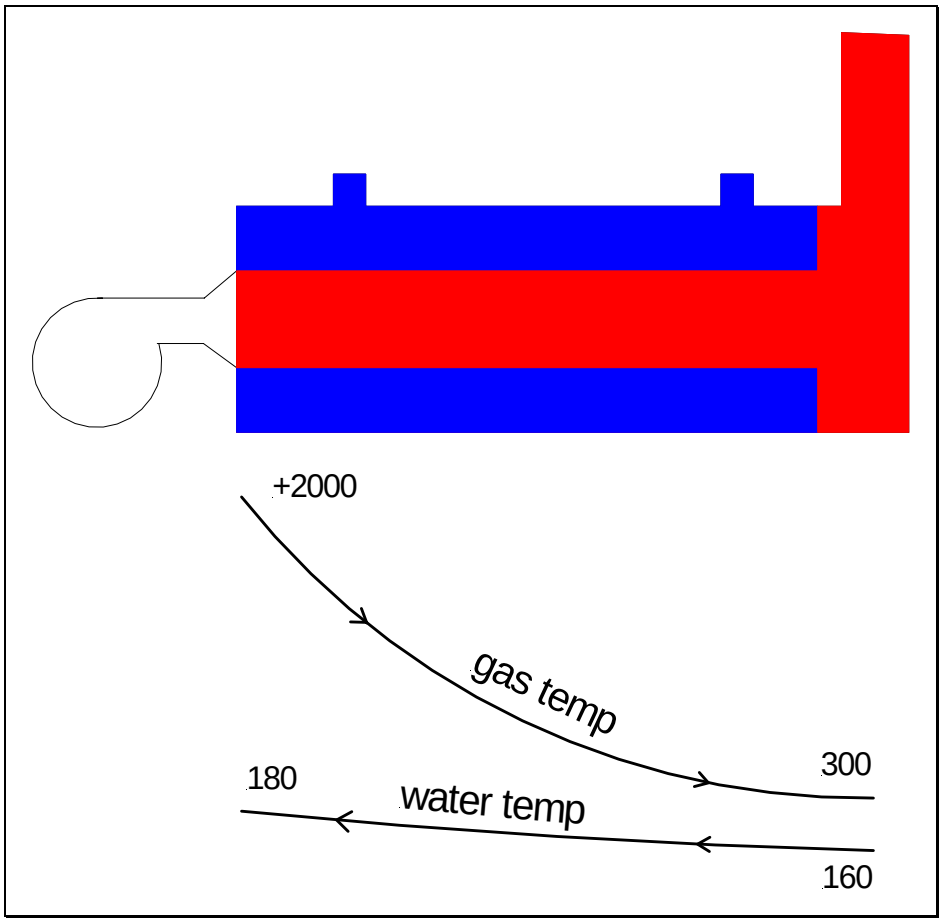
102 % efficient boiler : how does that work?

I'm sure you've noticed that certain manufacturers are offering natural gas fired boilers with up to 99% efficiency. That is impressive indeed!

Any boiler can be run at 99% efficiency. We could even set one up to run at over 100% efficiency with the right conditions. How does that work?

Below is a sketch of what happens in a boiler:



The hot combustion gas gets cools as it contacts the relatively cold boiler wall temperature as is passes through the boiler. About 12% of the potential heat in the combustion gas from burning natural gas is in the form of water vapor. So unless water vapor condenses, giving up its latent heat energy to the boiler water, the maximum efficiency cannot exceed 88%. Obviously to get the 99% efficiency advertised, nearly **ALL** of the water vapor must condense.

Condensation occurs when the water vapor molecules contact a surface below the dew point. The entering and leaving water temperatures in the boiler in the sketch above are both above the dew point, somewhere around 125^{o}F. Therefore NO condensation is possible. It doesn't matter if there are countless water vapor molecules or just one single one.

To increase the efficiency above 88% there must be condensation of water vapor in the flue gas. In order to condense that water vapor, there must be metal temperatures below about 125^{o}F. To get that cool metal temperature, colder water must be introduced into the boiler.

The colder the water, the more water vapor is condensed and the higher the efficiency becomes. But only to a point; there are other factors.

The goal of boiler designers is to have each flue gas molecule hit a metal surface to give up heat energy. Turbulators, baffles, pins and other items are used to help reach that goal. The time a flue gas molecule spends inside the boiler also increases its chance to hit metal too, so surface area is used to help as well. Obviously trade-offs are used or the boiler cost would soar out of control.

Let's say that there are a zillion molecules of flue gas and only an extremely small surface of cold metal. There won't be much condensation.

Let's say that there are only a few molecules of flue gas and an enormous surface of cold metal. Perhaps ALL of the water vapor will condense.

There are fewer flue gas molecules put into the boiler when on low firing rates compared to high rates. Therefore there is a smaller velocity and longer time for a given molecule to bounce around in the boiler. But because there is turbulence built into the boiler, there is a greater chance of a water vapor molecule to hit cold metal. More water vapor condenses at lower firing rates and higher efficiency results.

To achieve higher than 88% efficiency in a boiler, there must be cold water brought into it. ANY boiler will be a condensing boiler when you bring cold water into it! ANY boiler can operate at even 102% efficiency if the water temperature is say 40^{o}F and the firing rate is low enough. With that condition, the flue gas can be lower than the incoming air and fuel temperature: thus efficiencies over 100%.

While that might be good, the water temperature will be too low to do any sort of heating and unless the boiler is constructed of proper materials it will rust and otherwise corrode to the point of uselessness as well.