Why Build an Ultra Low Water Content, On-Demand Steam Boiler?

Sometimes in life, we lose sight of the forest for the trees. For many years, Miura has touted the benefits of their ultra low water content, “on demand” high pressure steam boiler design. We’ve marketed benefits such as the reduced footprint, quick start up, and “on demand” responsive performance, which, as an industry first, allows multiple steam boilers to be successfully operated in a modular arrangement. Further, this modular approach has shown itself to be capable of delivering superior performance over industrial watertube and firetube designs, both in responsiveness to varying steam demands, as well as a providing a more redundant, integrated system. Especially relevant, have been the resulting efficiency gains, with accompanying lower emissions, that result from operating the boilers in an on demand, modular arrangement, rather than modulating a single large boiler, or a couple of boilers to match steam demand.

Now this next line might shock you. While all these benefits are significant in today’s marketplace, and each a result of the ultra low water content design; whether assessed individually, or cumulatively, the gains they represent are not enough to justify such a radical redesign of a technology that has changed very little in the last 100 years. So why build an ultra low water content, on demand, high pressure steam boiler in the first place?

In a word: **Safety.**

While there are still many places in the world where boiler operator laws are weak, or non-existent, wherever industrialization has existed for a prolonged period of time, people start putting safety measures in place to better protect their lives and well-being. While most hot water, or hydronic boilers, along with low pressure steam boilers for heating, are operated without any type of licensed supervision; high pressure steam boilers, on the other hand, do require a licensed operator to run in many jurisdictions.

Why is this? Let’s talk for a few minutes about latent heat and flash steam. First, it is important to understand that a pound of water takes up a very different volume than a pound of steam. That ratio is about 1:1600 between water and steam. That is, a pound of steam takes up 1600 times the volume of a pound of water. That’s a big difference.

Next it is important to understand the amount of energy, or what steam folks call “latent heat”, that is required to change water into steam. If you’ll remember back to the experiment you did in science class at school, where you observed temperature change as you heated water to boiling, you’ll remember how temperature rose steadily to about 212 F, and then hung out there for several minutes before vigorous boiling started to occur, and steam was produced. You didn’t stop adding heat energy to the water during this period, even though the temperature stayed the same. No, you were adding “latent heat”. In fact, it is this latent heat contained in steam, which made it quite popular for district heating systems in places like NYC, Boston, Hartford and others, but that is a story for another time. For our discussion, latent heat is important to understand as the “heat energy stored in saturated water/steam”.

Finally, it is critically important to understand the effects of pressure and temperature on the physical state of water. When you were conducting that science experiment in your classroom, you were boiling water at what is referred to as "atmospheric conditions". While atmospheric conditions vary with altitude above sea level, for our discussion here, that variation is not important, though it is worth noting that water tends to boil at a slightly lower temperature in Denver, than in LA. Likewise, as pressure increases above atmospheric pressure, boiling occurs at even higher temperatures than 212 F. In fact, there is a direct correlation between the temperature at which water will boil, and pressure enacted on that water. We'll referred to this phenomena as saturation conditions. For instance, at just 15 psig, or approximately 2 atmospheres, water won't boil until it reaches approximately 250 F.

Very importantly, this also works in the opposite direction, with pressure, which brings us finally to the subject of flash steam. Should pressurized water at saturation conditions of 250 F and 15 psig suddenly have pressure drop to 0 psig, or atmospheric pressure, the latent energy present will cause a portion of that water to immediately flash to steam. Imagine if you will, an entire gallon of water instantly flashing to steam, and suddenly trying to occupy the equivalent volume of 1600 gallons of water.

Another important thing to know about flash steam is that the proportion of pressurized water volume that will flash instantly to steam, increases as the pressure differential from atmospheric conditions increases. For instance, in order to flash off an entire gallon of 250 F pressurized water by reducing pressure from 15 psig to 0 psig, as previously mentioned, there would need to be 25 gallons present, since the percentage of flash steam resulting from that pressure drop is approximately 4%. Should saturation conditions corresponding to 60 psig be present, that percentage jumps to approximately 10%. At saturation conditions corresponding to 250 psig, the percentage of flash steam would be approximately 20% of available pressurized water volume.

To bring some perspective to the situation, consider that a small 200 Hp Scotch-Marine type firetube boiler capable of operating up to 150 psig, contains a little over 1,000 gallons of water during operation. That's over 7 million Btu's of stored energy in the form of latent heat. Now imagine a pressure vessel breach, and 162 gallons (16.2% of 1,000) of that water suddenly trying to occupy 1600 times that volume, the equivalent of 259,200 gallons of water. That's roughly 40% of the volume of an Olympic sized swimming pool! To put it another way, if 162 gallons occupies approximately 22 cu.ft. of volume, then when that same volume flashes to steam, it would be trying to take up 35,200 cu.ft., and most likely, that is much more volume than is contained within the boiler room. That is quite an explosive force. The energy behind that explosive force is stored within the volume of every operational high pressure steam boiler. Just do an internet image search for "steam boiler explosion", and you'll see what I mean.

So as you can see, there is inherent danger present when water exists in saturated conditions at pressures well above atmospheric pressure. The amount of danger is directly related to two things: 1) the volume of saturated water present, and 2) the pressurization of that volume above atmospheric pressure. So how can a high pressure steam boiler be made safer?

The high pressure steam boiler industry, generally speaking, has not responded to this question by radically redesigning their equipment, but rather, attempting to improve the operational safety of these inherently unsafe designs through two legal avenues spelling out codes and regulations for:

- automated safety devices
- operator licensing

While well-intentioned, and when applied successfully, these codes and regulations can be acknowledged to have reduced the associated death toll and damage, boiler explosions are still prematurely ending a significant number of lives, and costing hundreds of thousands of dollars in property damage worldwide every year. Even where excellent laws exist, they are inherently reliant on 1)proper enforcement, as well as 2)sound maintenance practices combined with 3)operator vigilance. That situation, especially in areas of rapidly developing industrialization, unfortunately, leaves plenty of openings for failure.

It's a bit like car safety. Seat belt laws, required safety devices like airbags, ABS, rear cameras, crash testing, and the like, all have saved numerous lives, yet motor vehicle deaths continue year after year, due to inherent dangers. We accept those dangers, because to date, for many, an automobile is still the best way to get around. This lack of viable safer options is not the case in the boiler world.

So what to do? As time has passed, repeated efforts have been made to simply replace the need for steam altogether, especially high pressure steam, with safer, more energy efficient, less maintenance intensive methods of energy transfer. In many instances, hot water generators, and/or industrial thermal fluid heaters have taken over systems previously served by steam. Despite the continuous improvements in those technologies, however, their inherent limitations cannot completely eliminate the need, or surpass the suitability of high pressure steam for many applications.

The answer then, is that a safer, high pressure steam boiler must be built. If you'll recall from earlier in our discussion, inherent boiler safety is 1) directly related to the volume of water present at saturation conditions, as well as 2) the pressurization of that volume above atmospheric pressure. Practically speaking, only one of these two factors, that of water volume, can be addressed without completely negating the value of high pressure steam in the first place. In most cases, operating steam pressure and temperature is dictated by the district heating or process condition requirements for which steam is deemed the most suitable solution.

So, water volume then. Reducing water volume in a steam boiler poses a few large challenges. The water volume in a steam boiler serves dual purposes. First, and most obviously, steam cannot be generated without boiling water present. So there must be enough water present in the pressure vessel to produce the required capacity of steam, at the required temperature and pressure. Secondly, and just as importantly, the furnace side of the boiler, where the flame and hot flue gases are generated, is very hot. Flame temperatures typically exceed 2,000 F at the burner. The materials the pressure vessel is constructed from, typically welded carbon steel, cannot maintain their structural integrity at temperatures of less than half that. So the water content of the boiler also serves to cool the pressure vessel. The trick then, is to design a boiler that can contain the minimum amount of water required to produce a given capacity of steam, while still having enough cooling capacity to maintain the integrity of the vessel in substantial excess of the steam pressure desired. Sounds easy, right? Why weren't boilers designed like this from the beginning?

Back at the beginning of the Industrial Revolution, when steam was just beginning to be employed for heating and process use, most boilers were coal fed, and often manually. Think about those guys you see in the old movies, all sweaty and covered in soot, shoveling coal into the furnace of a locomotive engine, or the boilers of big ship. Water level controls, and feedwater delivery were relatively primitive as well. At the outlet of the boiler, however, steam flow and pressure would vary with whatever heating or process demand was being supplied. These steam demand changes can happen very quickly. The only way an operator could adjust heat input, or water level enough to keep up with these changes, was to slow down the reaction time needed. A large mass of water in the boilers served as a buffer, necessarily slowing down the reactions from increased steam output, and heat input to a more manageable level. As long as water level was kept within a given range, there would be sufficient water present to flash to steam in the event of a sudden demand increase, and enough cooling present should steam demand fall off while the heat in the furnace was still increasing due to the addition of fuel.

In fact, controlling heat input, along with water level and flow are still the greatest challenges to building an ultra low water content, on-demand boiler. As the buffer of water volume is removed from the steam boiler design, burner and water level controls must be designed to be able to react quickly to steam demand changes, in fact, near instantaneously, and they must be designed to act in concert. Gone are the accumulator like properties in a large water mass boiler that allow it to suddenly compensate for a sudden elevation in steam demand. Instead, the on-demand boiler shifts from low to high fire instantaneously to compensate. Of course, this also means that should steam demand suddenly dissipate, the on-demand boiler faces little danger of "running away" towards a pressure spike as well.

In fact, the primary trade off for significantly reducing high pressure steam boiler water content, and the danger that it poses, is that without that added buffer volume, everything speeds up, hence the "on-demand" terminology. From a design standpoint, in order to deliver the quick output changes required to match steam demand, the pressure vessel itself must be capable of heating up and cooling down quickly without risk of thermal shock. Miura provides for this capability with a multiple watertube, "floating header" design, whereby the portion of the pressure vessel above the watertubes, is supported by those tubes, and allowed to "float" freely above them as they expand and contract. The welded construction of the pressure vessel, especially where the tubes meet the tubesheet, makes for very durable construction, relative to other high pressure boiler designs.

In some cases, such as the burner controls, the requirement for quick response actually allows for simplification. Because system steam pressure changes can occur very rapidly, and no accumulator effect is present, gradual modulation of the burner would be too slow to bring a boiler from low fire to full output. Instead, the ability to shift from low fire to full capacity instantaneously, while less sophisticated, provides a superior operational response. Additionally, from a maintenance standpoint, this high/low/off burner staging goes a long way to simplifying one of the more complex and maintenance intensive subsystems relative to traditional boiler designs.

From a water level control perspective, with two stages of output, and no fixed water line, water level is maintained for each stage, be it low fire, or high fire, by a series of probes in a sidestream liquid volume control column, and accompanying control logic. While mechanically simple, with no moving parts, the sophistication resides in the control logic programmed into the boiler control board. This control logic very simply calls for feedwater delivery from a typical vertical multi-stage feedwater pump, or does not. A timing logic ensures that feedwater flow is being delivered at the proper flow rate and pressure. This simple on/off flow setup, as simplicity often does, provides for very reliable water level control, and immediate indication should there be a problem. Should a fault in the control occur, the boiler will quickly trip offline, and alarm, requiring the operator to physically reset it.

Another often cited, and vitally important concern, is the way in which water chemistry is affected by the reduction in operational water content. While the physics of water chemistry remain essentially the same, just as every other system control must increase in responsiveness, the timeframe in which water treatment effects occur is also significantly reduced in a less diluted environment. A gallon of water delivered to an on-demand boiler makes up a much more significant portion of operational water content, than a gallon of water fed into a more traditional storage tank boiler design. If water chemistry has been properly maintained free of scale causing minerals, and corrosion contributing ions, then the transition away from a storage tank boiler design to an on-demand boiler will be fairly painless. On the other hand, if maintenance of system water quality has been lax, or inconsistent at best, issues will begin to show up in short order.

While repairing pressure vessel heat transfer surface damage due to poor water treatment in any high pressure steam boiler is expensive, low water content, on-demand steam boilers, due to necessarily tighter design tolerances, and more sophisticated construction, are not designed with incremental repairs to these surfaces in mind, but rather wholesale replacement, if required. It’s not that some limited incremental repairs cannot be performed, but rather, the pressure vessel design is not compromised to ease such a repair.

With this in mind, it is not uncommon for manufacturers of ultra low water content, on-demand style boilers to provide a proposal which includes not only typical plant accessory equipment such as DA/Feedwater skids, and blowdown coolers, but also water treatment equipment such as softeners/RO and chemical feed. Miura, in fact, offers not only the full extent of boiler plant

equipment, but integrates it all into an industry exclusive control and communications system for maximum results.
Speaking of controls, the ability that ultra low water content steam boilers have for being operated on demand, has opened up the possibility of operating them in a modular, multiple boiler system, which keeps the water content of each individual boiler very low, preserving safety, while also allowing these systems to match and/or exceed the performance and steaming capacity of traditional industrial watertube (IWT) designs up to hundreds of thousands of pounds per hour. The key to successful operation of such a system is the master control, and the logic, or "Modular Intelligence" contained within it, which automatically starts, stops, changes the fire rate, and rotates the firing order of the individual boilers to match actual steam demand, as measured by main steam header pressure.

So, as you now understand, while the technology that is necessary to reliably operate an on-demand boiler didn't exist, and wasn't fully developed until a few short decades ago, that technology is now well advanced, and available for mainstream adoption.

Just how safe are on-demand boiler designs? Let's go back to the example we discussed earlier of a 200 Hp boiler operating at 150 psig saturated steam conditions. While the firetube we discussed held over 1,000 gallons of water while operating, an ultra low water content, on-demand boiler of the same exact output capacity maintains only up to 75 gallons of water, less than 7.5% of volume of the firetube. That is less *operational* water content, by more than half (46%) of the volume (162 gal) we estimated would flash off, were a breach to the firetube's pressure vessel to occur! Not only that, but direct flame impingement on heat transfer tubes, and the feeding of cold feedwater into a hot boiler, two very dangerous operational "no-no's" when discussing traditional boiler types, are a non-issue for the on-demand design. In fact, they commonly occur *by design*, during normal operation.

In fact, in a commonly cited worst case scenario, where all controls and safeties fail, with water level dropping below the LWCO and where the burner remains firing, by the time there isn't enough water remaining to cool the tubes, and a rupture occurs, the volume of water flashing to steam could be contained within the furnace volume of the boiler, and safely vented up the exhaust stack, without an explosion and loss of life.

With hundreds of thousands of operational on-demand boiler units installed worldwide, over the span of a handful of decades, there is yet to to be recorded a single death in association with their operation. If the safety of your people and property is a top priority in your business, aren't on-demand high pressure steam boilers worth your consideration?

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