

CONDENSATION WITHIN BOILERS

(and dew point calculation)

Through the years, we've encountered a variety of claims that relate to potential dangers to consider in boiler system design. This report will address condensation of flue gases.

The claim has been made that in a high pressure steam boiler, if the burner turndown exceeds 2 to 1 then there will be condensation of flue gasses and the boiler will be destroyed within a couple of years. Can that be true? {It should be noted that many of these same vendors now offer burners claiming to have a 10:1 turndown ratio}

Condensation is a thermodynamic process whereby moist gasses condense on a surface that is below the dew point temperature.

That is true of the windows on your dwelling and it is true in boilers as well. In your house, you've noticed that the colder the outside temperature is, the more condensation you get on the windows. When the temperature is hot outdoors, there is no condensation on the windows. The same phenomenon is true for equipment that contains products of combustion. Surfaces with a temperature above the dew point cannot have condensation on them.

With that said, can the dewpoint temperature of products of combustion be found? Sure, that is covered in first year thermodynamics at any Mechanical Engineering school. Attached is a sample calculation for natural gas that shows a dew point of 131.3 F.

Now what is hard to determine is how there can be condensation in a high pressure steam boiler. At 100 psi, the water temperature in the boiler is 338 F. Since 338 F is well above the 131.3 dew point, it not possible to have condensation. The turndown of the burner can be infinite in this case!

Where condensation in a boiler is possible is in water boilers. Every water boiler manufacturer lists what the minimum return water temperature. The reason is fairly obvious because the colder the temperature the water is, the colder the boiler tubes will become. When the tube temperature becomes at or below the dew point temperature, there will be condensation.

If the set point temperature in a hot water boiler is too low, say 120°F, then the exit temperature of the gas can be cooled to below the dew point. Burner turndown has nothing to do with this, only the gas temperature versus the dew point temperature.

The key to discovering whether the boiler is condensing or not is therefore to know three items; the dew point of the fuel being burned, the stack temperature and the lowest temperature anywhere in the boiler.

The dew point of the fuel depends on several factors but can be calculated.

Assume natural gas (considered methane CH_4 for this discussion) is burned in clean dry air. The flue gas analysis shows by molar analysis that the products on a dry basis are $\text{CO}_2 = 9.15\%$, $\text{CO} = 0\%$, $\text{N}_2 = 86.85\%$, $\text{O}_2 = 4\%$.

On a 100 lb-mol basis the combustion equation reads:



Applying conservation of mass to hydrogen, carbon and oxygen:

$$\text{C: } 9.15 + 0 = a$$

$$\text{H: } 2c = 4a$$

$$\text{O: } (2)9.15 + 0 + (2)4 + c = 2b$$

Solving for this set of equations $a=9.15$, $b=22.45$. and $c=18.6$

Put back into the original equation the mole fraction of the water in the combustion products is 18.6%.

To determine the dew point of the water in the products we need to determine the partial pressure of the water vapor, p_v . p_v is determined using the formula $p_v = y_v p$, where y_v is the mole fraction of the water vapor and p is at the pressure the combustion takes place, we will assume atmospheric pressure. Thus

$$y_v = 18.6 / 100 + 18.6 = 0.157$$

Atmospheric pressure is 14.696 psi, therefore the partial pressure $y_v = 0.157(14.696) = 2.31\text{psi}$

Interpolating from properties of saturated water table we can find the dew point of the gasses:

Temperature	Pressure
130 °F	2.225 psia
	2.31 psia

140 °F

2.892 psia

solving for (dew point):

$$(\text{dew point}) = (2.31-2.225)/(2.892-2.225) * (140-130) + 130 = \mathbf{131.3\text{ }^{\circ}\text{F}}$$

So for this example as long as the stack exhaust temperature is above 131.3 degrees we will not have condensation of those flue gases. This also means that the inside wall temperature of the stack must be assured to be above 131.3 degrees until it exits the stack. The stack must be designed to not give up enough heat to allow the flue gas temperature to drop from the exhaust temperature to 131.3 degrees throughout its run since most modern stacks are at minimum double wall insulated this is not difficult.