Enhancing and Optimization
Of
Condensing Boilers

By
James Romersberger
7/16/12

Introduction

Condensing boilers have been in use in the US for some time now, and the principles regarding their operation are generally known. However, there is little practical information to draw on in actually applying these principles to piping systems. And I have found no detailed information which attempt to optimize these systems. What I have seen in the use of radiant technology in general is the replacement of baseboard systems with radiant floors with no attention to radiant system design (installers have by and large just put the pipes in the floor and continued as usual). With regard to using condensing boilers I have seen the same (just stick in a condensing boiler where no attention is given to optimizing the design).

Aside from the fact that residential and light commercial systems are rarely ever designed, it is a fact that if you properly design a system for a conventional boiler, but replace it with a condensing boiler, and all things being equal, the condensing boiler will out perform the conventional boiler. The reason is that the condensing boiler's heat transfer is more efficient even if it is not running in condensing mode. It is designed for maximum extraction of heat rather maintaining a minimum stack temperature to *prevent* condensing.

This paper is intended to open up a discussion on the optimization of condensing boilers, and how they can be more effectively used in all applications whether new construction or higher temperature systems normally found in retrofits. It is not intended to provide solutions to any particular situation, but to open up the field of options. It is also intended to promote awareness of the underlining principles of condensing boilers. It does assume a general knowledge of how condensing boilers work. For a good refresher on condensing visit http://en.wikipedia.org/wiki/Condensing_boiler.

Factors Affecting Efficiency of Condensing Boilers

The Key Factor

Everyone remembers the cliché regarding the three most important principles/rules of real estate are: **Location, Location, and Location**. Well, the main principle of condensing in any furnace or boiler can likewise be summed up as: **Reduce flue gas temperature**. In boilers the main ingredient that affects this is ***Return Water Temperature to the Condenser***, although recovery of heat directly from the stack can also be significant. Notice that I didn't say "Return Water Temperature to the Boiler" but to the "Condenser". These can be two different things.

Practices to Avoid
There are many sound installation practices that are acceptable for conventional boilers, but violate this principle and will drastically reduce the efficiency of a condensing boiler. Most of these involve tempering the return water. Here are some examples that produce undesirable results:

4- way mixing valves, recirculation pumps, recirculation injection loops, pressure by-pass valves, and anything that tempers the return water should not be used. Over pumping and using too high of a “mix” also reduces the ΔT and raises the return temperature. Imbalanced pumping between injection pumps and supply pumps will also raise return temperatures, producing high temperatures when not needed. In a conventional boiler this last is not particularly an issue, but when using a condensing boiler, it is critical.

Reduced Return Temperatures
Remember, the controlling factor is reduced return water, not supply temperatures. But lower supply temperatures generally translate to lower return temperatures. So if higher supply temperatures are needed we need to further increase the ΔT in order to more effectively utilize the efficiencies that come with condensing.

More on Temperatures
I see publications use the phase “when running in condensing mode”. First of all what does this mean? It means that if you cannot get the flue gases below a certain temperature, the boiler will not condense. The next section discusses this. However, most of these publications refer to new construction, so why have a system that runs in non-condensing mode at all. There are times when this may occur but it can be minimized and sometimes we are working with existing systems that require elevated temperatures. The point is systems should be designed for the lowest water temperatures possible. While a 10-degree difference may does not affect the efficiency of a conventional boiler, it certainly does with condensing boilers.

Fuel
The operating characteristics of a system are also influenced by the fuel used. The reason is that different fuels have different properties that affect condensing. The major two are Natural Gas (gas) and Fuel Oil (oil). Gas condenses at higher temperatures than oil. This means it is easier to make the flue gasses condense. Under ideal conditions, gas will condense at about 131° F, while oil stack gasses must be reduced to about 115° F. The reason is gas (CH_4) has more hydrogen in it than oil, and thus more water, and thus a higher dew point. But even though gas is more forgiving of higher temperatures, higher efficiencies can be obtained the more the stack temperature is reduced.

Boiler Design and Configuration.
The type of condensing boiler also influences the operating characteristics of a system. There are two basic configurations used today. They are single heat exchanger/condenser vs. a primary heat exchanger and a secondary condenser. The single heat exchangers are made from stainless steel. Although expensive to make, there are advantages. One is that they can run at very low temperatures that promote great condensing, and in the case of gas, they can modulate the BTU output thereby producing the amount of heat needed at the temperature needed. The trade off with single heat exchangers is that there is one supply and one return. So although two supply

temperatures are easily managed, all return water is mixed thereby raising the total return temperature (the cool return is contaminated with the hot return) and this results in decreasing efficiency. There is no way to operate at maximum efficiency when supplying water in both modes simultaneously.

The primary/secondary types are ideally suited for multiple temperature returns. High temperature water returns to the primary, and low temperature water to the secondary condenser. However, if the primary is cast as opposed to welded steel the boiler shock issue needs to be accounted for. So the key factor to remember here is that in these systems not all of the return water needs to be used for cooling the condenser. They can operate in condensing and non-condensing mode simultaneously. Keep this in mind we look at some optimizing techniques.

Enhancing and Optimization

The following discussion pertains to the efficiencies of all systems that use condensing boilers but can drastically increase the efficiency of higher temperature systems such as retrofits, pushing the efficiencies into the 96% to 97% area.

As optimizing a condensing system consists of reducing flue gas temperatures primarily by reducing return water temperatures, we'll look at some options. Some of these will seem simple and obvious, but are certainly not discussed in the mainstream hydronic media. In general here are some techniques. Each one has the goal of reducing temperatures some where in the system:

- Add more heat emitters (lowers supply temperature needed)
- Preheating domestic water with the return
- Preheating HRV air
- Unit heaters in series
- Series plumbing - Baseboard feeding slab or baseboard feeding a cold area such as a garage
- Reduced mixed output temperatures result in reduced returns
- Reduced pumping speeds (increases ΔT)
- Add an after-condenser to a single heat exchanger system
- Add another after-condenser for DHW well water
- Add a stack robber (condensing in the stack is as effective as condensing in a condenser if the heat is recovered). Open stacks (not walled in) or vented chases allow for heat recovery.

Partial Reductions

Note that it is not necessary to reduce the temperature of entire volume of return water to make a system effective. For example, if there is a total return of 4 gpm and you add a device to get a further 10 degree temperature drop for all the water, wouldn't it be better to drop 2 gpm by 20 degrees and put this reduced volume of lower temperature through the condenser? The following are a couple of examples of how the use diversion valves for split returns and series pumping.

Simple Two Temperature Systems
When looking at a combined high and low temperature system such as a radiant floor and a DHW tank, the solution is simple, put the cool return in the condenser and the hot return in the primary. So let's look at a few other systems.

Complex Systems
One option if you have a combined slab and baseboard is to use a 3-way zone valve to divert the baseboard return to the condenser when the slab is not on. This will allow for more heat recovery and some condensing when only the baseboard is on. Remember that the condenser is a heat exchanger and *increases efficiency even if it cannot reduce the temperature of the flue gas far enough to condense. Even when running hot a condensing boiler can have a burn efficiency of 90 to 91%.*

Another method would be to feed the slab from the return of the baseboard. A 3-way zone valve could be used here for flexibility. A 3-way diversion valve could also be incorporated to provide flexibility in volume control. A thermostatically controlled bypass valve could have application in the ability to modulate volumes based on temperature.

Even though many baseboards or radiant wall panels are rated at 180 degrees, don't size for these temperatures. I know from my own experience that good baseboard works quite well at the 120 to 130 range.

Further thoughts on baseboard: First of all, high temperature water may not be needed year round. See Brookhaven labs study on mixed circuits with set back control for baseboard. (**www.fcxalaska.com/PDFs/BrookhavenBaseBoard.pdf**). So a mixed circuit will work at least for a good percentage of the year, (the lower the supply, the easier it is to get a lower return with the same ΔT. So next let's look at a unique application.

DHW Systems
In a system whose primary purpose is to produce DHW the runs most of the time when water is being used, and there is nearly continuous incoming fresh water. Consider re-plumbing the condenser from the boiler return water and routing fresh water from the source through the condenser. Well water in Alaska is just above freezing so the condensing effect would be in the 97% to 98% region.

Notes on Efficiency Testing

Electronic Testers – a Grain of Salt
These devices measure directly stack temperature along with O2 and CO. Based on the fuel type, it calculates CO2, excess air, and efficiency. The devices that do add the efficiency from condensing based on these and an **algorithm** that that uses **stack temperature** and **fuel type**. This is basically a guess because stack temperature does not create condensing, only lowering the return water in the condenser cause condensing. This results in lower stack temperatures.

So this means that a 150 degree or for that matter, a 200 degree stack temperature could either be or not be condensing, depending on the return water temperature in the condenser. In fact, on the first stage of condensing, the overall flue gas temperatures do not have to be lowered at all. The key here is that when the water part of the flue gas condenses, it does not change temperature while giving up the latent heat of vaporization. This happens when the water goes from the vapor state at 212 °F to the liquid state at 212 °F (no change in temperature). The tuning device has no way of measuring this. This is why the condensing boilers easily attain an efficiency of 93%+ in radiant applications.

Comparisons
Brookhaven National Labs have done testing comparing efficiencies of various boilers. In reading these, what has struck me is that they do not make apples to apples comparisons. For example, a conventional boiler *must* run at temperatures high enough to prevent condensing in either the boiler of the flue. So in order to level the playing field and make for uniform testing, the tests are geared to the lowest common denominator, which is that which a conventional boiler can operate. So the effect is that, optimization for a condensing boiler is not taken into consideration, simply because conventional boilers are not capable of the optimization under any circumstances. So even though enhancement controls for set-back, purging, cold starting, etc. apply to all boilers, the conventional boiler has reached maximum efficiency with these. However, the condensing system out of the box (even with controls) can still be improved on. This is because there is no physical reason why flue gas temperatures cannot be lowered more (its already condensing in the plastic stack). Consider that in the preceding example of preheating well water there is *no reason stack temperatures cannot be lowered considerably below room temperatures*. This is why the efficiency ratings for conventional boilers max out at about 87%. The rated efficiencies for the condensing boiler are just the starting point.

The Bottom Line

So design your system to take advantage of using low temperature water, and maximizing the ΔT. Use the best heat emitters for the application you are working on. Use the best DHW indirect tanks designed for low boiler temperatures. Use the latest in technology in ΔP or ΔT Variable Frequency Drive (VFD) pumps.