different. It goes to the heart of why steam is being used – in order to move and utilise large amounts of heat energy with precise control. Steam quality is about defining the physical characteristics which are fundamental to its ability to perform consistently in this way under all load conditions. The good news is that there is already a standard that can help us with this definition. In fact, HTM01-01 Part C contains many 'cautionary notes' regarding issues that may affect heat transfer but, in order to summarise and define these clearly, it directly references this standard – BS:EN285 : 2015 +A1 :2021 (commonly shortened to 'EN285').

There are three key properties of steam essential to effective heat transfer and defined in EN285 - we should (and do) therefore assess all steam quality data against them. These are: air and other non-condensible gases (NCGs) of ≤3.5% by volume, superheat of ≤25°C and steam dryness of ≥ 95%. (There is also a water conductivity measure, which we will not deal with in this article). All can be measured through recognised methods of steam quality testing using dedicated equipment for this specific purpose. However, what do they each mean and what can we do to ensure we are meeting the standards?

Steam dryness is probably the most challenging of these to understand clearly and to measure accurately under dynamic load conditions. Using our extensive steam knowledge and expertise, along with state-of-the art research and test facilities at one of our UK manufacturing sites, we have covered both issues and are happy to share these insights.

One of the fundamental aspects of steam, that we should firstly remind ourselves of, is that it gives up the large amount of heat energy that it carries by transferring this heat directly to cooler surfaces it comes into contact with. While this heat transfer occurs, steam remains at a constant temperature but begins to condense back to a liquid state (water). When we generate steam we are effectively doing the opposite of this and, by adding more and more heat energy at our steam generating plant, we are aiming to reach the point where our steam is 100% vapour with no water (condensate) content. This would be steam dryness of 100%, sometimes expressed as a 'dryness fraction' of 1.0, and would give us steam with an energy content (in kJ/Kg) exactly as stated in dry saturated steam tables – in other words, a 'known quantity' of heat energy available for use in our process.

So, we can clearly see from the information above, that knowing only the pressure and temperature in our steam space is not enough to be able to confirm steam quality. Steam condenses in order to give up its heat energy to the process so that, at a given pressure and temperature, we may have steam or we may simply have hot condensate (water) at the same temperature. This can be illustrated in Fig.1 'The temperature / enthalpy curve diagram'.

In this diagram temperature is shown on the vertical ('y') axis and energy content, or enthalpy, is expressed in kJ/kg on the horizontal ('x') axis. The 'origin' point where the axes meet is zero energy content and 0°C - the gradient line on the left of the curve therefore representing increasing temperature and energy content.

The descending vertical lines on the right of the curve indicate various values of pressure, with the right hand boundary of the curve representing the point at which 100% dry saturated steam occurs. The area to the right of this line represents the superheated steam region. The horizontal lines within the curve therefore are evaporation lines and represent the amount of energy that must be added to water at a given pressure and temperature to achieve dry saturated steam with no water content remaining.

For the purposes of this example, we have chosen steam at 2barg (bar gauge) which will have a temperature of 133°C as shown at the dotted line on the left. Looking at the three values indicated along the horizontal evaporation line, we see that at this pressure and temperature it is possible we could have steam at any number of levels of dryness. We have highlighted 10%, 50% and 90% to illustrate the point (remember that EN285 calls for ≥ 95%).

Is there an answer to the quality challenge?

If maintaining pressure and temperature alone are insufficient to guarantee steam quality, what is the answer? There are some mechanical 'best practice' steps that can be taken within both our plant steam and clean steam systems that will help us to ensure resilient steam quality. We can take steps to eliminate condensate build-up in our plant steam systems (strainers, traps, separators all correctly selected, installed and working) - any dead-legs or poorly isolated/drained areas of our system can also be addressed. Our steam generating plant can be properly sized, configured and controlled to eliminate any risks of "carry-over" of boiler water.

Air must be allowed to escape (through proper venting) but must also be driven out of

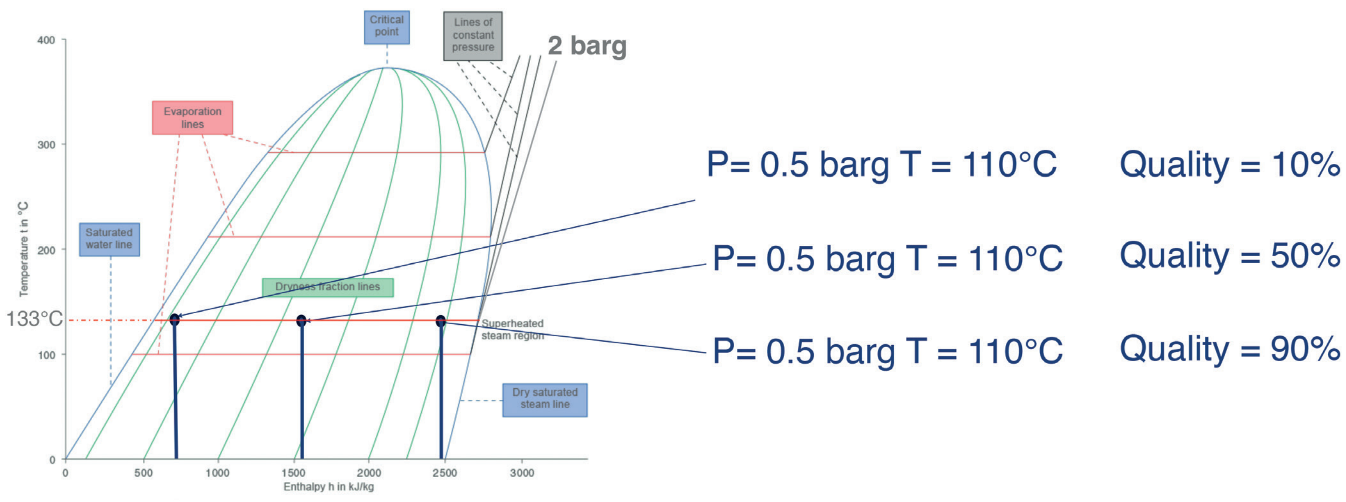

Figure 1. What is steam quality and why is it so hard to monitor?

the feedwater by way of chemical treatment, use of R.O. (reverse osmosis) plant or adequate pre-heating and "de-gassing" in order to 'purge' oxygen from the water before steam is generated. This applies also on the clean steam side of our system.

Recognising the importance of these steps in combination, our research team have developed a healthcare-specific De-Aerator Tower in order to purge non-condensible gases from the clean steam feedwater and to ensure that this remains the case under all load conditions. This is shown below *in situ* at our test facilities and is now incorporated into our Clean Steam Generator solution.

Another critical factor in achieving consistent steam quality is the ability of our steam generating plant to respond to dynamic load conditions with multiple items of plant being served, or significant fluctuations in demand (for example on test/start-up) from individual equipment. If our steam generating plant, whether a separate generator of plant steam or a smaller generator "on board" our sterilser unit, does not have sufficient stored energy or overall capacity to be able to respond appropriately to such changes, then it is very unlikely that we will be able to maintain steam quality in accordance with EN285.

In order to test this in a practical example we used our test and research facilities in the UK to recreate such conditions. Using a control system to create various dynamic changes to the steam load placed on our Clean Steam Generator, incorporating the healthcare De-Aerator Tower and measuring steam dryness, we are able to show the consistency of performance that needs to (and indeed can) be achieved. This is illustrated on the five-minute timeline captured in Fig 3.

We can clearly see that despite a varying load during pulse/vacuum phases and with multiple steam loads coming online (up to 188kg/hr flow rate), using this technology we are able to maintain a steam dryness in accordance with EN285 under all conditions. Note, however how much the steam quality (dryness) still varies even with this specifically designed solution, imagine what this would look like without these safeguards in place.

In addition to the right equipment being used, it is critical that this is well-maintained and properly reviewed. Whether on the plant steam or clean steam side of the process, a regular maintenance schedule – ideally covered by a service contract – is vital, alongside regular surveys and audits of the system to ensure that all is as it should be. This is also a vital 'check and balance' to review in the context of changes to site demands and systems.

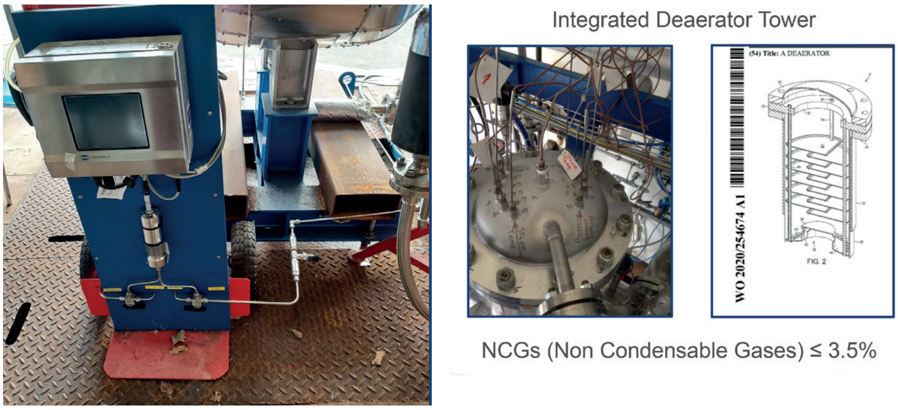

Figure 2. Heathcare specific innovation to ensure EN285 NCG compliance

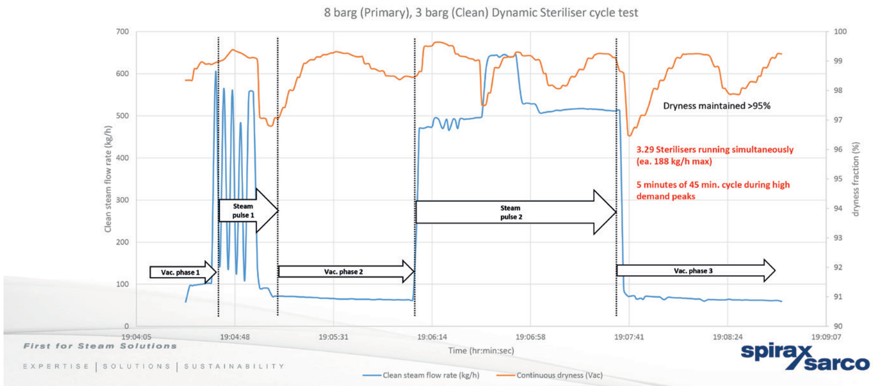

Figure 3. Responsiveness to load changes when using bulk steam generation

What about the future and our decarbonisation challenges?

As the ticking of the Net Zero clock becomes ever-louder, it is tempting to rush headlong into activities and select apparently easy-to-implement solutions. In some cases, this will be adequate and may not adversely impact services. In many instances, this requires much more careful consideration, as the consequences for hospital infrastructure and the knock-on effects for decontamination services can be potentially lethal. As things presently stand, electrification represents the best realistic opportunity for decarbonisation and ultimately achieving Net Zero.

However, caution needs to be exercised in selecting our electrification solutions; it is absolutely vital that we give consideration to the points raised within this article and select a decarbonisation partner that is well-placed to advise on such. The ultimate system design and solution will need to deliver steam quality in accordance with EN285 under all conditions, to avoid problems with decontamination processes and the introduction of potential patient risk.

Reassuringly, we have recognised the critical nature of these issues for the future of critical services in healthcare and have developed a range of electrified solutions for both plant steam and clean steam systems. We recognise that maintaining system resilience and dealing with ever-increasing demand, while improving quality is a key challenge – with our global steam systems expertise, we are always on hand to help strerile services departments embrace these challenges. **CSJ**

About the author

Steve Bishop is a Business Development Specialist at Spirax Sarco (UK & ROI). He has a particular focus on the hospital sector, as well as many years' experience of a variety of general industrial and steam-using processes, including manufacturing experience across a variety of industries.

Steve is passionate about the crucial role that steam continues to play in the delivery of Thermal Energy for customers. The business is focused on rapidly developing new technologies and approaches, as well as achieving Net Zero goals.