USE OF IMPROVED COMBUSTION TECHNOLOGY TO REDUCE UNBURNED CARBON

What is combustion? It is a complicated chemical process. Perfect combustion would follow this simple chemical equation in which all the available hydrocarbons are reacted with oxygen to form carbon dioxide and water:

$C_nH_n + O_2 = CO_2 + H_2O$

However, there is no such thing as prefect combustion. In actuality the combustion process is never complete resulting in the formation of unburned carbon. Unburned carbon can be in the form of CO and/or unburned carbon particles. The only thing that can be done is to try to optimize the combustion process.

Dr. Goran Moberg, who obtained a doctorate in Fluid Dynamics at Chalmers University in Gothenburg, Sweden, realized the importance of good combustion in a furnace when he started work for Petrokraft, Sweden designing low NOx burners. For improved combustion it is necessary to improve the three T's: time, temperature and turbulence. In other words the retention time should be increased, the temperature should be more evenly distributed, and the turbulence should be increased.

When you plot retention time versus temperature, the combustion profile looks like this as shown in figure 1. You will note that as the temperature increases along with an increase in retention time, more NOx is formed. However, as the temperature is decreased and the retention time is decreased, the NOx generation is also decreased; however, CO is increased and unburned solids are increased. If you look at the bell curve, there is an area of optimum combustion where CO, unburned solids, and NOx generation are all at the best possible level.

Many utilities have gone to the use of low NOx burners to reduce NOx. Basically low NOx burners reduce NOx by making combustion less efficient resulting in an increase of CO and unburned solids. The combustion conditions end up in the lower left hand side of the graph. As you all know, CO and unburned solids are money going out the stack.

What you want to do is get most of the conditions in the furnace in the optimum combustion zone. You want to change the bell curve to get as much of the retention time and temperature distribution in the optimum combustion zone as shown in figure 2. When you do this, combustion is improved in the furnace resulting in:

1. Reduced CO
2. Reduced unburned solids
3. Reduced NOx generation

Okay, how do you shift the combustion in the furnace to the optimum zone? You create turbulence. Not a small amount of turbulence but a lot of turbulence to obtain a much better mixing of the fuel and air. This better mixing improves the chance for complete combustion.

When you improve turbulence, you

1. Increase the retention time in the furnace
2. Distribute the temperature more evenly through out the furnace
3. Give the fuel and air a better chance to react with the necessary oxygen to complete combustion
4. Reduce the generation of CO
5. Reduce the amount of unburned solids
6. Reduce the formation of NOx

As a result of his experience in designing low NOx burners, Dr. Moberg designed a process to improve combustion in the furnace that he called ROFA or Rotating Opposed Fire Air. ROFA has been installed in 19 furnaces in Sweden and 1 furnace in the USA. ROFA is patented in the USA.

ROFA is different than OFA. With ROFA high velocity air is introduced into the furnace as close to the nose as possible. This high velocity air is introduced into the furnace through ROFA boxes. Each ROFA box has between 3 to 5 nozzles that penetrate the furnace only as far as the water wall. The high velocity air is supplied to the ROFA boxes by a booster fan. The air to the booster fan is taken from the secondary air supply. Between 20 to 30% of the secondary air to the furnace is diverted to the booster fan. The stoichiometry is about 1.0. The ROFA boxes are place asymmetrically on the furnace to create a swirl in the furnace. These boxes are at two different levels on the furnace and there will be either two or three boxes on opposite sides of the furnace. The placement of the ROFA boxes on each furnace is determined from the results of a CFD.

The ROFA boxes do the following:

1. Create a large amount of turbulence in the furnace resulting in better mixing of the fuel and air.
2. Increase the retention time in the furnace
3. Distribute the temperature more evenly through out the furnace.
4. Supply oxygen to the upper part of the furnace to complete combustion.

All these actions result in:

1. Reduced CO
2. Reduced unburned solids
3. Reduced NOx

The same ROFA system can be used to inject urea or ammonia into the furnace to reduce NOx further. Because of the mixing action created by the ROFA system, less urea or ammonia is needed. Also limestone can be injected through the ROFA system to reduce SOx and mercury. It is a multi-pollutant removal system.

These are pictures of the ROFA installation at the Cape Fear Station operated by Carolina Power and Light. These pictures are of the booster fan, the ductwork from the booster fan to the ROFA boxes, one ROFA box at the upper level, and two ROFA boxes at the lower level.

Here are the results obtained at various ROFA installations in Sweden and the one installation in the USA.

In summary unburned carbon can be reduced by improving the combustion in the furnace.

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