"A Comprehensive Common Sense Approach to Low NOx Combustion in Pulverized Coal Fired Boilers"

Authors: Richard F. Storm, P.E.
Thomas J. Reilly
Danny S. Storm
All of Storm Technologies, Inc. Albemarle, N.C.

Each year electric power generation is becoming more and more competitive. It has become a difficult task for many utilities to operate at high load factors with extended time between outages and remain within the strict state emission limits. Typical challenges which utilities face every day are as follows:

- High Loss On Ignition (L.O.I.) or unburned carbon
- High or stratified flue gas temperatures at furnace or economizer exit
- Slagging and fouling
- High de-superheating spray water flows or low steam temperatures
- False oxygen indications (inadequate oxygen at furnace exit)
- Poor airflow management of the primary and secondary airflow
- Stack opacity near limits
- Flame instability
- Tube metal overheating and re-occurring failures
- Inadequate fan capacity
- Inability to make rated capacity
- Poor control and response of load changes
- Poor coal fineness and distribution from pulverizers
- Difficulty in meeting emission compliance levels with efficient operation

Because of many inter-related factors, such as those listed above, a comprehensive approach is preferred in dealing with these previous items, rather than one specific solution, such as new burners. Low NOx burners are critical for achieving lower NOx, however they alone do ***<u>not</u>*** provide optimized combustion. Optimized fuel and air distribution is necessary for any low NOx burners to perform as designed. From the authors experience, there are "*<u>Twelve Essentials of Optimum Combustion</u>*" and these are a very useful check list to provide a comprehensive approach. These twelve essentials are as follows:

1st Furnace exit must be oxidizing (preferably 3%)
2nd Fuel lines balanced to each burner by "Clean-Air" tests within ±2% or better
3rd Fuel lines balanced by "Dirty Air" tests with a "Dirty Air Velocity Probe" within ±5% or better
4th Fuel lines balanced by fuel flow ±10% or better
5th Fuel line fineness shall be 75% or more passing a standard 200 mesh screen and less than 0.1% particles remaining on a standard 50 mesh screen
6th Primary airflow shall be accurately measured & controlled within ±3% accuracy
7th Air/Fuel ratio should be correct depending on the type of pulverizer
8th Fuel line minimum velocities shall be 3,300 FPM
9th Mechanical tolerances of burners and dampers shall be ± ¼" or better
10th Secondary air distribution to burners should be within ±5% to ±10%
11th Fuel feed to the pulverizers should be smooth during load changes and measured and controlled as accurately as possible (load cell equipped gravi-metric feeders are preferred)
12th Fuel feed quality and size should be consistent. Consistent raw coal sizing of feed to the pulverizers is a good start

These previous "Twelve Essentials of Optimum Combustion" have been tried and proven at many utilities and this paper will discuss several of these results of this comprehensive approach on different boilers.

Case Study of a Front-Wall Fired Boiler with Riley 1st Generation Low NOx Burners:

This comprehensive approach was applied on a unit with the first generation Riley low NOx CCV burner. This plant was originally equipped with C-E horizontal R-O type burners with a 20" I.D. coal nozzle tapered to a 15" I.D. at the nozzle exit. The primary air required for this large nozzle was around 24,000 Lbs/Hr per burner with a coal flow of around 6,650 Lbs/Hr. This calculates to a 3.6 Lb Air/Lb Fuel ratio, which is about two times the desired ratio for these Raymond 533 pulverizers. Pre-Modification tests were conducted and summarized as follows, the state limits are also shown:

As Found Pre-Modification Stack Test

Furnace Exit Oxygen	4.5%
Flyash L.O.I.	10.55%
NOx @ 3% Oxygen	680 PPM 0.95 Lbs/MMBTU
CO @ 3 % Oxygen	30 PPM 0.03 Lbs/MMBTU

State Limits For This Unit

Contaminant	PPM @ 3% O_2	PPM @ 7% O_2	Lbs/MMBTU	Lbs/Hr	Goals (Lbs/Hr)
SO_2	700	540	1.34	479.7	479.7
NO_2	440	340	0.62	220	160*
CO	26	20	0.02	7.38	7.38
THC	6.5	5	0.003	1.23	1.23
Particulate			0.084	30	30

* Only NOx (Lbs/Hr) was reduced as a goal for burner supplier

The previous test results shows that this unit was well above the regulatory limit. The guarantee for the low NOx burners and overfire air system were based on full load operation below the state limits and maintaining flyash loss on ignition (L.O.I.) of less than 6.0%.

The R-O burners were removed and Riley Low NOx Controlled Combustion Venturi (CCV) model 90 burners were installed. The overfire air system consisted of five openings on the front-wall above the burners in two compartments. The overfire air was controlled by two separate dampers to control the amount of airflow. The dampers could either provide 1/3, 2/3 or 100% of overfire air to the unit. The overfire air quantity could not be measured due to the arrangement and absence of test connections. The areas of the O.F.A. relative to the burners are such that at 100% opening, 15-20% of total airflow is estimated to be overfire air. Post "Low NOx Conversion" testing was performed with the new burners and overfire air system, the results are as follows (Note how Test No. 1 was borderline on NOx and both tests failed CO and L.O.I.):

Post Low NOx Conversion Testing Results Before Optimization Program

	Test No. 1 (No Overfire Air)	Test No. 2 (100% Overfire Air)
Control Room O_2	3.4%*	2.5%*
Measured O_2	6.2%*	5.7%*
Measured NOx	368 PPM	271 PPM
Measured CO	23 PPM	28 PPM
Measured Gas Temp.	784 F	782 F
NOx Corrected from Measured 3% O_2	448 PPM or 0.61 Lbs/MMBTU	319 PPM or 0.44 Lbs/MMBTU
Flyash L.O.I.	>10%	>18%

* Storm Technologies recommends oxygen be measured at furnace exit due to air infiltration

After obtaining these results, Storm Technologies started with the comprehensive approach by working to achieve the "Twelve Essentials of Optimum Combustion", some of which are as follows:

- Originally the Raymond bowl mills were operating above 3 Lbs air/Lb fuel ratio to control the coal spillage into the pyrite hopper. As the airflow was lowered the spillage became excessive. For this particular make of pulverizer, our experience indicates a preferred air/fuel ratio of 1.8 to 2.0 at the upper load points. The 1.8 air/fuel ratio was achieved with minimal spillage by reducing the throat area to keep the throat velocity around 7,000 FPM to keep the coal particles in suspension. The classifier blades were also freed-up and precisely timed. The authors have found that high primary air is usually associated with higher than expected NOx formation. This has been especially the case on wall fired boilers, the high primary airflow also reduces the coal fineness, which impacts the L.O.I. as well as the fuel distribution. Originally the fineness was found to be about 65% passing a standard 200 mesh sieve. Storm Technologies goal was to achieve fineness results of <0.1% on a standard 50 mesh sieve and >75% passing a standard 200 mesh sieve, some results are as follows:

Fineness Results After Throat Reduction and Classifier Timing

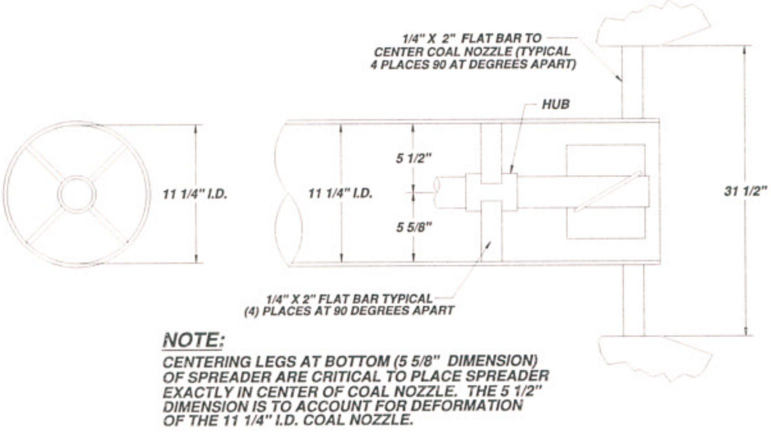
Test No.	1	1	1	1
Mill:	A	A	B	B
Pipe No.:	A1	A2	B3	B4
Classifier Setting:	3	3	3	3
% on 50 Mesh:	0.0	0.2	0.4	0.8
% thru 100 Mesh:	97.4	96.4	92.4	93.2
% thru 140 Mesh:	95.0	90.2	84.8	84.2
% thru 200 Mesh:	70.4	78.0	73.2	71.0

Fineness Results After Adjusting Spring Tensions & Increasing Mill Temperature

Test No.	1	1	1	1
Mill:	A	A	B	B
Pipe No.:	A1	A2	B3	B4
Classifier Setting:	3	3	3	3
% on 50 Mesh:	0.08	0.08	0.28	0.20
% thru 100 Mesh:	98.30	98.88	97.26	97.54
% thru 140 Mesh:	93.92	95.50	92.44	92.30
% thru 200 Mesh:	83.42	85.96	81.80	79.58

* Average mill fineness improved to >82% passing 200 mesh sieve and <0.2% on 50 mesh sieve

- A comprehensive inspection was conducted by Storm Technologies and some of the items which were addressed and completed are as follows:
  - Burner dimensions & tolerances set per Storm Technologies standards (see sketch below)



NOTE:

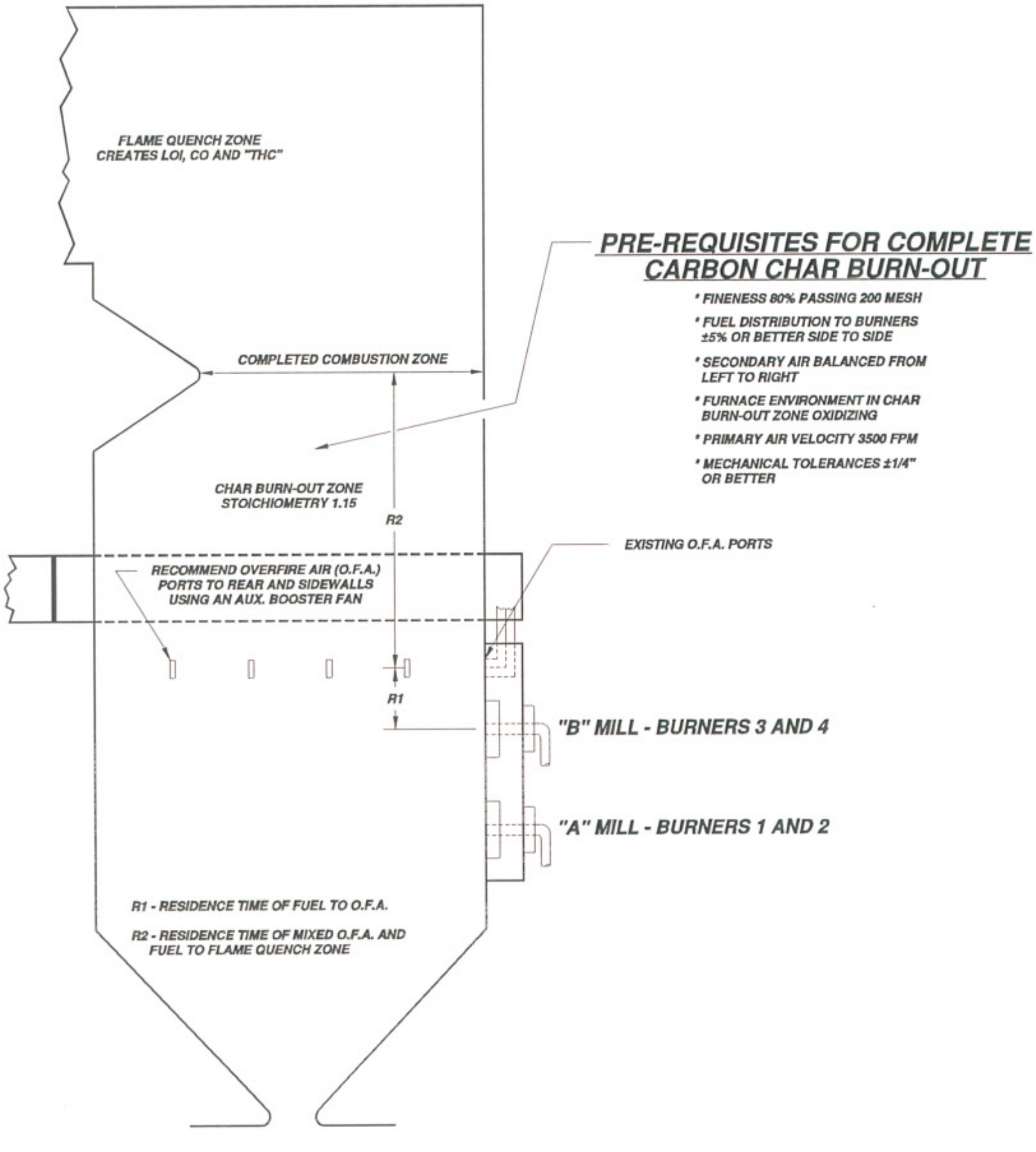
CENTERING LEGS AT BOTTOM (5 5/8" DIMENSION) OF SPREADER ARE CRITICAL TO PLACE SPREADER EXACTLY IN CENTER OF COAL NOZZLE. THE 5 1/2" DIMENSION IS TO ACCOUNT FOR DEFORMATION OF THE 11 1/4" I.D. COAL NOZZLE.

- Reduce air in-leakage at penthouse, nose arch dead air space and pulverizers
- Timed and stroked all registers, adjustable air sleeves and dampers
- Reset airheater seals to O.E.M. specifications

Upon completion of achieving and maintaining the *"Twelve Essentials of Optimum Combustion"*, this unit was capable of running at below the stack emission limits as well as L.O.I. remaining around 6%-7% (See the table of results below). Additional modifications are planned for the winter of 1996 to further reduce the L.O.I. to below 6% with Emission limits remaining below the State limits.

Results	1/3 Overfire Air Test
Measured NOx	0.50 Lb/MMBTU
Measured CO	9.1 PPM
Measured THC	3.1 PPM
Flyash L.O.I.	6.95%

Future recommendations to further reduce the flyash L.O.I. and remain with the compliance limits is to install a fan boosted O.F.A. system as shown in the figure below for more effective use of O.F.A.



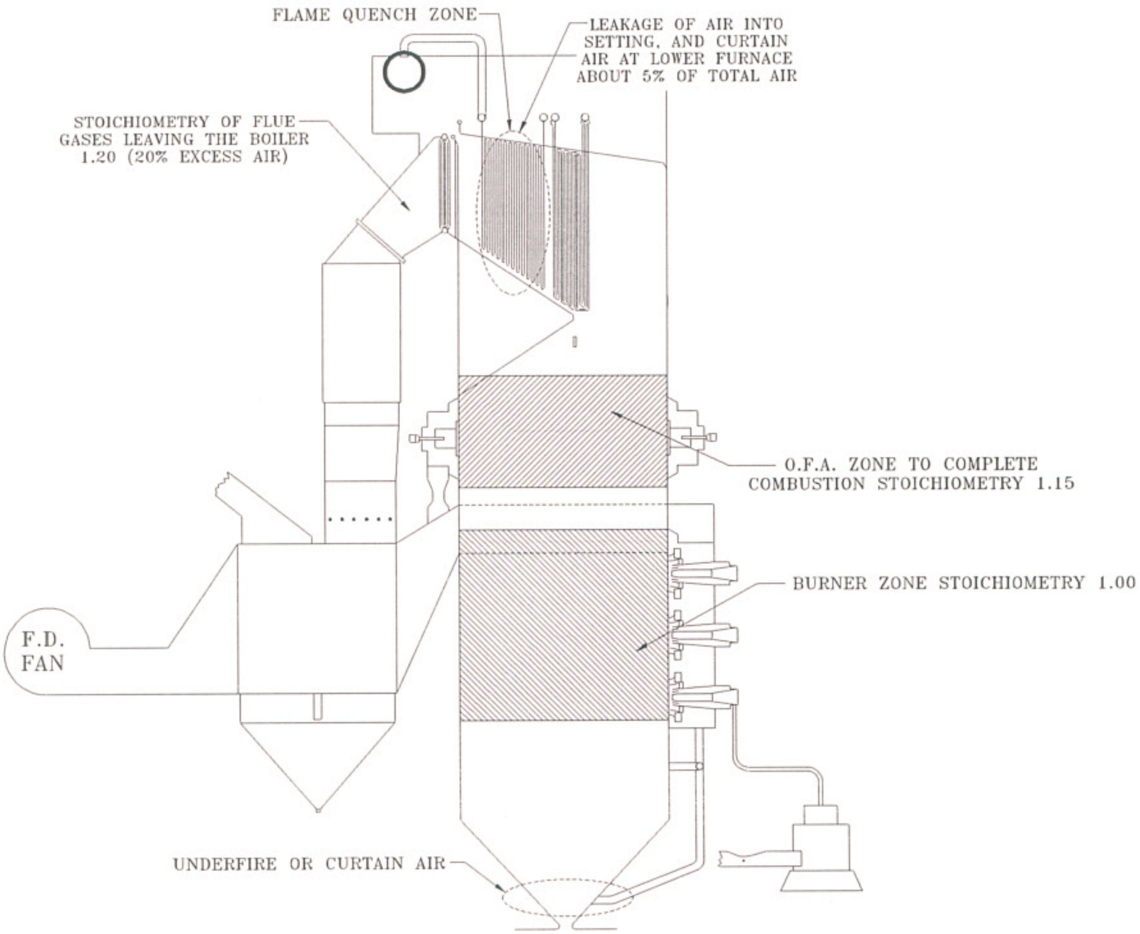
Case Study of a Front-Wall Fired Foster Wheeler Boiler with Low NOx Burners:

Another similar comprehensive approach was applied to two (2) 66 Mw Foster Wheeler boilers designed for low NOx firing. Initial baseline testing was conducted to determine the initial conditions of this unit and the results were as follows:

- Flyash loss on ignition levels of 9-10%
- High desuperheating spray flows of 70-80 K lbs/Hr
- Visibly high levels of carbon in the bottom ash
- Sporadic NOx values
- Poor flame quality resulting in unstable boiler operation

After determination of the baseline results, performance improvement goals were set and are as follows:

- Flyash L.O.I. of 3-5% under all operating loads
- Superheat De-superheating spray flows of 40-50 K lbs/Hr at full load
- "Clean" bottom ash
- Consistent NOx Levels of .30-.32 Lbs/MMBTU
- Consistent flame quality and stable boiler operation
- Predictable pulverizer performance throughout the wear cycle



A similar approach of the previous case study was used on this unit to work toward the "*Twelve Essentials of Optimum Combustion*". A primary airflow measuring device was designed and fabricated for each pulverizer to accurately measure and control the primary airflow within ±3% accuracy. Airflow management of secondary air, primary air, overfire air and underfire air were of paramount importance after all "*Twelve Essentials of Optimum Combustion*" were satisfactorily achieved and the following results were found:

Avg. Excess Oxygen	Air/Fuel Ratio	NOx (Lbs/MMBTU)	O.F.A. (%)	L.O.I. (%)	Spray-Flow (Lbs/Hr)	Peak Temp. (Degrees F)	Efficiency (%)
2.59	2.06	0.366	0	2.6	67,000	2,245	88.86
3.99	1.96	0.461	0	0.9	67,140	2,175	87.64
1.53	1.95	0.308	100	2.6	79,010	2,275	87.78
2.74	1.86	0.323	100	2.5	66,880	2,216	88.11

* boiler efficiencies measured by ASME P.T.C. 4.1 short form, heat loss method

The goals which the plant wished to achieve were met and exceeded in some areas. The plant noticed that the number of forced outages dropped considerably due to the comprehensive approach of performance improvement, controls, tuning, inspections and technical direction of repairs or changes during the outages. Subsequent to the data shown in the table above, water wall de-slaggers were added and these have provided the ability to clean the waterwall slag, which increases furnace heat absorption as needed. By careful operation of these soot-blowers, the superheater de-superheating spray water flow can be controlled to about 5% of feedwater flow, ***maximum***.

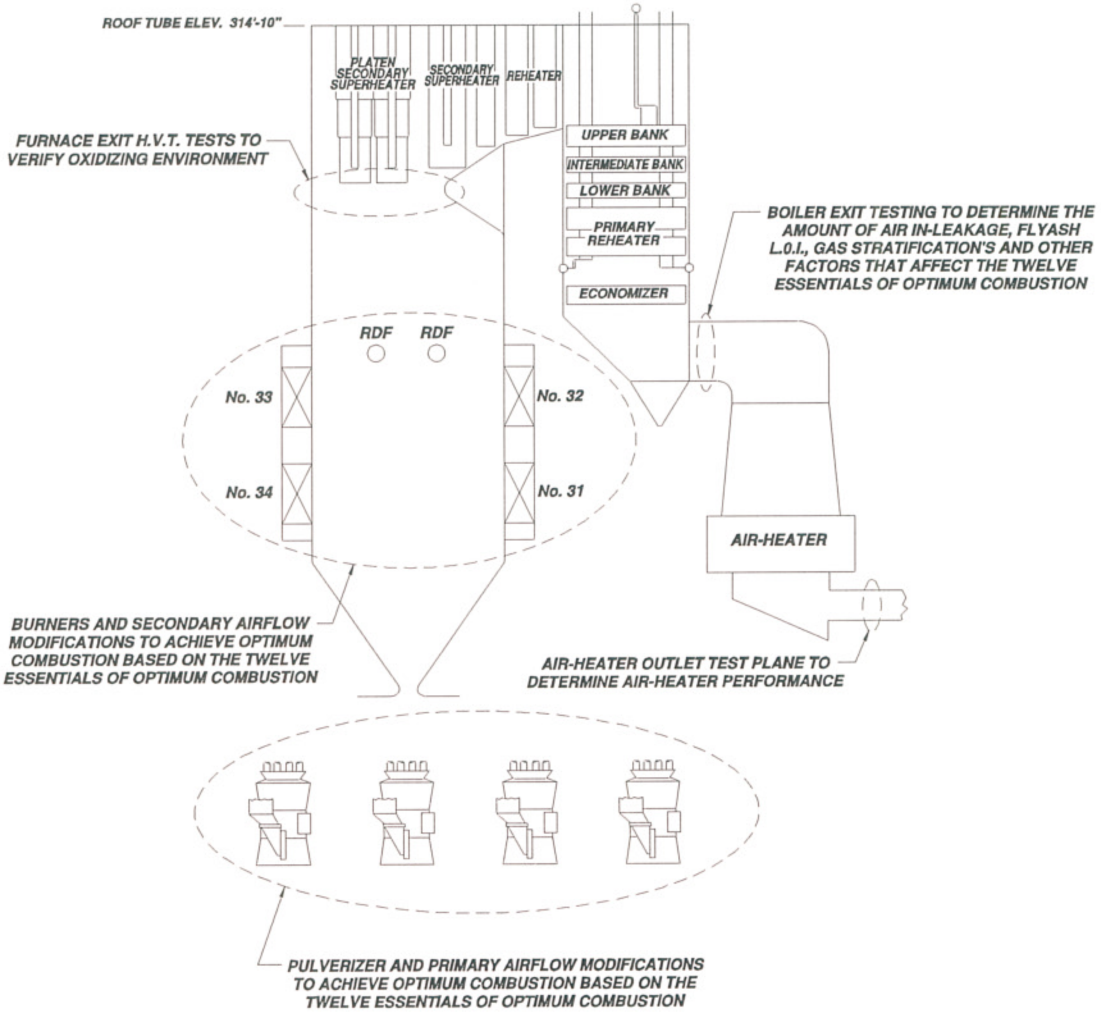
Case Study of a Opposed Fired B&W Boiler with 1st Generation Low NOx Burners:

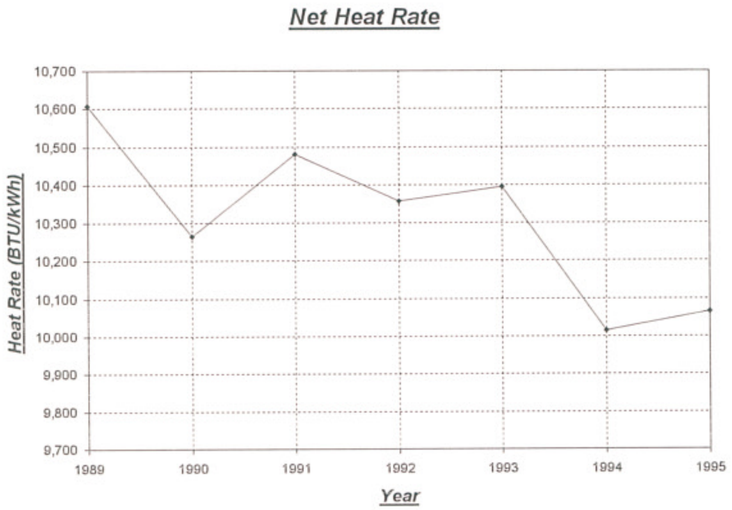
This third example of the comprehensive approach to low NOx combustion in a pulverized coal fired boiler is a 350 MW B&W Radiant Boiler (RB). This particular unit burns several variations of fuel such as coal, municipal refuse, petroleum coke and gas. The "*Twelve Essentials of Optimum Combustion*" were utilized as a base for testing and to determine which changes were required to meet these essentials. Some results after this comprehensive approach are as follows:

	Baseline Test	1994	1995	1996
Load	350 MW	350 MW	350 MW	350 MW
				20% Pet. Coke
Total S.H. Spray	300-380 KLbs/Hr	300-380 KLbs/Hr	200-300 KLbs/Hr	140-180 KLbs/Hr
Reheat Spray	98-112 KLbs/Hr	50-100 KLbs/Hr	50-100 KLbs/Hr	75-110 KLbs/Hr
Flyash L.O.I.	8.00%	4.50%	3.00%	4.50%
Airheater Exit Temp.	341 F	330 F	290 F	310 F
Airheater Inlet Temp.	640 F	635 F	625 F	625 F
Fuel Fineness:				
Passing 200 Mesh	59%	65%	76%	71%
Remaining on 50 Mesh	1.50%	1.00%	0.10%	0.10%
Excess Oxygen	3.60%	3.60%	3.20%	3.40%
NOx	.45-.50 Lb/MMBTU	.45-.50 Lb/MMBTU	.40-.45 Lb/MMBTU	.45-.55 Lb/MMBTU
Net Heat Rate	10,500 BTU/Kwh	-	*10,051 BTU/Kwh	10,120 BTU/Kwh

* 10,051 BTU/Kwh is a record heat rate for this plant

The performance improvements resulted after measuring element changes for primary airflow measurement and secondary airflow to the compartmentalized windbox. Also, pulverizer classifier modifications were completed to improve fuel distribution and fineness. A view of this boiler and a heat rate trend for the last six years are shown on the following page.




Net Heat Rate

All three of these previous case studies are based on applying the "*Twelve Essentials of Optimum Combustion*". Comprehensive testing and tuning was required to measure these essentials. Specialized diagnostic testing equipment was used to determine the variables needed for a combustion improvement program and they are discussed in the remaining sections of this paper.

Oxygen and Temperature Measurement Probes:

The High Velocity Thermocouple (H.V.T.) Probe (See Figure No. 1) is used to determine the actual oxygen and temperature levels across a grid at the furnace exit. The purpose of this probe is to determine if there is an oxidizing furnace, temperature and any stratification. If there is no oxygen at the furnace exit (determined by the H.V.T. probe) and the control room is reading 3%, then there is a problem with air-inleakage. No oxygen at the furnace exit also means that there is secondary combustion taking place in this area which will contribute to high furnace exit temperatures and these high temperatures may cause slagging and tube metal overheating failures, as well as poor performance characteristics. This probe is also a very useful tool to determine the oxygen rise from the furnace exit to the boiler exit to determine the amount of air-in-leakage and stratification. A boiler exit probe (see Figure No. 2) is used at the boiler exit to determine the oxygen and temperature readings. The boiler exit probe is also used to determine the air-heater performance. The High Velocity Thermocouple or H.V.T. probe gets its name because the flue gas is extracted at a high velocity to provide an accurate temperature of the flue gas. The radiation shield protects the thermocouple from the radiant heat. The water-cooled H.V.T. probe has been most useful for determining oxygen levels and stratification's.

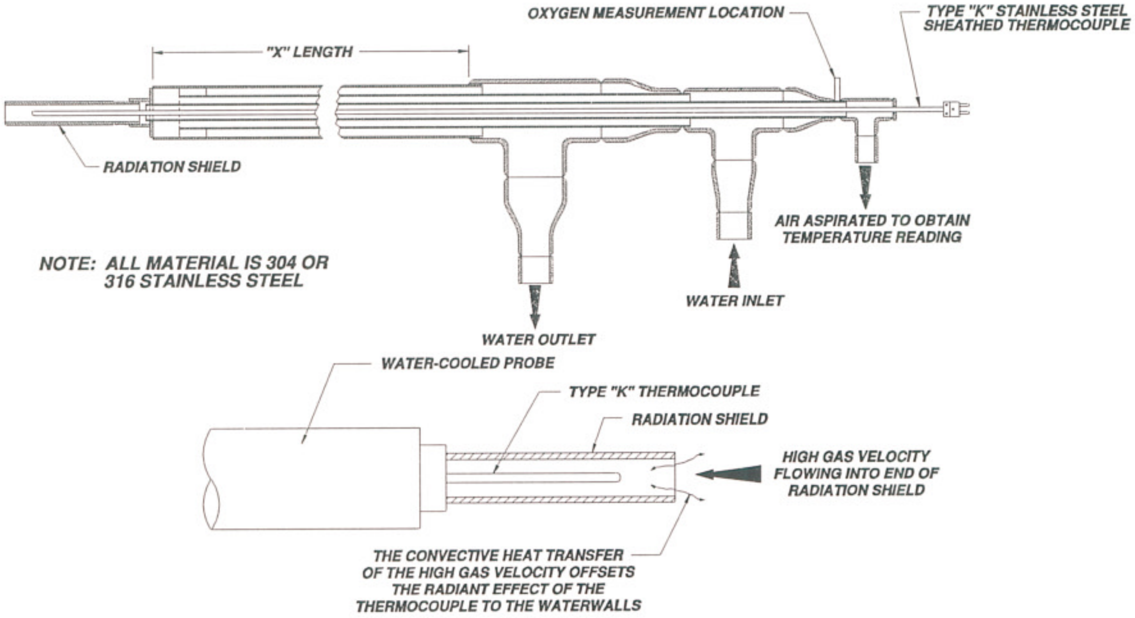


Figure No. 1 - (H.V.T. Probe)

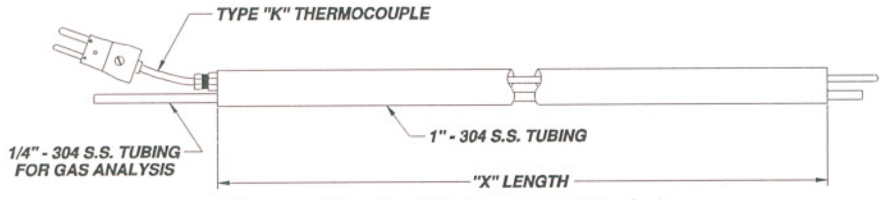
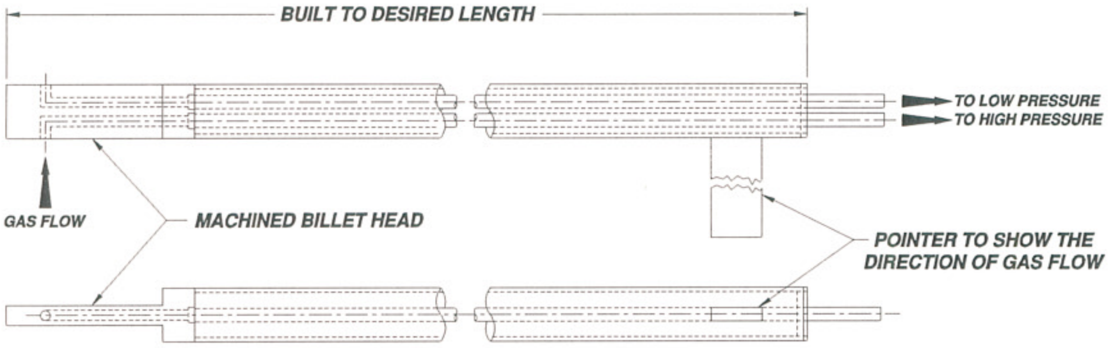


Figure No. 2 - (Boiler Exit Probe)

Airflow Measurement Probes:

Airflow measurement of the primary and secondary air is very important in balancing the airflow from one side to the other or for calibrating the airflow measurement devices. Sometimes it is also necessary to measure the airflow to or from the fans or other locations of the boiler to quantify the total airflow and whether or not duct modifications are needed such as turning vanes or balancing dampers. A Forward/Reverse Pitot tube (Figure No. 3) would be used in most ducts to determine the airflow. Sometimes a Fecheimer probe (Figure No. 4) is used if a more precise measurement is needed or if the velocity vector angles need to be measured.



NOTE: 1. ALL MATERIAL 304 STAINLESS STEEL
2. FORWARD/REVESE PITOT CAN BE FABRICATED TO MEASURE OXYGEN AND TEMPERATURE

FRONT AND SIDE VIEW OF FORWARD/REVERSE PITOT TUBE

Figure No. 3 - (Forward/Reverse Pitot Tube)

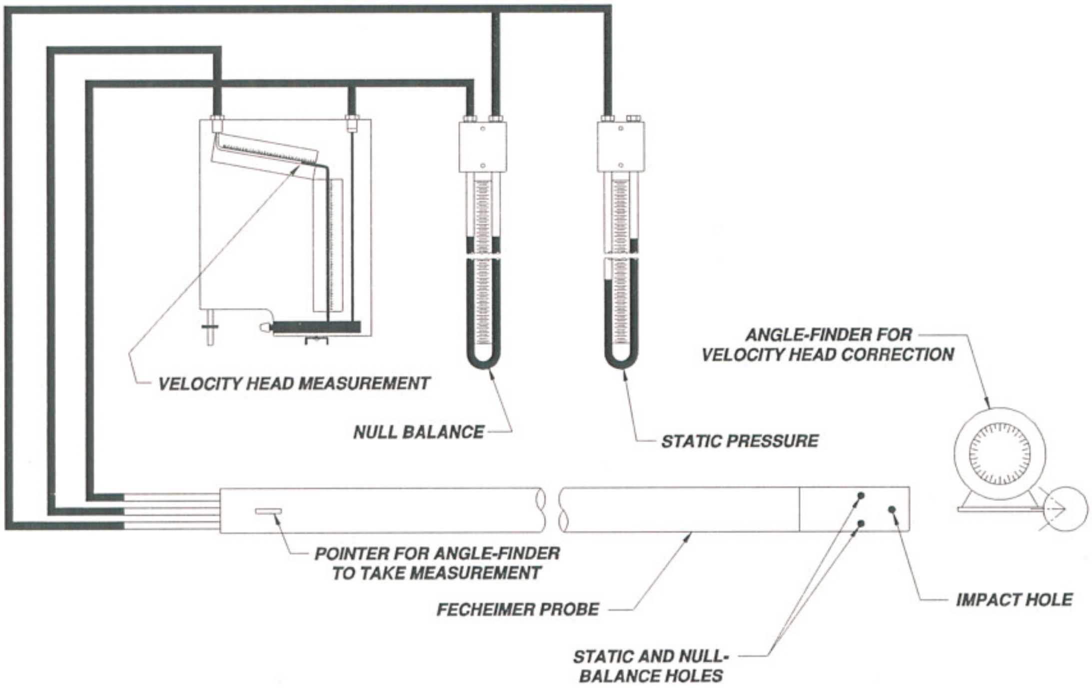
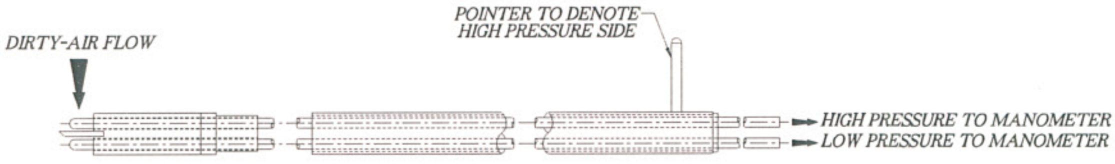


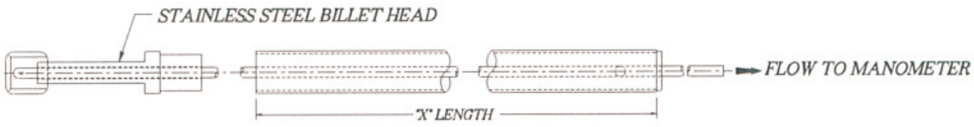
Figure No. 4 - (Fecheimer Probe)

Pulverizer Testing:

It is necessary to determine the velocity in the coal pipes in order to perform an Isokinetic Coal sample test. Once the static pressure and temperature in the coal pipe have been recorded, the velocities can be determined with the dirty air probe (Figure No. 5). Once the average velocity head in the coal pipe has been calculated, the isokinetic sample rate can be determined for that individual coal pipe. A needle valve and aspirator assembly is used to throttle the air across an orifice to maintain the sample rate during the extraction of the coal sample. The sample is extracted through the sampler tip at the same velocity as the coal/air mixture in the coal pipe (or Isokinetic sample). The coal particles are separated by a cyclone separator and collected in a sample container (Figure No. 6 shows the Isokinetic coal sampler and Figure No. 7 shows some typical "*As Found*" conditions of fuel distributions to each burner).



SIDE VIEW OF DIRTY AIR PROBE



FRONT VIEW OF DIRTY AIR PROBE

Figure No. 5 - (Dirty Air Probe)

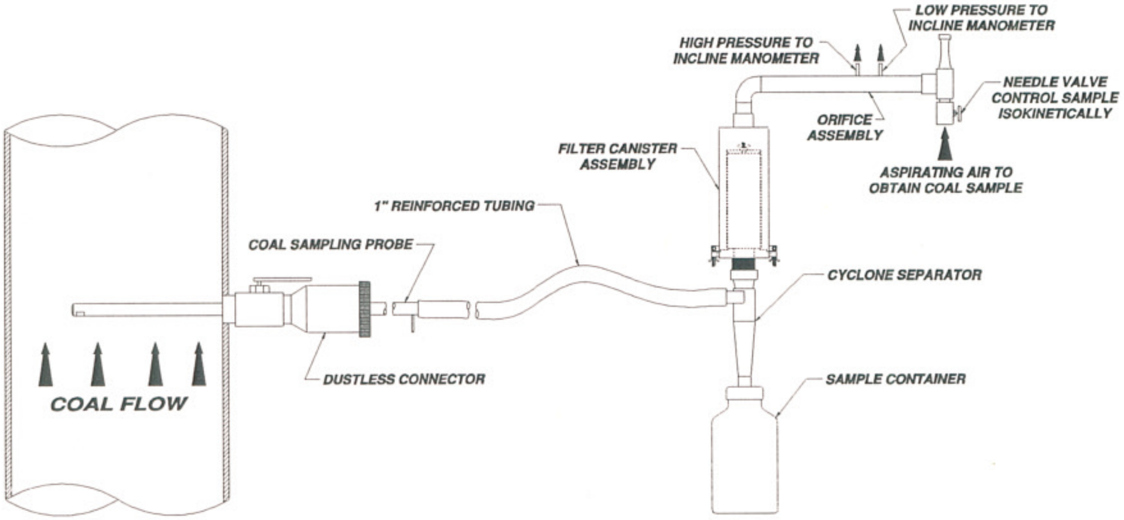


Figure No. 6 - (Isokinetic Coal Sampler)

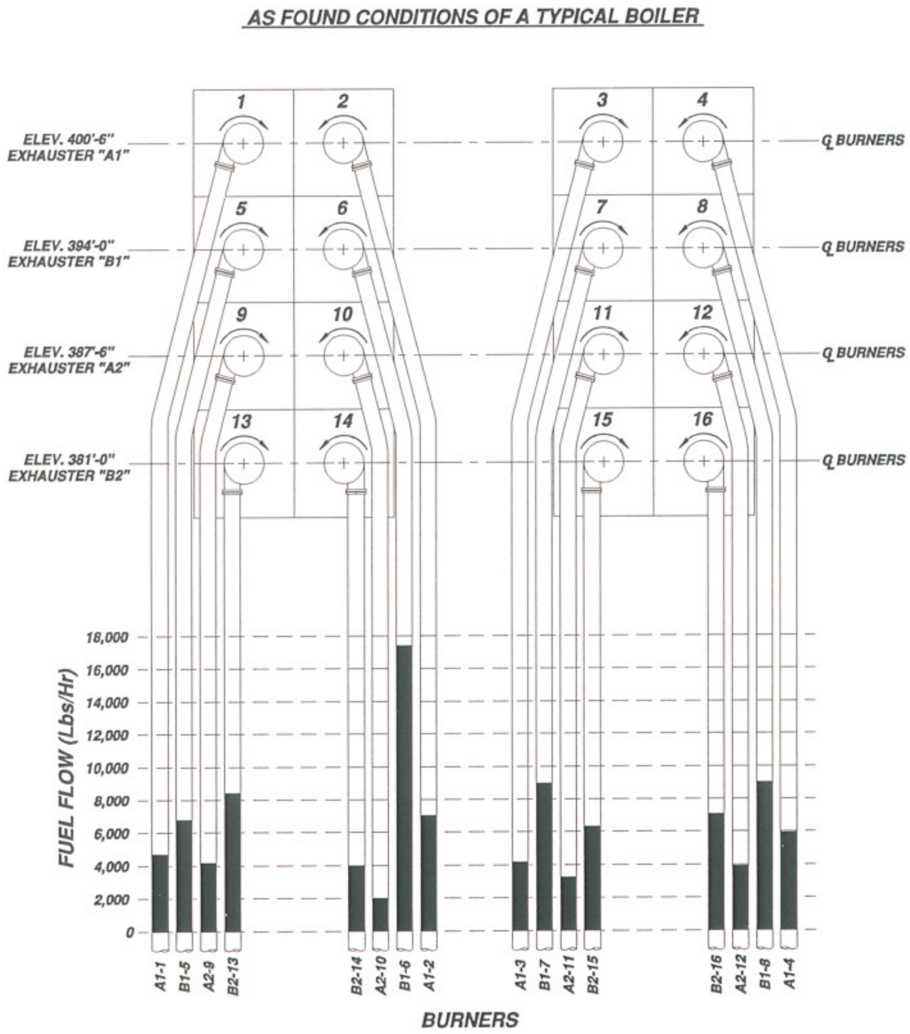


Figure No. 7 - (Typical "As Found" Conditions of Fuel Flow)

Determining L.O.I. or Unburned Carbon:

A flyash sampler such as Figure No. 8 or 9 provides a sample from the flue gas, rather than a hopper sample which usually is not consistent or accurate. A volumetric flyash sampler is a "Near Isokinetic" sample and is shown in Figure No. 8 and a Isokinetic flyash sampler is shown in Figure No. 9.

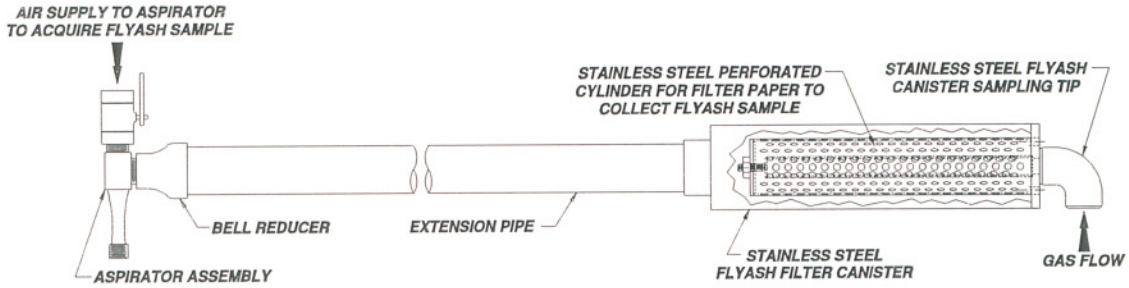


Figure No. 8 - (Volumetric Flyash Sampler)

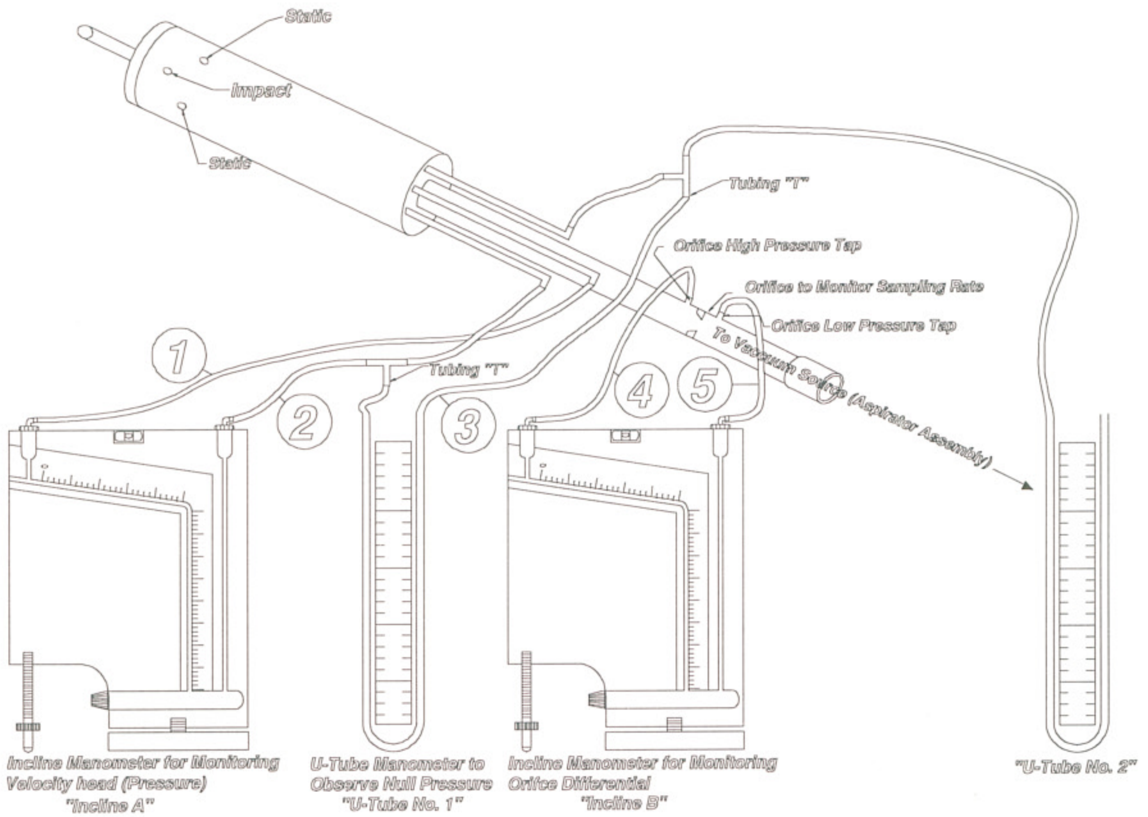


Figure No. 9 - (Isokinetic Flyash Sampler)

Summary:

Achieving maximum combustion performance, boiler efficiency, ever more stringent emission limits and doing so with changing fuel qualities is a large challenge. The check list approach of quantifying these "*Twelve Essentials of Optimum Combustion*" is one practical approach to achieve optimum combustion. This has worked for the authors and we trust that it will for others. We acknowledge the hard work, attention to detail and a committed team approach by the maintenance, operations and engineering personnel of each of the utilities involved.

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