SENSOR TECHNOLOGY FOR ADVANCED COMBUSTION CONTROL AND MONITORING INSTRUMENTATION

Michael A. Richard, Otis W. Bynum, David R. Sheridan, Priscilla H. Mark, Glenn C. Morrison, and Loan T. Brewer

Sonoxco, Inc, 430 Ferguson Drive Bld # 3
Mountain View, CA 94043

KEYWORDS: GAS SENSORS, COMBUSTION CONTROLLER, EMISSIONS MONITORS

ABSTRACT

With increasingly stringent environmental legislation, there is a growing need for low cost instrumentation for combustion control and emissions monitoring. While low cost is necessary, advanced instrumentation also must be simple to operate and calibrate, require minimum maintenance, and give stable, reliable data. Combustion of fossil fuels leads to formation of CO, NOx, SO_2, and other pollutants depending on the fuel and the combustion conditions. We will describe catalytic heat flux sensor technology and instrumentation based on these sensors for the quantitative measurement of CO, NOx, and SO_2. Various strategies for control of emissions and for maximum fuel efficiency based on these measurements will be discussed.

INTRODUCTION

The 1990 Amendments Act of the Clean Air Act require tighter control of the emissions released during the combustion of fossil fuels. The new legislation is now targeting small industrial and commercial size combustion processes such as heaters, boilers, and stationary IC engines. Continuous Emissions Monitoring (CEM) systems capable of monitoring the major fossil fuel combustion emissions, NOx, SO_2, and CO, have been used for over ten years on utility size boilers and large gas turbines. However, the prohibitively high cost of these systems, as much as $150,000, is too high of an expense burden for smaller combustion processes. Sonoxco has developed a line of sensors to measure the stack gas levels of NOx, SO_2, and CO on coal-, oil-, and gas-fired processes. The sensors are low cost and easily configurable into monitoring and control instrumentation to provide continuous measurement and control of these gases.

SENSING METHODOLOGY

The Sonoxco CO, NOx, and SO_2 sensors are catalytic heat flux devices. Each sensor is comprised of two temperature sensitive elements, one active and the second a reference. The active element is coated with a highly selective catalyst that promotes an exothermic reaction of the component to be measured. The temperature difference between the active and reference elements is directly proportional to the gas concentration. As an example, the CO sensor operates by catalyzing the reaction of CO with oxygen as follows:

$$CO + \frac{1}{2} O_2 \rightarrow CO_2 \qquad \Delta H_{600K} = -67.6 \text{ kcal/mol} \qquad (1)$$

Resistance temperature detectors (RTD) are used for the temperature measuring elements for the three sensors. Because the RTD resistance is proportional to temperature, the corresponding difference in resistance between the active and reference elements is linear with gas concentration. A bridge circuit can be used to produce a 0-5 Vdc signal that is directly proportional to the gas concentration as shown in Figures 1 and 2 for the CO and NOx sensors. The SO_2 sensor signal is also very linear with changes in SO_2 concentration [1]. The designs of the NOx, CO, and SO_2 sensors are identical with the exception of the proprietary active catalyst coatings. The Sonoxco sensor configuration is shown in Figure 3.

Catalytic heat flux type sensors have been used commercially for decades primarily for LEL (Lower Explosion Limit) applications. What distinguishes our sensors from the other heat flux sensors and from sensors using different sensing methodologies such as electrochemical are; 1) high sensitivity, the CO and NOx sensors have sensitivities on the order of 5 ppm, the SO_2 sensor about 20 ppm, 2) high selectivity towards the measuring gas, and 3) long sensor life even in harsh applications such as coal-fired processes.

CO SENSOR FOR MAXIMUM FUEL EFFICIENCY

Combustion efficiencies vary with air/fuel ratio. At low excess air levels incomplete combustion lowers efficiency while at high air/fuel ratios, energy is wasted by heating the unused air. In theory optimum combustion control efficiency can be achieved by monitoring either oxygen or CO and controlling the air/fuel ratio. In practice using both CO and oxygen provides better control of the combustion process efficiency than using either component alone [2]. An example of such a system utilizing both CO and oxygen measurements for control is the Bailey Controls ICCS (Industrial Combustion Control System). The ICCS unit uses a ZrO_2 solid electrolyte oxygen sensor and the Sonoxco CO sensor. The ICCS system is closed-coupled mounted to the stack eliminating costly heat traced sample lines. In addition, both the oxygen and CO sensors operate a temperatures above the dew point of the process gas and as a consequence water is not removed from the sample gas prior to measurement. This greatly simplifies the design of the sampling system bringing significant savings in the overall cost of the system. The ICCS system sells for $4200, a cost that can be paid for from the fuel savings in a few years even on small industrial combustion processes.

SENSOR ARRAY FOR COMBUSTION AND NOx CONTROL

The overall simplicity and compatibility of the Sonoxco CO, NOx, and SO_2 sensors make the sensors particularly suited for sensor array networks. By combining the signal information from each of the array sensors the effect of sample condition variability, such as changes in sample flow and temperature, may be distinguished from real changes in gas concentration. The array can also be used to correct for cross-interferences from the other gas components on each individual sensor.

Sonoxco is currently working on a program funded by the Gas Research Institute to develop a sensor array for natural gas combustion control systems. The array is comprised of the Sonoxco CO and NOx sensor, and a ZrO_2 solid electrolyte sensor provided by another OEM sensor manufacturer. Presently the sensor array algorithms are being evaluated using a test apparatus that simulates the conditions of a real gas-fired process. Later in the program, control strategies will be developed to use the sensor array to control combustion efficiency and NOx emissions from gas-fired processes. The control system is intended to be a low cost system applicable to small industrial and commercial size combustion processes. A preliminary design of the system utilizes a closed-coupled mounting of the sensor array to the stack with the unconditioned sample gas drawn directly over the sensors via an air-driven aspirator or sample vacuum pump. Conditioned sensor signals are then transmitted serially to the controller housed in a separate enclosure. The inherent simplicity of the system combined with such features as auto calibration should provide a system requiring minimum maintenance and operator intervention.

The control system can use the NOx measurement in a closed-loop with an EGR (Exhaust Gas Recirculation) valve to control NOx levels, or alternatively to meter the quantity of steam injected in water/steam injection systems used to lower flame temperatures to reduce NOx emissions. The system can also be used on large combustion processes as feed forward or feed back control to NOx reduction systems such as SCR (Selective Catalytic Reduction).

REFERENCES

1. Dalla Betta, R.A.. Sheridan, D.R., Reed, D.L. "Development of Reliable SO_2 and NOx Sensors and an Integrated In-Situ Analyzer for Flue Gas Monitoring" Final Technical Report, August 1991, DOE SBIR Phase II Program DE-AC03-86ER80421.

2. Dalla Betta, R.A. and Bynum, O.W. "A New Combustion Control Sensor" Sensors, April 1989, Vol. 6, No. 4.

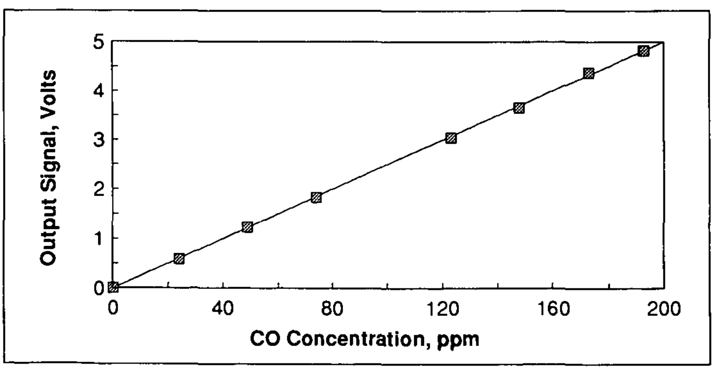

Figure 1. Signal linearity of the Sonoxco CO sensor.

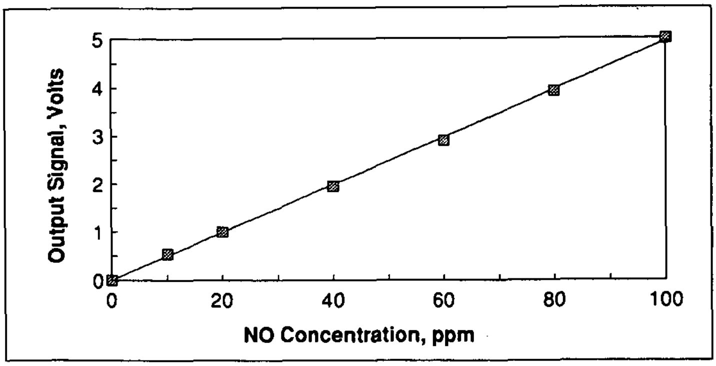

Figure 2. Signal linearity of the Sonoxco NOx sensor.

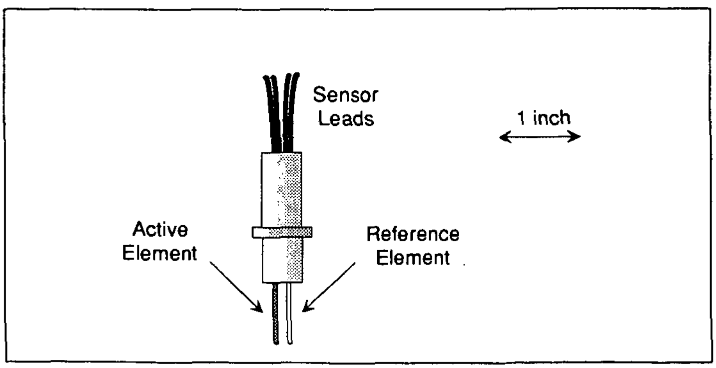

Figure 3. Sonoxco CO, NOx, and SO_2 sensor configuration.