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Steam in Distribution and Use: Steam Quality Redefined

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If an analysis showed that a particular device or program could increase the efficiency of a central station boiler by *5* percent, in most cases it would be carefully considered and exhaustively researched. An observed industrial phenomenon takes place when the same scenario occurs outside the powerhouse walls. The same efficiency improvement potential may not receive the same consideration, analysis or study. This is, of course, a generality but in many cases the statement is accurate.

What makes up quality steam? Steam that is *conditioned to maximize energy transfer.* The following discusses some of the factors contributing to quality steam:

Pressure. Steam pressure plays an important role when trying to maximize the energy transfer of steam. The higher the steam pressure, the higher the temperature and total energy content of a unit of steam. Latent heat or heat of vaporization is the energy released by steam changes as pressure changes. Latent heat quantity increases as pressure decreases. To maximize latent heat transfer, steam should be used at as low a pressure as possible.

Steam pressure also controls the saturated steam temperature. As pressure increases, so does temperature. Since temperature difference governs heat energy transfer, the higher the temperature, the easier it is to transfer heat. The ease of energy transfer can yield a smaller heat exchanger due to the improved heat transfer. The tradeoff for the smaller heat exchanger could be that much more steam is consumed, due to the decrease in latent heat of the higher pressure steam.

When steam is distributed through the piping system, steam pressure drops. Steam mains and steam branch lines are sized to distribute the steam without excessive pressure drop. When steam pressure drops, the total energy content of the steam also drops. To avoid this energy loss, steam mains and branches must be sized very carefully to avoid making the energy loss even higher than normal. In the system when pressure drops, so does temperature. This could slow heat transfer, creating a demand for more steam, which increases the pressure drop even more, wasting more total energy. In addition, velocity will increase, contributing to more erosion and noise within the piping.

Cleanliness. Steam that is clean goes a long way toward improving energy transfer, and reducing system maintenance. From an energy aspect, the biggest impact will be seen in instrumentation and control devices. Clogged control parts can lead to poor pressure and temperature control. In the previous section, it was shown how pressure can impact energy transfer. In control devices, particularly pressure reducing stations and control valves, clean steam is far less likely to cause leaks at the valve seating surfaces. Valve leaks are likely to cause steam loss, poor pressure control and result in energy loss. Steam flow measurement, pressure measurement, and temperature measurement will most likely produce accurate data on clean steam. When not accurate, poor control decisions can result with resultant energy loss.

Heat Transfer Potential. Pressure has been discussed as having an impact on heat transfer potential through its impact on steam flow, steam temperature, and heat energy release.

Accumulations of air and noncondensible gases in the steam system can also limit steam flow, steam temperature, and heat energy release. Air is present in the system on startup and is also introduced through vacuum breakers on temperature controlled processes. Noncondensible gases are liberated in the boiler. Carbon dioxide and oxygen are dissolved in the boiler feedwater as carbonates and bicarbonates. These noncondensible gases, when released, flow with the steam and can create energy problems.

The gases cause a temperature reduction by contributing to total system pressure. Dalton's Law of Partial Pressure states that the pressure of the mixture of steam and other gases is equal to the sum of the partial pressures. This effectively reduces steam pressure and the resultant temperature. As steam temperature drops, so does the energy transfer.

When steam condenses, the other gases are forced to the heat exchange surface, forming a stagnant film. As we all know, air is a good insulator. (See Fig. 1.) As a comparison, a film of air 0.01 in. thick has the same resistance to heat transfer as a film of water 0.2 in. thick, or steel 15.5 in. thick, or copper 11 ft thick. So besides reducing temperature, the gases can act as an effective insulating barrier to energy transfer.

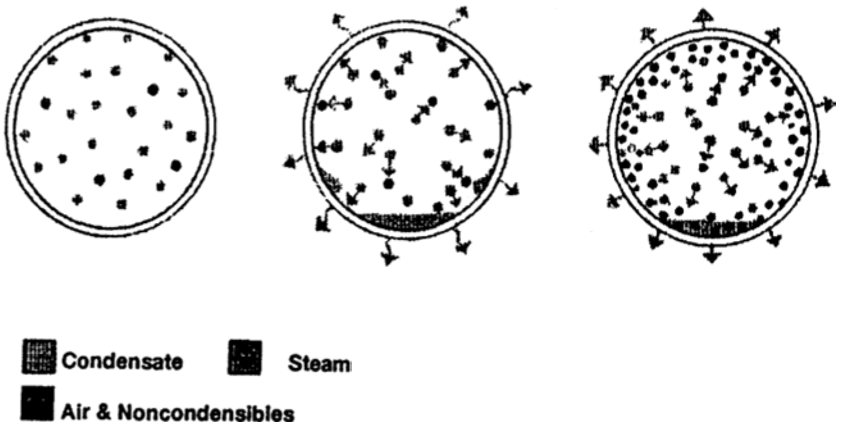

Fig. 1. Plating Out Noncondensibles Cause Insulating Effect

The gases also take up volume and don't condense into liquid as readily as steam (hence the term noncondensible). If allowed to accumulate for long periods, they take up enough volume to effectively block steam flow and all energy transfer. When condensate flow is also blocked, dangerous water hammer can also occur.

When allowed to cool in the presence of condensate, carbon dioxide can combine with the water to form carbonic acid. Since gas accumulation causes a temperature drop, this acid formation is highly probable. The corrosion of iron forms a soluble bicarbonate which leaves no protective coating on the metal. If oxygen is also present, rust forms and CO2 is released, which is now free to cause more corrosion. Once the gases become dissolved, they could be drained and removed, but they corrode on the way. This corrosion is free to cause steam leaks which are an energy loss and the corrosion is a maintenance and safety problem.

In summary, steam energy transfer can be affected by many factors. The traditional definition of steam quality covers one such factor; the amount of water entrained in the steam. Other factors include steam pressure both in the distribution system and at delivery, steam cleanliness, and the amount of air or noncondensible gases present in the heat transfer equipment.

Measuring Steam Quality

The measurement of traditional steam quality is possible with standardized test instrumentation. Measurements are essential to the safe accurate and reliable operation of the steam plant. Some types of quality meters and methods are outlined by the American Society of Mechanical Engineers (ASME). Quality must be measured to qualify flowmeter readings for steam billing purposes, to check boiler treatment practices, and as a troubleshooting tool. Trends in boiler and steam generating equipment design have increased heat transfer surface areas in more compact packages. Since more steam is coming from smaller units, there is a greater likelihood that the equipment will carryover (throw some water out with the steam).

As steam travels through the distribution system, the piping radiates heat and some condensate forms. Boiler treatment with chemicals can cause upset conditions and cause priming (boiler overflow). This introduces water into the boiler header and distribution piping. Chemical treatment can also affect the specific boiling action within the boiler and also affects carryover. Steam quality must be measured to assure and control the safe, reliable operation of the boiler or steam generating equipment.

Field testing methods and procedures for steam quality measurements are described in the ASME Performance Test Code 19.11 Steam and Water Purity in the Power Cycle. One of the methods, the throttling calorimeter is capable of measuring steam quality directly. (See Fig. 2.) The other methods include:

(1) ion exchange
(2) conductivity (electrical)
(3) sodium tracer flame photometry
(4) specific ion electrodes

These methods determine the solids content of steam, including the solids carried over by water droplets.

The throttling calorimeter is the only direct way to determine steam quality. This method is most accurate below 600 psi and where moisture content is above 0.5 percent. The calorimeter is a simple, easy to use instrument. When properly insulated and installed, it is very accurate. The calorimeter works on the principle that when steam expands without doing work, the heat content does not change. If the steam is dry and is discharged to atmosphere, it will become superheated due to the pressure drop. If there is any moisture present, the temperature of the atmospheric discharge will be reduced. Measuring the temperature and comparing to the maximum possible temperature will indicate the steam quality.

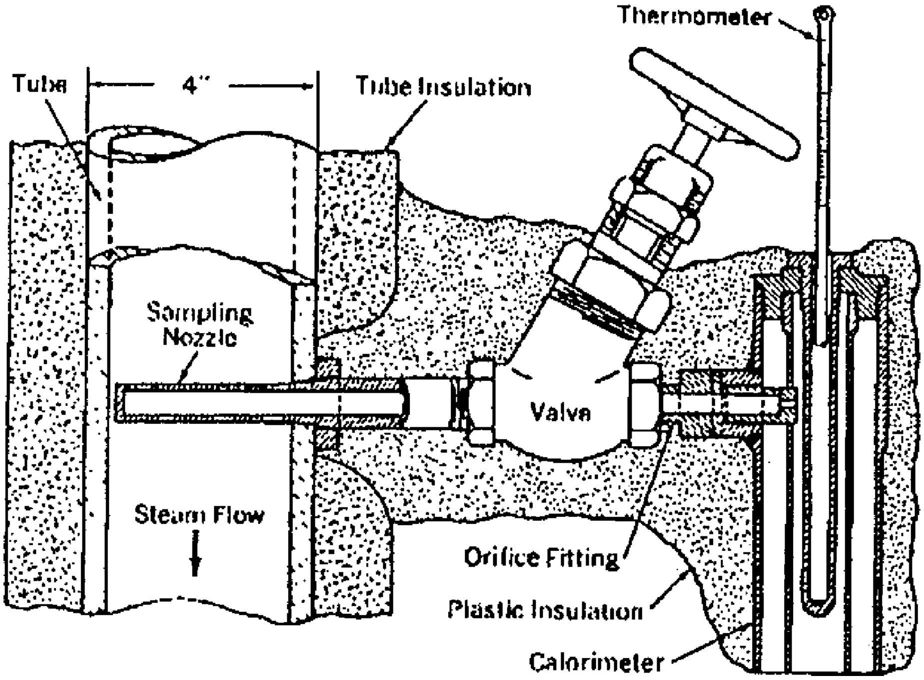

Fig. 2. Throttling Calorimeter Shown Installed in a Steam Pipe
Source: Babcock and Wilcox, Steam, Its Generation and Use, 1978

The other methods, by measuring solids, give an indirect measure of steam quality. The solids in the steam are sampled and counted, and then compared to the solids content of the water in the boiler. This relationship has been found to be highly accurate. It has limited application at locations away from the boiler, where the calorimeter can still be used.

Low Quality Problem

When low steam quality is detected, it usually indicates a problem with the water level control, feedwater treatment, blowdown cycle or even boiler sizing. Equipment such as separators, baffles, and mist eliminators may have failed. Boiler or steam generator operating procedures may need to be changed.

A boiler or steam generator that is making low quality steam tends to overload the distribution system. Moisture increases the mass flow through the steam lines, increasing the pressure drop. Noise, velocity and generally poor operation can result. Steam quality is therefore an important function to control.

Redefine Steam Quality

When considering the definition of maximizing energy transfer, other characteristics of the system must be considered. If steam is to serve its function of heat energy transfer, the steam system should be designed, installed, and maintained to allow maximum heat energy transfer to occur. To do this, the steam must be:

(1) delivered at the highest pressure possible
(2) used at the lowest pressure possible
(3) be kept as clean as possible, especially at control devices
(4) be free from high concentrations of air and noncondensibles, especially at condensing surfaces
(5) be free from excessive moisture (the traditional definition of steam quality).

By setting objectives to accomplish these steam quality goals, an action plan can be developed for a steam quality program. Implementation of a steam quality program takes the cooperation of engineers, energy staff, and operations. All these groups must understand the potential benefits and how improvement techniques can be applied.

Steam Quality Objectives

The following objectives should be recognized as an integral part of a program to accomplish the steam quality goals listed above:

Steam Pressure.

(1) Steam pressure should be distributed at a high enough pressure as is practical to overcome line losses and satisfy the highest pressure user.
(2) Steam pressure should be reduced at usage to as low a pressure as is practical.
(3) Steam velocity in distribution piping should not exceed 12,000 ft/mm.
(4) Total pressure drop within the distribution piping should not exceed 20 percent of boiler pressure.
(5) Steam pressure drops should be avoided to preserve total energy content and steam temperature.

Cleanliness.

(1) Drip points and dirt legs within the system should be present in the system at regular intervals.
(2) Control valves should be protected by a strainer which is free from condensate accumulation.

Heat Transfer Potential.

(1) Use steam at the lowest possible pressure to take advantage of low pressure latent heat.
(2) Boiler feedwater should be deaerated to reduce noncondensible gas production.
(3) Heat transfer devices should incorporate automatic vents to reduce noncondensible accumulations.
(4) Steam traps should be selected to discharge condensate before it cools and becomes corrosive.
(5) Automatic vents and steam traps should be located properly to discharge air and noncondensible gases before serious accumulations occur.

Steam Quality Action Plan

For each objective listed above, these are some suggested steps to take.

Steam Pressure.

(1) Investigate generating steam at higher than required pressure (up to 600 psig) to take advantage of specific volume. At higher pressures, steam volume decreases, and more steam can flow through a given size pipe. For the same flow, less pressure drop and less energy loss will occur.

(2) Investigate steam pressure requirements of major users. Latent heat savings and improved control are possible by utilizing pressure reducing valves, temperature control valves or sensor- control valve combinations.

(3) Compare pipe sizes of major distribution and branch lines to sizing charts. One major steam user found a boiler expansion could be avoided by adding and repiping several lines to reduce pressure drops.

(4) While comparing line sizes also check for steam velocities to be not above the 6,000 to 12,000 ft/mm. range and total system pressure drop should not exceed 20 percent of the total maximum pressure of the boiler.

Cleanliness.

(1) Drip legs with dirt pockets should be installed throughout the steam distribution system at least every 500 ft and ahead of valves or regulators.

(2) A special situation exists ahead of valves that are protected by a strainer. The strainer body is a low point and accumulates condensate naturally, reducing the effective area of the strainer screen. (See Fig. 3.) Some of the condensate is picked up by the flow created when the valve opens, impacting the valve and seat with dirty condensate. Installing an inverted bucket steam trap on the strainer blowdown drains the condensate, freeing the screen area from blockage and keeps the strainer clean. (See Fig. 4.). Look for control valves that have perpetual dirt and wear problems to try this simple solution on.

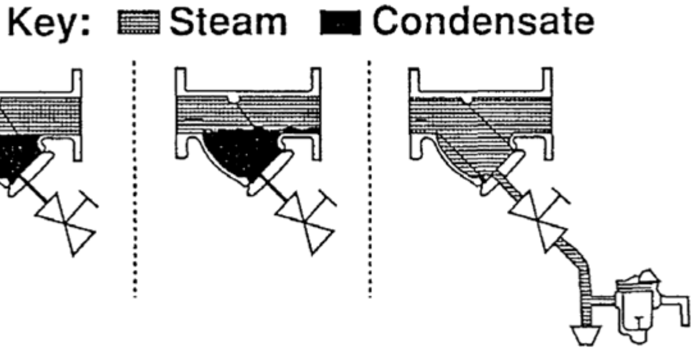

Fig. 3. Automatic Strainer Blowdown Prevents Water Carryover

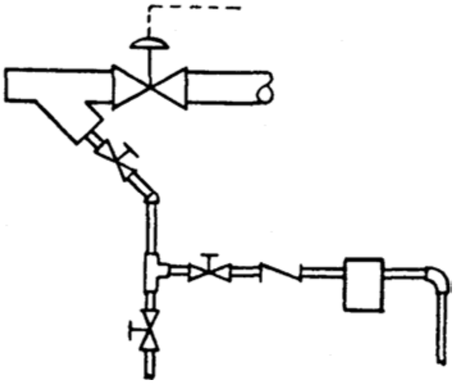

Fig. 4. Trap Draining Strainer Ahead of Control Valve

Heat Transfer Potential.

(1) Evaluate heat exchangers for oversizing or poor control. Pressure reducing stations for entire areas might be considered, but a pressure or temperature regulator at the equipment can achieve the same results with some savings. The central reducing station is not needed, the valve can often be smaller due to the greater pressure drop, and large size distribution piping is not needed due to the specific volume of the high pressure steam.

(2) Relying on chemical treatment rather than deaerators should not be done. Many corrosion problems that make deaerators a nuisance are due to the corrosion the system is supposed to prevent. Never mix makeup water with condensate return, even at the spray head. Always allow the deaerator to freely vent, never restrict the gas flow, rather use a vent condenser to limit steam venting.

(3) Bellows-type thermostatic steam traps can be used as automatic air vents on heat exchange equipment. Air in the system tends to be lighter than steam and does not condense, so it gets pushed to quiet zones by the flowing condensing steam. At these locations, the thermostatic device senses the temperature reduction caused by air. Batch process cookers, large shell and tube heat exchangers, and large steam coils should incorporate automatic air vents to eliminate air accumulations. (See Fig. 5.)

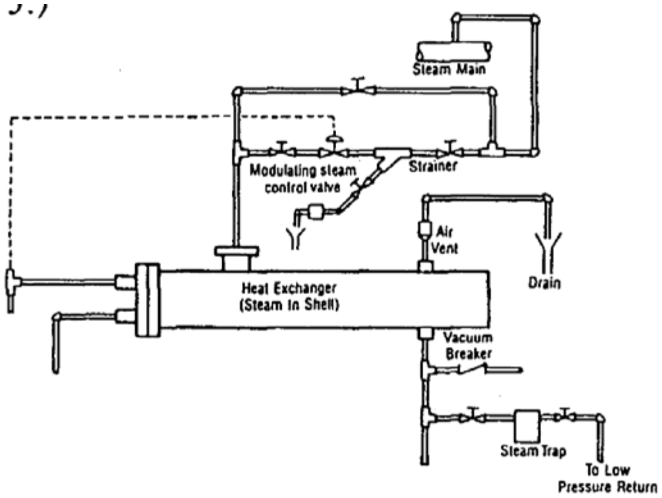

Fig. 5 Shell and Tube Heat Exchangers (Typical Piping Diagram)

(4) Steam traps should discharge condensate from process applications at or near saturation temperature. Selection of traps that back up or subcool condensate will accelerate carbonic acid corrosion, future steam leaks and maintenance. Properly sized non-subcooling traps, such as inverted bucket traps and thermostatic traps will help maximize heat energy transfer.

(5) Air vents and steam traps must be properly located to function efficiently. When traps are installed, the ABC's should be followed: Accessible for inspection and repair, below drip points whenever possible, lose to drip point. To locate air vents properly requires visualization or a good pyrometer.

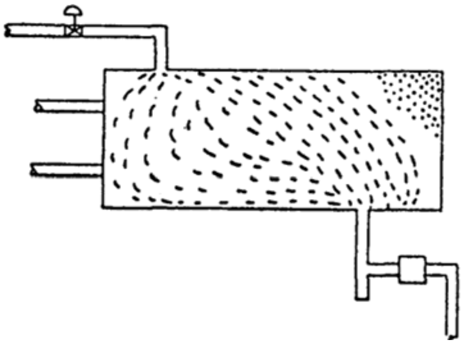

Fig. 6. Steam Flow Pattern in a Shell and Tube Heat Exchanger

With a pyrometer, it's possible to measure skin temperature of the heat exchanger to find the gas accumulations as cold spots. This will be the proper place to locate an air vent. Without a pyrometer you should visualize the flow within the heat exchanger. Imagine the flow of steam rushing in and condensing. (See Fig. 6.) Imagine the condensate flow down and out the drain. The proper air vent location is away from these active flow areas. Usually the best locations are high points, away from the inlet. A non-subcooling steam trap properly located can usually take care of the lower quiet zones since the traps will vent air also.

Conclusion

There is a big difference between generating good quality steam and delivering steam that has high usable quality. This difference centers around maximizing energy transfer. The traditional definition of steam quality is the percentage of steam to moisture. Yet high quality steam should also be usable, efficient and effective.

Steam that is delivered at a controlled pressure is clean and has high heat transfer potential are important quality features. The benefits of quality steam are many and are attainable by setting goals, objectives, and implementing an action plan to study potential improvements. A complete action plan would entail:

— Studying steam pressure delivery and usage requirements.
— Analyzing existing steam velocities and pressure drops.
— Analyzing existing system dirt collection, straining potential and valve protection practices.
— Checking deaeration system problems.

— Incorporating and properly locating air venting and checking steam trap selection and location on heat exchangers.

High quality usable steam that maximizes energy transfer is attainable if all the aspects of quality are acknowledged, studied and controlled. Expect a difference in your steam system performance if you make the effort now.

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