Air Monitoring
By Dario DiMaggio
Instrumentations, flow in particular

Emission

The Importance of accuracy in combustion measurements and why

Excess Air

Combustion Efficiency

Plants Operators
Coal and co-fire plants will be around for a very long time but because of climate changes any form of combustion using fossil fuel is now under the microscope.

It is important to note that emissions requirements when carbon fuel is present will continue to become more and more stringent as world expectations and awareness increase.
first waves of refurbishing upgrades started right after the implementation of the EPA 1992 POLLUTION PREVENTION ACT which focused, among other things on the emission control of CO2 and NOx in order to prevent the formation of acid rain.

This Act forced gradually all combustion plants to install CEM stack emission’s systems or Continues Emission Monitoring.
These systems started to get installed on all emission stacks to deliver a basic snapshot of what was the rate of emission into the atmosphere.
Waste Incineration Monitoring System

- Emitter
- Power supply
- O₂ monitor
- Receiver
- Temperature
- Pressure
- Dust
- Flow
- Thermo FID MV, VOC
- Fibre optic cables
- Data logging system
- Analyser cabinet in monitoring room

UV DOAS: NO, NO₂, SO₂, NH₃, Hg, etc.
IR DOAS: CO, CO₂, HCl, HF, H₂O, etc.
A CEM is like a thermometer for a patient....will show only the status of his sickness, but not the cure.

If we want to imagine a coal fire plant as a sick patient we can envision the plant stacks CEM’s system as a thermometer in the mouth of the patient testing his temperature.

Unfortunately this will only define his sickness without providing any diagnose, cure nor solutions for the sick patient.
Solutions like:
Installation of low NOX burner
Flue Gas Recirculation
Fuel stage
Stage combustion
all designed to break down the boiler’s temperature into stages to avoid reaching the very high temperatures that would increase NOx.
The first phase of improvements, in the 90’s included the upgrading of the boiler’s primary air intake by removing old and antiquated air measurement devices to make sure the air/O₂ measurement in the first stage of combustion was accurate.
Nice TUBE work, but also 8 hour of preventive Maintenance time a month!
In order to provide reliable data for an accurate Air/Fuel ratio calculation key for efficiency as the first stage of the combustion process.

Major exhaust gas components vary as the air/fuel ratio changes. Stoichiometry coincides with maximum CO₂, the best measure of combustion efficiency. Lean mixtures are characterized by higher O₂ concentrations, while rich mixtures signal their presence by elevated CO levels.
During the second phase of refurbishing, the concentration was mainly in the installation of systems that could remove the harmful gases chemically, systems like:

SCR, SNCR, ESP, FGD, Fabric Filters and later Mercury Control devices. Great and expensive methods which sounded perfect to the point of making plant managers skip to the second phase bypassing the first one altogether, especially outside the united states where many countries are still struggling with phase one, or even worse didn’t even started any form of refurbishing or upgrades.
What is combustion?
Combustion is the correct amount of fuel and Oxygen in the form of air which chemically combined produces heat and with heat energy.

The final objective is to reach a complete burning of the fuel with the precise amount of Oxygen reaching what is called a perfect stoichiometric combustion.

Under these conditions there is no more fuel left to burn, meaning zero Oxygen needed.
Reaching a stoichiometric combustion it’s impossible and can also be dangerous to be on the safe side the operators, depending of the fuel used do increases the air (Oxygen) to a pre-set point above, and historically much beyond the stoichiometric point, generating in the process what we call **EXCESS AIR** in the flue gas.
The reason why monitoring Air/O₂ becomes so important is because excess oxygen not consumed during combustion will absorb usable heat and carried away in form of stack losses.
Across the length of the plant excess air in the form of flue gas can be a good indicator of many things, like:
Incomplete combustion (Rich) if the CO registers high readings or can indicate the wrong amount of O2.
The monitoring of O₂, for instance if reduced only of 1% in the flue gas can increase the efficiency of about 2.5%
this can be an immediate way to reduce fuel costs and atmospheric emissions at the same time.

1% efficiency can be worth up to $500K in annual savings.
The monitoring and the controlling of excess air is a primary way of optimizing boiler’s efficiency.
A gas turbine with an O₂ inaccuracy of .5% at 15% gives an error of about 10% in reportable NOx reading.
EXCESS AIR OPTIMIZATION IMPROVES EFFICIENCY

Operators recognize the importance of using the right instrumentation for measuring combustion air and flux gases for maintaining the optimal conditions that meet operation efficiency and emissions requirements. By replacing inefficient or error prone Pitot Tubes, Venturis, or single-pass Ultrasonic tools with Kurz thermal instrumentation, it becomes much easier and more cost-effective to design and maintain your combustion control system while saving potentially hundreds of thousands of dollars per year in maintenance costs.

Oxygen (O₂) and carbon monoxide (CO) concentrations are the primary indicators of combustion efficiency. All carbon in the fuel converts into Carbon Dioxide (CO₂). A high concentration of CO indicates incomplete combustion, while a high concentration of O₂ suggests too much Air through the primary intake to the burners.

The O₂ and CO in the flue gas are critical parameters and require monitoring throughout the combustion phases. Reducing the Oxygen level in the flue gas from 5% to 4% translates into an efficiency gain of about 2.5%.

A 0.5% error of O₂ reading (for example, from 15% to 15.5%) will result in a rise of about 1% in reportable NOₓ.

1% Efficiency can be worth up to $500K per year in savings.

WHAT IS EXCESS AIR OPTIMIZATION?
It is controlling and minimizing heat losses and improving combustion efficiency by reducing excess air to the Stoichiometric point. There are three ways to achieve excess air optimization:
- Control Primary Air to the burners
- Control induced draft leaks by checking all air leaks or drawn into the system due to vacuum caused by induced drafts
- Control the amount of air drawn into stacks causing stack draft leaks

Getting the right measurements with enough instruments will provide the operators with an accurate breakdown of the needed data like the precise amount of O₂, CO, SO₂, Excess Air and Temperature all data sometimes complicated and expensive to extract.
In the old days it was easy, the only thing the operators were concerned with was how much air they can blow into the boiler to make sure that every trace of fuel was burned, they didn’t care what was coming out of the stacks.
WHY THEY WANT TO MEASURE PRIMARY AIR FLOW ACCURATELY?

Magical Figures

AIR = 79% Nitrogen and 21% Oxygen
(RATIO BETWEEN NITROGEN and OXYGEN is 3.76)

1 Lb. of Carbon Needs 2.67Lb. or 32 FT$^3$ of O$_2$ which is 153 FT$^3$ of air to burn

1 Kg of Carbon Needs 2.67 Kg or 1.8 M$^3$ of Carbon which is 9.52 M$^3$ of Air to burn.

FT$^3$ (AIR) $\times$ 21 % - 32 CFM = O$_2$ % Volume

Example: 18250 FT$^3$ of AIR / 153 x .21 = 25% O$_2$ in Excess Air

The Air/Fuel Ratio:
Gasoline is 14.7:1,
Methane 9.53:1,
Hydrogen 2.38:1.

With the fuel change the A/F Ratio will change as well especially in the case of coal or biomass fuels.
Obtaining reliable Oxygen and other gases measurements is fundamental in combustion facilities, but not easy. Most of the plants have few and randomly located oxygen sensors, which rarely match the stack’s CEM’s Oxygen transducer. This is simply because, for a variety of reasons O2 readings do change as Oxygen travels with the Excess air through the plant. The changes are due to possible drafts, leaks, portals left opened, and many other factors, making the accurate monitoring of O2 even more important.
In Biomass or Cofiring boilers, combustible like CO emissions can be reduced by improving the control over the combustion process. For instance the most important characteristic of wood in reference to the CO emission is the moisture content. Tests with both types of wood chips and sawdust shows that between the excess ratio and the level of power facilities the optimization can minimize the CO by varying the excess air ratio relative to the power demand.

\[
\text{% Combustion Efficiency} = \frac{\text{CO}_2}{(\text{CO}_2 + \text{CO})} \times 100
\]

\[
\text{% Excess Air} = \frac{\% \text{O}_2 \text{ Measured}}{(21 - \% \text{O}_2 \text{ Measured})} \times 100
\]

To minimize emissions and optimize efficiency, the excess air ratio, the air distribution systems, and the fuel feed rates must be adjusted to maintain stable and efficient combustion.
So the excess air becomes the blood and life of a combustion facility carrying with it all the good and bad signs. We should display and accurately monitor the excess air composition all the way across a plant from the Air intake to the stack and to the atmosphere:

EXCESS AIR DNA

- CO₂
- O₂
- NOx
- CO
- SO₂
Too much air would translate into too much NOx and less CO2, while too little air would generate more CO2 and less NOx, creating the possible setting for a controllable balance between NOx and CO2, but with no reliable data or instruments the task becomes very challenging, if not impossible.
Unfortunately until recently it was unpractical to accurately measure flue gas, but now with new technologies available there are new and easy approaches to solve these challenging measurement.
Can you imagine having access to accurate CO, CO2, NOx, O2 or SO2 gas readings at multiple points across the plant and at any given moment of the day or night? Think of the possibilities. Operators would know immediately what to do and react instantly if they feel they are not with-in an optimum condition.
Our young engineers and future operators are graduating and join the work force with inadequate knowledge regarding combustion efficiency or in how to achieve efficiency in power plants in general.
They have also a very limited familiarity with the latest technologies and instrumentations, although having intimate knowledge with the theory, and they can easily mathematically calculate stoichiometric, Air/Fuel ratios, excess Air or efficiency.
Unfortunately we also graduate with a modest and a very low understanding regarding possible type of instruments needed in the monitoring of combustion applications, devices that can provide the best measurements, or perhaps a proper standardized design for boiler’s air duct system, which unfortunately contrasts greatly from one plant to the other, or where to install O2 sensors and which type, or if stage combustion is necessary?
Maybe Flue gas re-circulation? Although boilers or burning chamber design reflects standard requirements all the rest do not.
Each plant is its own ship with its own captain sailing his own sea.

Future operators should have a familiarity in mechanics, flow mechanics, instrumentations and chemistry in reference to combustion and efficiency conservation, but no classes are dedicated to applied combustion efficiency or plant efficiency in general.
Our texts are antiquated when it comes to the latest and greatest regarding techniques on how to improve efficiency and emissions.

In most cases university texts are still emphasizing 18th century technology concerning flow measurements.
Henri Pitot Invented the Pitot Tube in 1732

Great in laboratories, but it should be outlaw in combustion measurements.
Gian Battista Venturi Invented the Venturi in 1797 Published the Venturi Effect

The Venturi restriction in the above picture may cost the end user more than $100K per year in extra energy consumption.
In 1814 George Stephenson Invented the Steam Locomotive

A piece of history although revolutionary at the time belongs now in a museum.
Cars are 25 years ahead in combustion efficiency, the Principle is identical
Why we don’t have fully integrated control system like cars do? Perhaps we can have it.
Fuel Injectors in a car is non other than Stage Fuel in power plant.
Cars are many years ahead regarding the efficiency of Combustion Measurements

The lack of smart controls on the market maybe can be blamed to the possible technological challenges
A PACKAGE OF KURZ METERS TO MEASURE AIR INTAKE, FUEL, SECONDARY, FGR WILL PROVIDE ENOUGH INFORMATION TO MANUALLY OR AUTOMATICALLY CONTROL THE AIR FUEL RATIO EMPIRICALLY. A STEP THAT CAN SAVE HUNDREDS OF THOUSANDS OF DOLLARS BY JUST IMPROVING EFFICIENCY.
EFFICIENCY IMPROVEMENT

Air/Fuel Ratio changes drastically as the fuel changes, but this can be very elusive for a variety of reasons including inadequate mixing of air fuel, burner performance, ambient conditions, wrong air or fuel measurement or when biomass fuel is used.

Our system will allow the operators to keep the EXCESS AIR under control by measuring the $O_2$ and at the same time the amount of combustible in the flue gas which is a direct sign of the amount of excess air and of a total and complete combustion in the flue gas.

Strategically placed across the plant these instruments can provide the operator with an accurate measurements of the flow, temperatures and a variety of selectable...
BUT HERE

Optimization should not begin here

Rather, work from the bottom up
The Solution in Combustion Measurements

Kurz Introduces the first Permanent Flue Gas Efficiency Meter

For the first time ever it will be possible to install through one port a permanent meter capable of measuring:

FLOW, TEMPERATURE, O2, CO, CO2 AND OTHERS GASES FROM A SINGLE PORT.

We measure across the complete pipe or duct section taking into account the flow stratification.

40 Years at Work....
1% efficiency can be worth up to $500K in annual savings.

Whatever improvements will be implemented in order to increase efficiency it will be beneficial, because ultimately it can pay itself in few months.