Adam C. McClellan, P.E. and Shawn P. Cochran, P.E., Storm Technologies Inc., US, explain why remembering the fundamentals can yield cost-effective results in coal combustion.

Firm foundations

This article presents three case studies that illustrate how applying the fundamentals and fine-tuning furnace inputs can result in improved efficiency, reduced emissions, increased capacity, better turn down, reduced slagging, reduced fouling and improved fuel flexibility and reliability in coal combustion.

Most of the world's coal-fired power generation is from pulverised coal. Excellence in pulverised coal combustion begins with applying 13 essential principles. However, in many cases, even experienced engineers from major OEMs can overlook or disregard these.

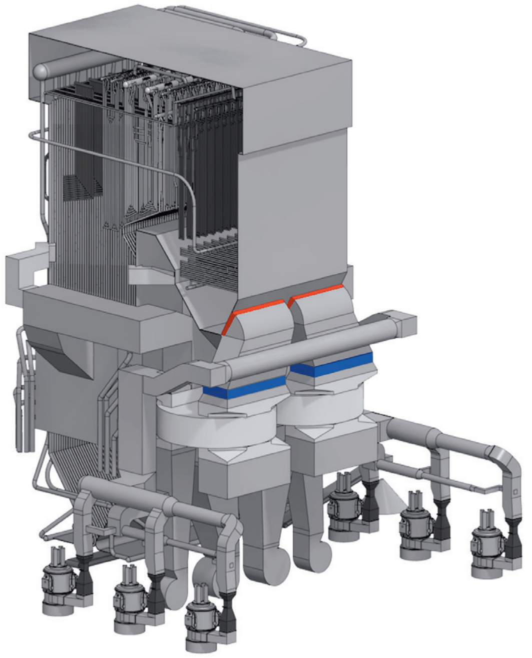


Figure 1. The area highlighted in red is the expansion joint at the economiser outlet.
The area highlighted in blue is the usual location of oxygen analysers, immediately before the air heaters. The problem here is that, when the boiler setting is negative pressure and not airtight, tramp air can leak in, which is measured by the analysers and assumed to be the oxygen level of the furnace.

Figure 2. Massive air in leakage path made possible by the coal ash erosion of the thin metal expansion joint at the economiser outlet flue gas location, upstream of the boiler oxygen analysers.

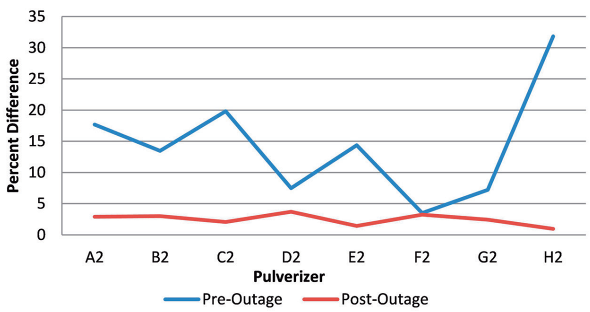


Figure 3. Primary air flow measurement accuracy pitot tubes vs. venturi.

Storm Technologies lists the following as 13 essential principles:

1. Furnace exit must be oxidising preferably 3% free oxygen.
2. Fuel lines balanced to each burner by "clean air" to within ±2%.
3. Fuel lines balanced by "dirty air" using a dirty air velocity probe to within ±5%.
4. Fuel lines balanced in fuel flow to within ±10%.
5. Fuel line fineness shall be 75% or more, passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%.
6. Primary airflow shall be measured and controlled to within ±3% accuracy.
7. Overfired air shall be measured and controlled to within ±3% accuracy.
8. Primary air-to-fuel ratio shall be accurately controlled when above minimum airflow set-point.
9. Fuel line minimum velocities shall be above 3300 ft/min (100 m/min).
10. Mechanical tolerances of burners and dampers shall be within ¼ in. or better.
11. Secondary air distribution to burners should be within 5%.
12. Fuel feed to the pulverisers should be smooth during load changes, measured and controlled as accurately as possible. Load cell-equipped gravimetric feeders are preferred.
13. Fuel feed quality and size should be consistent. Consistent raw coal sizing of fuel to the pulverisers is a good start.

This article provides some examples of commonly found opportunities for improvement, documented for coal units on which the authors have been involved.

Case studies

Corner-fired boiler

A 500 MW corner-fired boiler experienced a problem with slagging at the superheater. The cause of the problem was a reducing atmosphere environment in the furnace. The first essential principle advises an oxidising furnace of at least 2% (and preferably 3%) free oxygen at all points. So why is this occurring? The vast majority of units are designed for at least 3% free oxygen in the furnace. The ageing fleet of coal units in the US has significant leakage of ambient air into the boiler setting and the oxygen analysers are almost always located at the economiser outlets.

Figure 2 is an example of an expansion joint failure that allowed the equivalent of 15% of the total boiler airflow to leak into the boiler outlet flue duct as tramp air. This is air that leaks into the boiler setting but too late to contribute to the combustion process.

The next most common problem is inaccurate combustion airflow measurement and control. The interesting chemistry of combustion is that all of the coals around the world, when fired at 15% excess air, will require within ±5% of the same amount of combustion air. That is 850 lb of air/million Btu (1 t/653,275 kcal or 1.53 g/kcal).

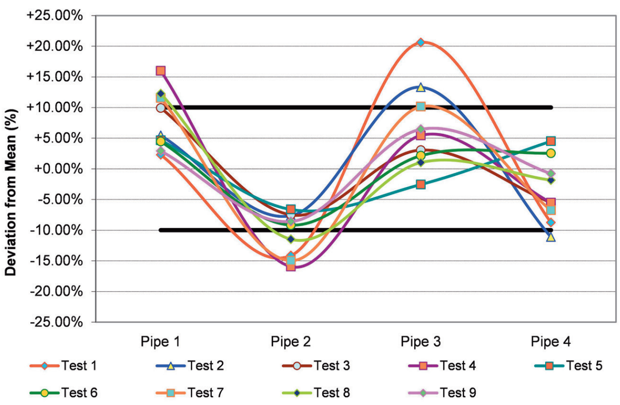
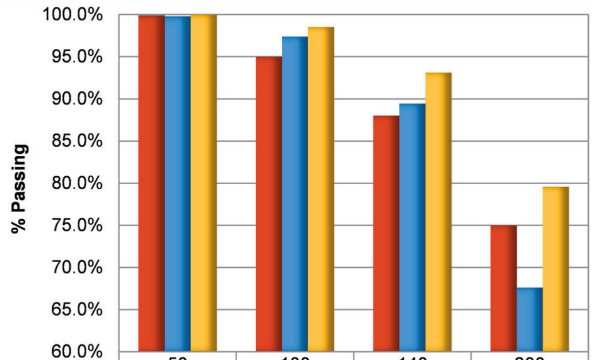


Figure 4. Fuel balance vs. air-to-fuel ratio.



	50	100	140	200
Recommended	99.9%	95.0%	88.0%	75.0%
Test 1	99.8%	97.4%	89.4%	67.6%
Test 2	100.0%	98.5%	93.1%	79.6%

Figure 5. Fuel fineness improvements.

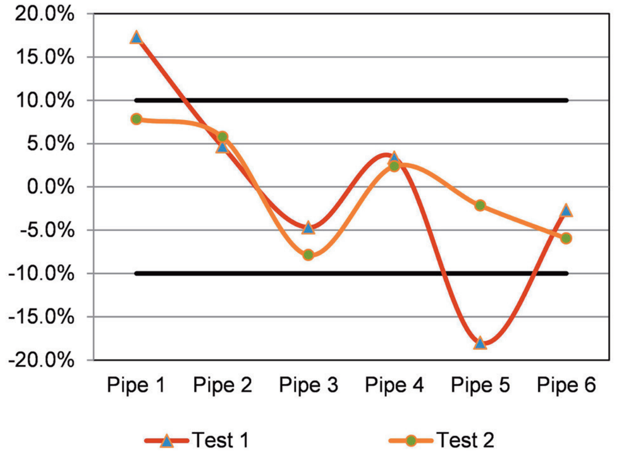


Figure 6. Improved fuel distribution from fineness improvements in Figure 5.

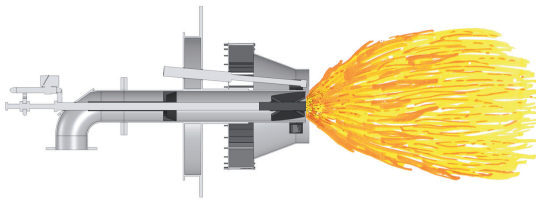


Figure 7. The short intense flame burner of 1970s design.

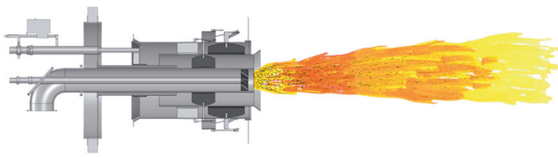


Figure 8. The long flames from a modern low NOx burner.

Airflows are often found to deviate by as much as 30% from the indicated quantity. In the first example, the common problem of measuring the excess oxygen at the airheater inlet only to find out that it may be a flawed reading because of tramp air-in leakage was described. That is, the airflow quality might actually measure 3% excess oxygen at the location of the oxygen analysers but, because 15% of the air leaked into the boiler setting after the flames were cooled below the ignition temperature of carbon char, then the last 15% of cold air leaking into the boiler convection pass is measured by the oxygen analysers but does nothing for combustion: hence the term tramp air.

What about airflow measurement to the pulverisers, windboxes and overfire air? This is another recurring problem, but one that is correctable.

Here are some examples of how the indicated airflow in an otherwise well run and well maintained coal-fired power plant can be in error by as much as 30% when compared to carefully conducted and accurate hand velocity traverses.

Wall-fired boiler

This case study involves a 500 MW pulverised coal utility boiler with wall-mounted low NOx burners. It is an example of primary airflow measurement and control discrepancies on a pulverised coal-fired boiler.

The primary airflow for wall-fired boilers is more critical than corner-fired combustion. The difference is that, in a corner-fired furnace, combustion is completed in the furnace as a mass burn, in which the entire furnace is the burner. The fuel and air are injected from the corners and the resulting fireball utilises the entire furnace. Therefore, the individual burners are not as likely to create extremely fuel-rich and air-rich streams of products of combustion at the furnace exit. This is not to say applying the 13 essentials on corner-fired units is not important. However, the mass burn furnace is more forgiving of fuel and air imbalances and high primary airflows than wall-fired boilers.

During the pre-outage testing shown in Figure 3, the difference in primary airflow between actual measured flow and the indicated flow ranged from 3.5% to upwards of 30%. Since primary airflow plays such a crucial role in the performance of the pulveriser and the pulveriser's capability to provide optimum fuel balance and fineness to each burner, primary airflow must be accurately controlled and managed. As a result of the pre-outage test results, over the next two years the pitot tubes were slowly replaced with venturi measurement devices designed by Storm Technologies. The deviation between the indicated and measured flows improved to within 3% on each pulveriser.

The primary airflow greatly affects the performance and reliability of the pulveriser and burners. Too little primary airflow, as a result of inaccurate measurement or non-optimum air/fuel curves, can result in increased coal spillage and coal layout in the horizontal runs (including the burner nozzle), which can result in burner line pluggage and, possibly, burner or mill fires. High primary airflow can hinder good fuel balance and fuel fineness and increase wear in the pulveriser, fuel lines and burners, as well as increase secondary combustion. Increases in secondary combustion can lead to elevated furnace exit gas temperatures, increased slagging and fouling, as well as increased NOx. Figure 4 illustrates the improvements made to fuel balance on a pulveriser with four fuel lines by simply lowering the air-to-fuel ratio. Test 1 had the highest air-to-fuel ratio, while Test 9 had the lowest air-to-fuel ratio that could be achieved.

A third commonly found opportunity is fuel fineness. Most combustion experts – and even some OEMs – do not recommend fuel fineness levels of $\geq$75% passing a 200 mesh sieve. However, Storm Technologies has found that, even with such a highly reactive fuel as Powder River Basin (PRB) coal, increased fineness is worth the auxiliary power, wear and attention to pulveriser mechanical tolerances to achieve it. Three reasons for this are:

- Fuel balance is improved when fuel fineness is greater.
- Because of improved fuel balance, the excess boiler air can be reduced to achieve the same unburned carbon in ash levels as previously experienced with poor fuel fineness.
- Low NOx burners perform more effectively because about 75% of a pulverised coal unit's NOx production is from the fuel bound nitrogen. Improved fineness helps improve performance of well designed low NOx burners.

MPS-89 coal pulveriser

Fuel fineness is affected by a number of variables in a pulveriser, including the HGI of the coal, spring pressures, grinding element and segment conditions, primary airflow, coal flow and classifier condition. Figures 5 and 6 illustrate before-and-after a classifier change and its effect on fuel balance and fineness. The classifier blades were lengthened to increase the spin and classification of the coal, which allows the fuel and air to behave in ways more similar to a gas than a two phase mixture. It should be noted that in previous years, until the classifiers were changed, the primary airflow had been controlled accurately with a venturi designed by Storm Technologies and the clean airflow was balanced to within 2%. Fuel balance to within 10% had not been achieved until fuel fineness levels increased to greater than 75%, passing 200 mesh with the installation of extended classifier blades.

Conclusion

Applying the basics may seem unnecessary with modern electronic controls, flow transmitters, neural networks and other contemporary improvements. However, in the authors' experience, the fundamental principles are more important than ever – specifically, the 13 essentials listed at the beginning of this article. The most advanced low NOx combustion systems are a perfect example. Figures 7 and 8 compare a conventional burner from the 1970s to a contemporary new variation on low NOx burners with the latest technology. The difference is that the contemporary low NOx designs deliberately separate the air from the fuel. This separation occurs both within the burners themselves and also with the injection of portions of the combustion air as overfire air, curtain air or underfire air. With less than 2 s of residence time to complete combustion, these divided airstreams can result in excessively long flames. The furnace exit gas temperature has been elevated by as much as 1000°F (556°C) above optimum. The high temperatures due to non-optimised burner belt conditions have been corrected on many boilers by applying the 13 essentials.

Storm Technologies recommends getting the inputs right and applying the 13 essentials to begin with. These fundamentals will help whatever the goals: optimising combustion for minimum furnace production of NOx, reducing stack CO, fuel flexibility, efficiency, slagging, reliability or overall plant heat rate.