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ACCURATE BURNER AIR FLOW MEASUREMENT FOR LOW NO_X BURNERS

by

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ABSTRACT

In 1990, Congress enacted an amendment to the Clean Air Act that required reductions in NO_X emissions through the application of low NO_X burner systems on fossil fueled utility steam generators. For most of the existing steam generator population, the original burning equipment incorporated highly turbulent burners that created significant in-furnace flame interaction. Thus, the measurement and control of air flow to the individual burners was much less critical than in recent years with low NO_X combustion systems. With low NO_X systems, the reduction of NO_X emissions, as well as minimizing flyash unburned carbon levels, is very much dependent on the ability to control the relative ratios of air and fuel on a per-burner basis and their rate of mixing, particularly in the near burner zones.

Air Monitor Corporation (AMC) and DB Riley, Inc. (DBR), and a large Midwestern electric utility have successfully developed and applied AMC's equipment to low NO_X coal burners in order to enhance NO_X control combustion systems. The results have improved burner optimization and provided real time continuous air flow balancing capability and the control of individual burner stoichiometries.

To date, these enhancements have been applied to wall-fired low NO_X systems for balancing individual burner air flows in a common windbox and to staged combustion systems. Most recently, calibration testing in a wind tunnel facility of AMC's individual burner air measurement (IBAM™) probes installed in DB Riley's low NO_X CCV® burners has demonstrated the ability to produce reproducible and consistent air flow measurement accurate to within 5%.

This paper will summarize this product development and quantify the benefits of its application to low NO_X combustion systems.

INTRODUCTION

In an effort to provide greater control of combustion air flow and subsequent burner stoichiometry on multiple low NO_X burner installations, DB Riley and Air Monitor Corporation, in cooperation with a large Midwestern electric utility company, have developed a unique probe for accurately measuring burner air flow. These probes, referred to as individual burner air measurement (IBAM™) probes, are currently used in all DB Riley low NO_X burners. The benefits of better air flow control in low NO_X burner installations is the ability to operate at lower NO_X levels and/or lower unburned carbon levels in the flyash.

This paper focuses on the development, application and benefits of the IBAM™ probes specifically in DB Riley low NO_X CCV® coal burners. The paper also discusses the benefits of accurately measuring combustion air flow in other low NO_X systems such as overfire air (OFA), secondary air in cyclones, and primary air in pulverizer systems.

REVIEW OF CCV® BURNER TECHNOLOGY

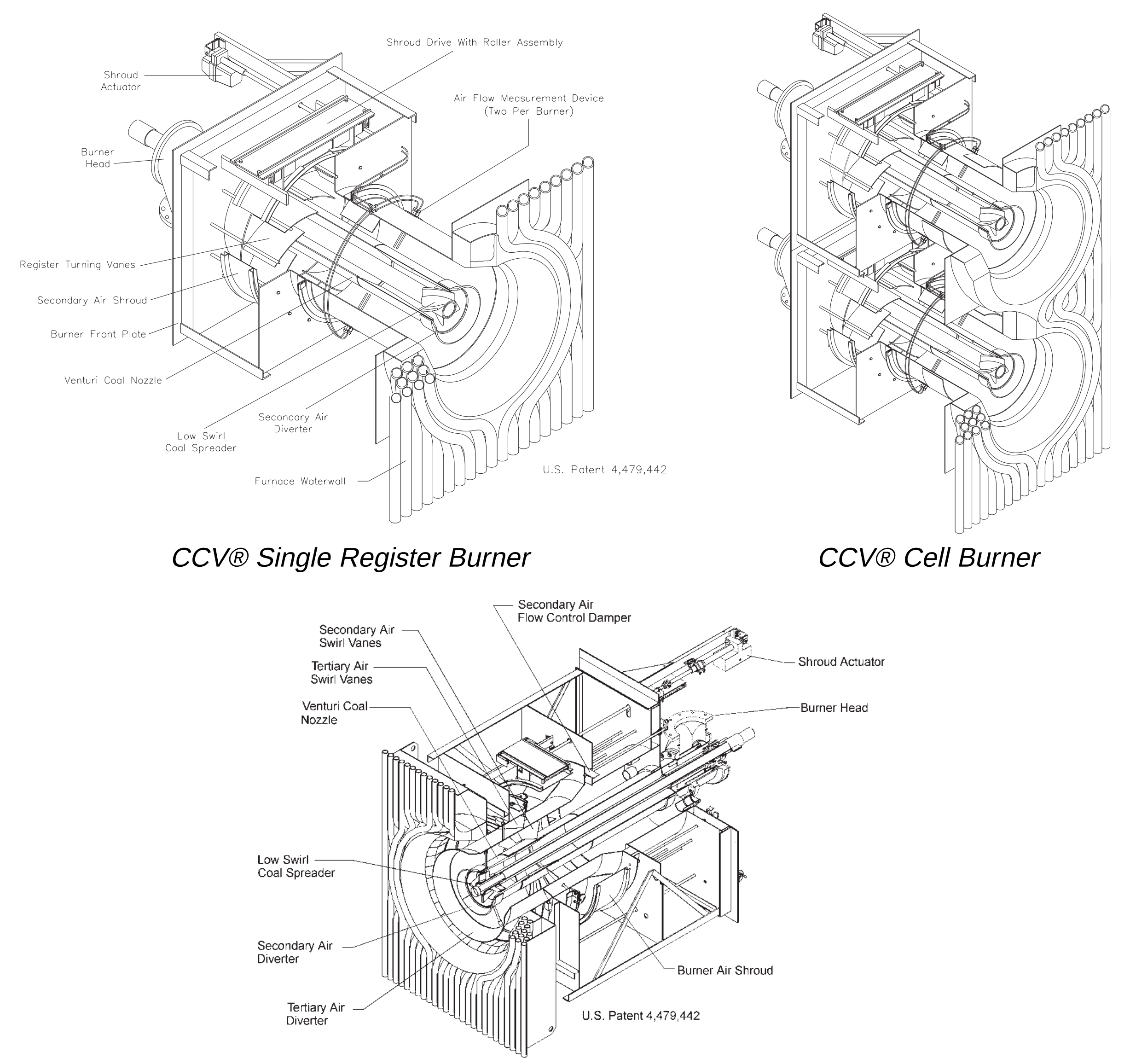
DB Riley has been using CCV® burners for reducing NO_X emissions from pulverized coal fired utility boilers for many years. With over 1500 low NO_X coal burners being supplied to the utility industry since 1990, the CCV® technology has developed into a "family" of low NO_X burners including the CCV® single register, dual air zone and cell burner designs. This wide range of designs allows the flexibility to select a design most suitable for a particular application, based on NO_X reduction requirements, boiler configuration, and budget constraints.

Figure 1 shows schematic drawings of the three low NO_X coal burner designs. Common to these designs is a unique patented venturi coal nozzle technology (U.S. Patent No. 4,479,442) which was developed in the early 1980's for reducing NO_X emissions on coal fired utility boilers. The venturi nozzle, low swirl coal spreader and secondary air diverter in all of these designs produce a fuel rich flame core, the fundamental conditions necessary for minimizing the formation of both fuel and thermal NO_X[2].

The combustion air side of the CCV® burner design is similar for single register and cell burner applications. Secondary air initially passes through the air register, which imparts swirl, and then through the burner barrel and over the secondary air diverter. Secondary air is diverted away from the primary combustion zone which reinforces the fuel rich flame core produced by the venturi nozzle for further control of NO_X emissions.

As shown in the schematic, the air flow measurement devices or IBAM™ probes are radially inserted into the burner barrel for measuring secondary air flow on an individual burner basis. As discussed later in this paper, the probes were uniquely designed and strategically located to provide accurate measurement of air flow in this highly turbulent, swirling, non uniform flow field produced by the air register of single register and cell burner designs.

The air register used on the CCV® dual air zone burner design contains axial swirl vanes installed in both the secondary and tertiary air passages of the burner. The IBAM™ probes for this design are positioned immediately upstream of the axial swirl vanes where the flow field is more uniform, axial, and non-swirling. Accurate measurement of both secondary and tertiary air flow on a per-burner basis is important to establish the proper flow split for minimizing NO_X in this burner design.



CCV® Single Register Burner *CCV® Cell Burner*

CCV® Dual Air Zone Burner

Figure 1 DB Riley Low-NO_X CCV® Burners

REVIEW OF AIR MONITOR FLOW MEASUREMENT TECHNOLOGY

The flow measurement technology used in DB Riley CCV® burners is based upon Air Monitor's VOLU-probe® design (U. S. Patent 4,559,835). The VOLU-probe® is a multiple point, self-averaging pitot tube requiring very little straight duct run to maintain an accurate flow signal.

The VOLU-probe® operates on the Fechheimer Pitot derivative of the multi-point, self-averaging pitot principle to measure the total and static pressure components of airflow. Total pressure sensing ports, with chamfered entrances to eliminate air directional effects, are located on the leading surface of the VOLU-probe® to sense the impact pressure (Pt) of the approaching airstream (Figure 2). Fechheimer static pressure sensing ports, positioned at designated angles offset from the flow normal vector, minimize the error-inducing effect

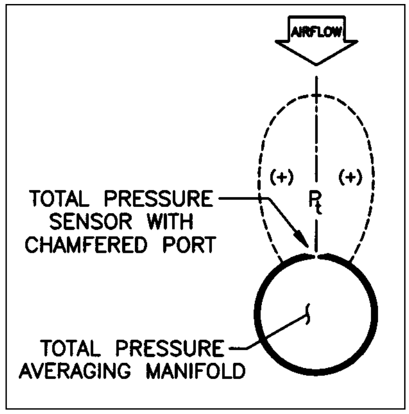


Figure 2 VOLU-Probe® With Total Pressure Sensing Ports

of directionalized, non-normal, airflow. As the flow direction veers from normal (Figure 3), one static sensor is exposed to a higher pressure (Ps + part of Pt) while the other is exposed to a lower pressure (Ps - part of Pt). For angular flow where a = ±30 degrees offset from normal, these pressures are offsetting and the pressure sensed is true static pressure. It is this unique design of offset static pressure and chamfered total pressure sensors that make the VOLU-probe® insensitive to approaching multi-directional, rotating airflow with yaw and pitch up to 30 degrees from normal, thereby assuring the accurate measurement of the sensed airflow rate without the presence of airflow straighteners upstream.

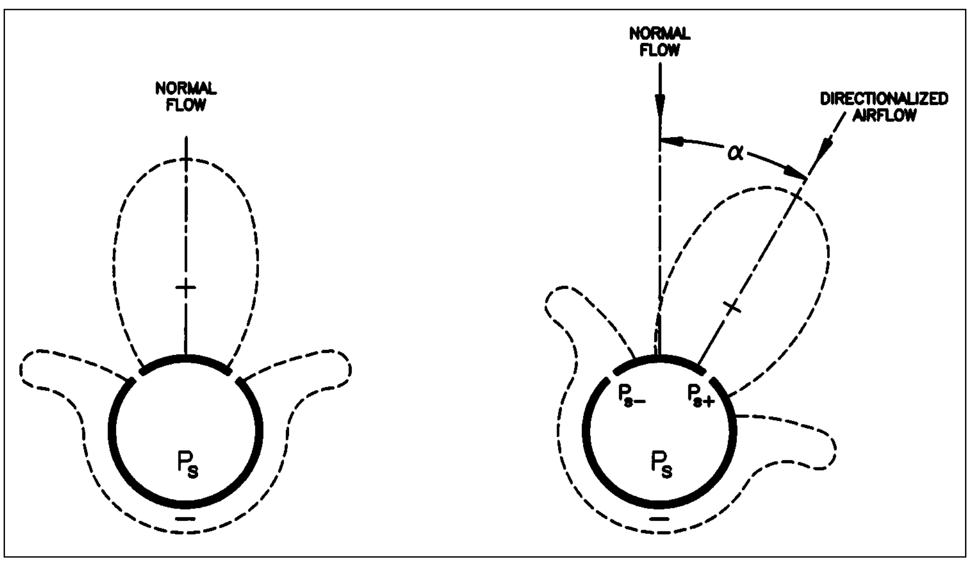


Figure 3 VOLU-Probe® with Static Pressure Sensing Ports

Air Monitor Corp. then applied these VOLU-probes® to DB Riley's CCV® burner designs. The resulting assembly was referred to as IBAM™ or individual burner air measurement probes. A photograph of a typical IBAM™ probe assembly is shown in Figure 4. As shown in Figure 5, the multiple point sensors used in the IBAM™ probes also minimizes the error caused by flow stratification.

The Fechheimer pitot method of flow measurement in a burner allows for true axial flow measurement even when flow vectors are non-axial. This is where traditional flow measuring devices (static pressure comparisons, forward-reverse pitot tubes, piezometer rings, ther-

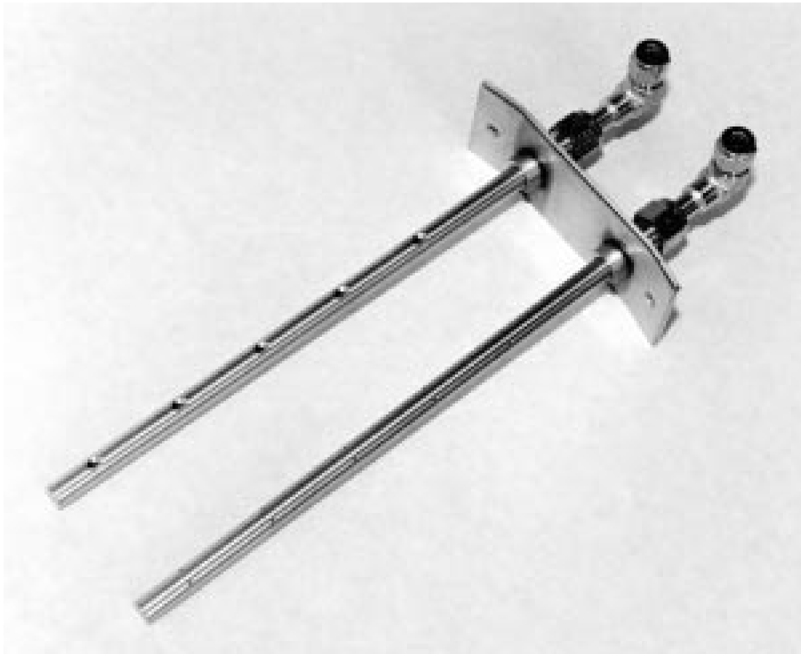


Figure 4 Typical IBAM™ Probe Assembly for Burner Air Flow Measurement

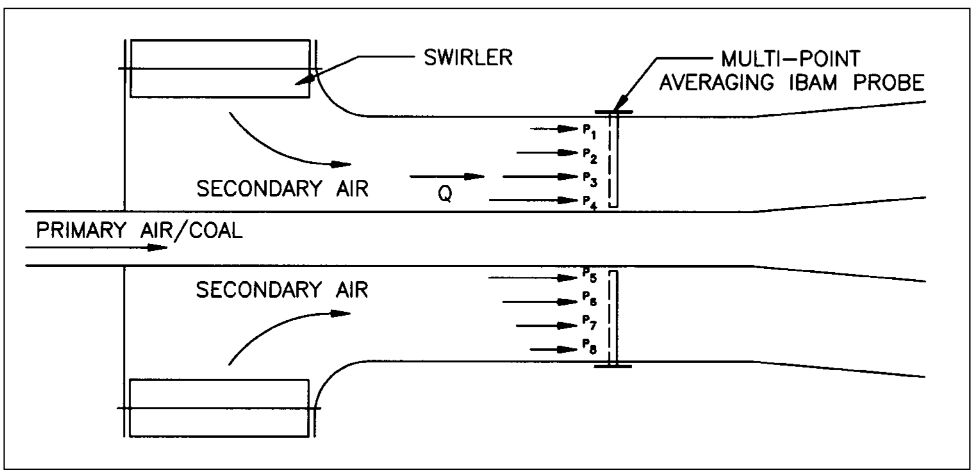


Figure 5 Burner Register Flow Stratification

mal anemometers and more) fall short. In fact, because many of these other devices cannot distinguish axial flow from swirling flow, the use of them can actually lead to a user unbalancing previously balanced burners. That is, two (or more) burners may have the same true axial flow but because the flow vectors approach the flow measuring devices at varying angles, the flows are interpreted as being different.

Thermal anemometers are not suitable for burner balancing because an RTD or resistance temperature detector in a flow stream cannot determine angular flow from axial flow. That is, thermal anemometers are calibrated for certain conditions and if these same conditions are not met, the calibration coefficients will be incorrect. If two anemometers for two different burners are calibrated to the same flow condition (i.e. axial flow) and they have the same axial flows but their angular orientations are different, they may read differently.

The result is that because burners lack straight duct run and because flow in burners becomes directionalized from flow obstructions such as swirl vanes and register vanes, traditional flow-measuring devices have proven to be ineffective.

INTEGRATION AND TESTING OF AN IBAM™ PROBES IN DB RILEY CCV® BURNERS

Figure 6 shows the typical application of Air Monitor's IBAM™ probes to a CCV® single register burner barrel. Two stainless steel probe assemblies, with both total and static pressure tubes, are installed perpendicular to the burner barrel and connected by appropriate tubing to a local pressure gage mounted on the burner front or to a flow transmitter. The probes are uniquely designed and oriented for accurate measurement of secondary air flow in the swirling non-uniform flow field.

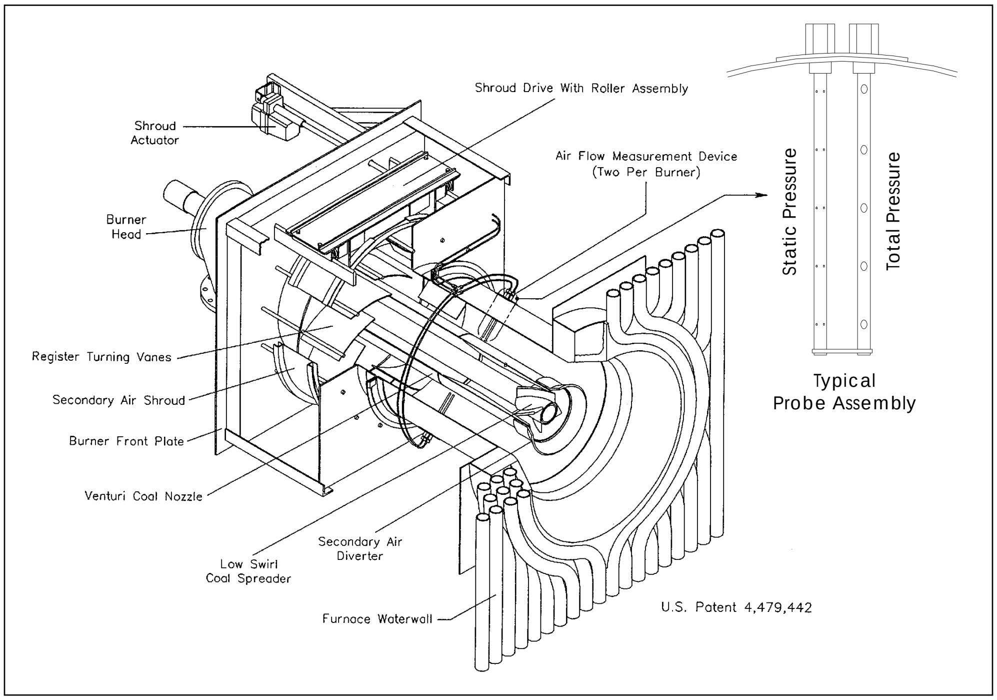


Figure 6 Application of IBAM™ Probes to DB Riley CCV Single Register Burner

Testing of the probes in late 1995 on a 600 MW utility boiler equipped with DB Riley CCV® single register cell burners was performed to determine the number of probe assemblies that would actually be required to produce a representative flow indication or measurement. Data were collected for 2, 3, and 4 probe assemblies. The results suggested that 2 or 3 probe assemblies were sufficient provided the probes are carefully located to preclude any adverse effects of flow obstructions or disturbances caused by ignitors, scanner tubes, and nozzle support legs. The actual accuracy of the probe measurement could not be evaluated since only a small number of burners were equipped with the IBAM™ probes. However, the results were found to be very repeatable during subsequent tests several months later.

Testing of the IBAM™ probes in a 100 million Btu/hr (29 MW) CCV® dual air zone test burner at Riley Research was performed in mid-1995 to evaluate probe location in the burner barrel and probe angle or orientation with respect to the burner axis when installed downstream of the axial swirl vanes in the secondary air annulus. The DB Riley Research

Combustion Test Facility, shown in Figure 7, can test a single full-scale coal burner for a wide range of firing conditions[3].

Results of locating one probe assembly at 0°, 120°, or 240° CCW from top dead center showed no significant variation in the flow measurement. This indicated good peripheral distribution of air within the secondary air annulus. However, the probe angle was sensitive

Figure 7 Aerial View of the Combustion Test Facility at DB Riley Research, Worcester, Massachusetts

to the swirl vane position in regard to accurate flow measurement. Various probe angles were tested which resulted in an optimum angle that appeared to be the least sensitive to swirl vane angle or positioning. With the probe oriented and positioned at optimum settings, the error in the IBAM™ probe air flow measurement relative to the ASME venturi flow measurement was only +2%.

More recently, extensive testing was performed in AMC's wind tunnel facility in Santa Rosa to actually calibrate the IBAM™ probes installed in a CCV® single register low NO_X burner manufactured for subsequent installation in a 260 MW Midwestern utility boiler. AMC's wind tunnel facility is equipped with multiple ASME flow nozzles for precise air flow measurement. The purpose of the testing was to quantify the accuracy of the IBAM™ probes, confirm the optimum probe angle or orientation from previous field and laboratory testing, and to evaluate the axial positioning of the IBAM™ probes relative to the air register.

Figure 8 is a photograph of the CCV® burner installed in the AMC wind tunnel facility. The IBAM™ probes were at the 1:30 and 6:00 clock positions in the photograph. A Plexiglas tube was used to simulate an oil ignitor while a cardboard sono tube was used to simulate the coal nozzle.

As shown in Figure 9, the results indicated the variance or error in the IBAM™ flow measurement, when compared to the flow measured using the ASME nozzles typically varied from -1% to +13% for a wide range of burner settings (various register vane and shroud settings) tested. The error band was reduced to +5% to +10% for more "normal" burner settings. Typically, on multiple burner installations, register or swirl vanes are all set to the same angle while only the burner shrouds are manipulated to various positions as necessary to balance air flow burner to burner. So, for a given register setting of 25 the error band reduces even more. The test results confirmed the probe angle or orientation selected from previous field and lab testing was still valid while the axial location of the probes relative to the air register was also found to be important. The data was observed to be extremely repeatable.

Future test plans are to calibrate a CCV® single register low NO_X cell burner equipped with IBAM™ probes in AMC's wind tunnel facility again for subsequent installation in a 1300 MW utility boiler.

Figure 8 IBAM™ Probe Calibration Testing in AMC's Wind Tunnel Facility

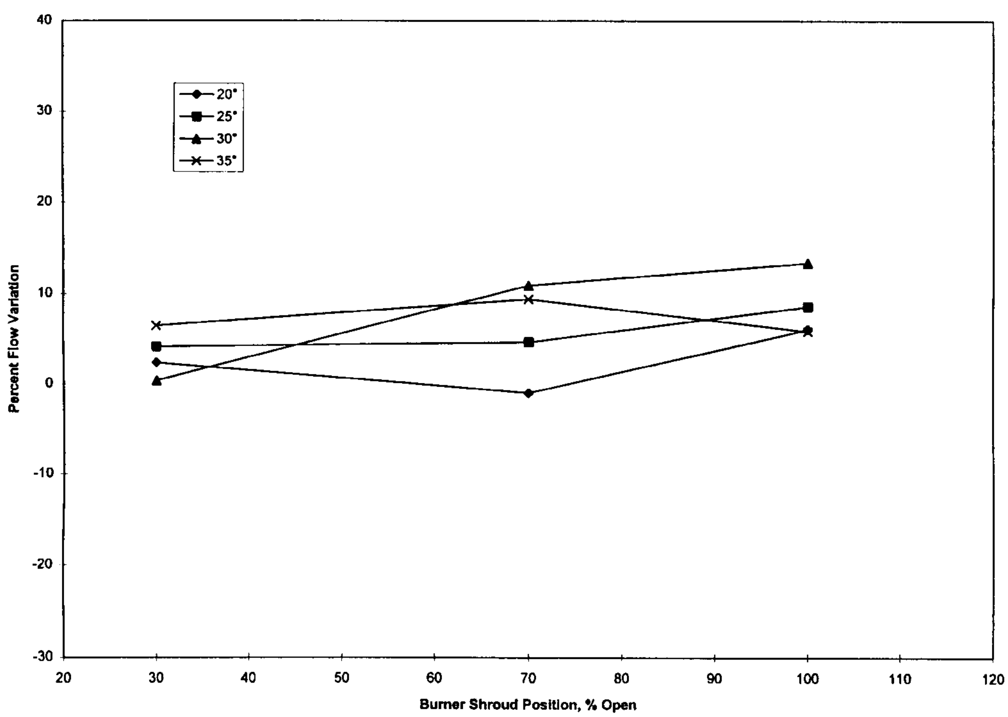


Figure 9 IBAM™ Flow Variance for Various Shroud Position and Register Vane Settings

BENEFITS OF ACCURATE AIR FLOW MEASUREMENT

The benefits of having the ability to accurately measure individual burner air flow in a multiple burner windbox arrangement are significant. The following lists the most important benefits in low NO_X combustion systems.

- Capability of balancing secondary air flow burner to burner
- Capability to deliberately bias air flow burner to burner if desired
- Improved control of NO_X emissions and flyash UBC
- Improved control of individual burner stoichiometry and air to fuel ratio
- Improved control of burner throat slagging
- Lower excess air operation for lower NO_X
- Greater burner turndown capability
- Reduces the potential for lower furnace corrosion

In this regard, DB Riley has standardized on the use of Air Monitor's IBAM™ probes for all low NO_X coal, oil, and gas burner applications.

The VOLU-probe® has also been successfully used in a variety of other combustion air flow applications. Pulverizer primary air flow measurement and control is an integral part of most low NO_X projects. Air Monitor has supplied the air flow probes for many of these applications, as shown in Figure 10.

Optimizing airflow to the mills has been important not only for helping to reduce NOx, but also for reducing LOI. Primary airflow can either be performed by measuring hot and tempering airflows independently or totalized, after they mix.

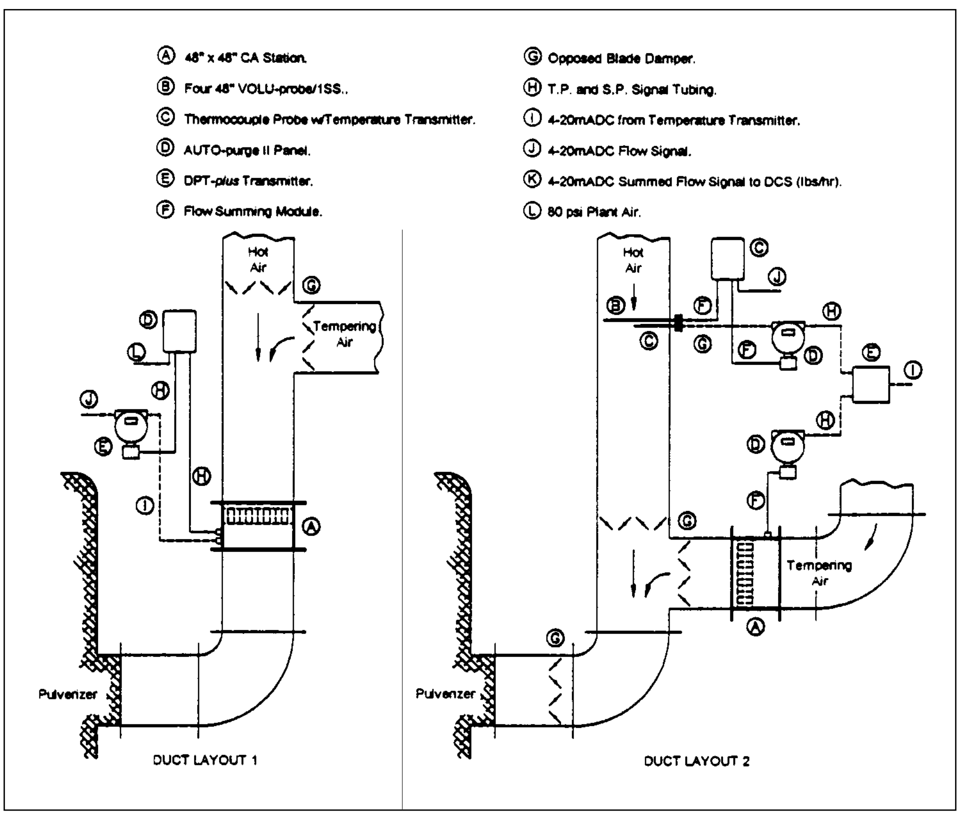


Figure 10 Primary Air Flow Measurement

In an effort to increase overall boiler efficiency, many plants are looking at ways to eliminate pressure drop from their systems. In many installations, airfoils, venturis, and/or dams can be removed from ducts and replaced with VOLU-probes® (Figure 11), providing the benefits of gaining extra FD fan capacity, gaining airflow, and improving the flow measurement, which can lead to control optimization.

DB Riley and AMC are currently working on a project to remove up to 10" w.c. of permanent pressure drop from existing cyclones by removing existing airflow measuring devices and replacing them with devices designed by AMC. This improvement will yield more needed airflow. It will also allow for the balancing of cyclones, helping NO_X and maintenance issues. Recently performed wind tunnel testing has shown that these new devices will allow for accurate cyclone airflow measurement as well as cyclone balancing to within 3%.

Overfire airflow is another application that has been successfully performed by DB Riley and AMC as part of low NO_X systems. Figure 12 shows an example of how VOLU-probes® are installed in a typical OFA duct on a low NO_X system. Accurate measurement of OFA flow in each duct provides the ability to balance the flows to each port for better NO_X and UBC performance.

Figure 11 Secondary Air Flow Measurement

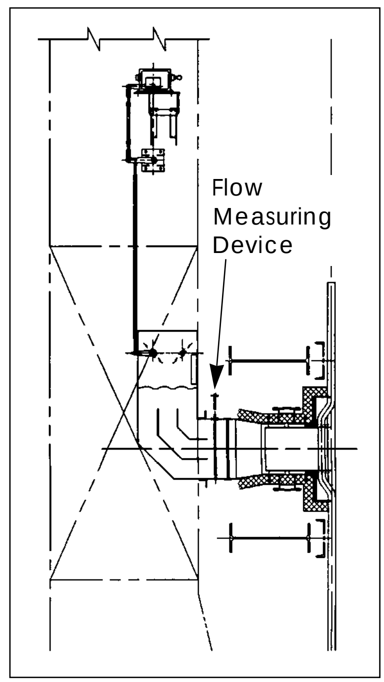


Figure 12
OFA Air Flow
Measurement

SUMMARY

Air Monitor Corp., DB Riley, and a large Midwestern electric utility have developed individual burner air flow measurement probes for accurate measurement of combustion air flow in DB Riley low NO_X CCV® burners. Results of extensive calibration testing in combustion test furnaces and wind tunnel facilities have yielded measurement accuracies to within 5%. The major benefit of accurate burner air flow measurement is the ability to balance burner air flow and stoichiometry in multiple burner common windbox applications, particularly for better control of NO_X and UBC in low NO_X systems. Accurate measurement of air flow has also been extended and applied to primary air entering mills, overfire air, secondary air to cyclones, and total secondary air flow to boilers. Current R&D efforts by other organizations focused at developing an ability to dynamically measure coal flow on a per-burner basis will further enhance the ability to more accurately control individual burner stoichiometry when combined with the burner IBAM™ probes.

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