By Paul M. Lemieux, Ph.D.

# Computer-Aided Data Acquisition for Combustion Experiments

Rotary kilns comprise a significant fraction of the population of the operating hazardous waste incinerators. Rotary kilns consist of a long, rotating, refractory-lined cylindrical shell, mounted on a slight incline, followed by a secondary combustion chamber, and various flue gas cleaning systems. One of the advantages of rotary kilns is their ability to burn a wide variety of waste materials, including combustible liquid wastes (frequently fed as auxiliary fuel in the burners), sludges (typically lanced into the rotating kiln section), or containerized solids (such as drums), which are often fed into the kiln whole, at periodic intervals.

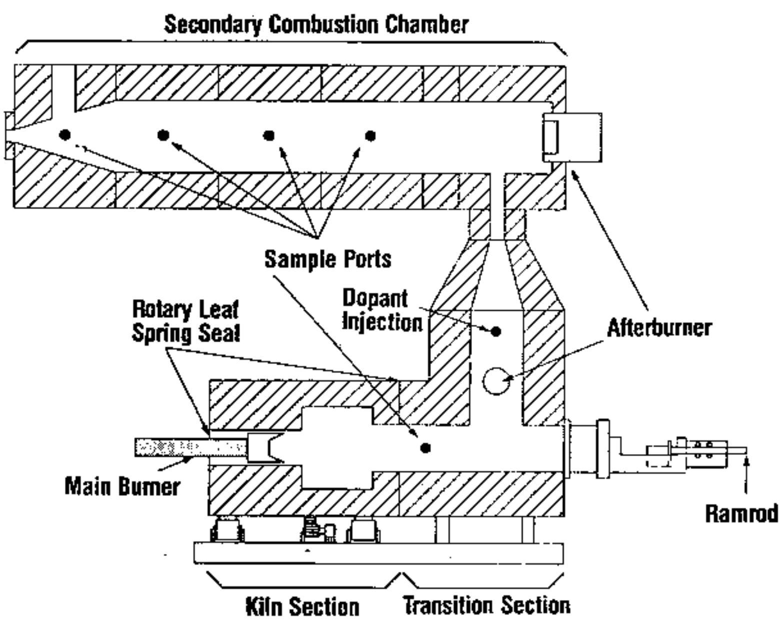



Figure 1. EPA Rotary kiln incinerator simulator.

### The Problem

One potential problem that can occur when drums are batch fed into kilns is the rapid release of volatile material as the drum ruptures inside the kiln. This phenomenon can lead to a transient puff of unburned material that can leave the kiln, and must be destroyed in the afterburner or captured in downstream pollution control equipment.

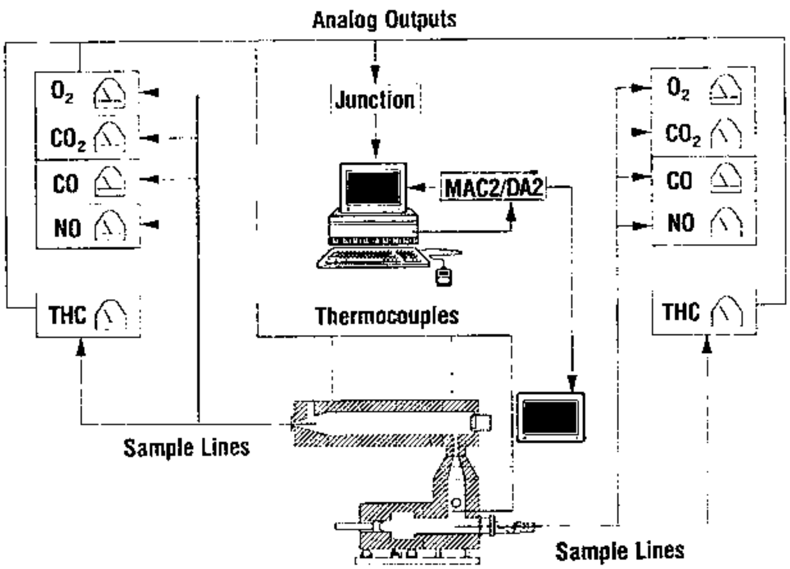
The U.S. Environmental Protection Agency has an ongoing research program designed to examine methods to minimize transient emissions from rotary kilns, using the bench-scale 73 kW rotary kiln incinerator simulator (RKIS) facility shown in Figure 1. The experiments on the RKIS usually involve manually feeding a small (0.9 L) cardboard container, filled with a mixture of 180g of ground corncob sorbent and approximately 100g of a reagent grade chemical, such as toluene, as a surrogate waste.

Upon introduction to the RKIS, the container ruptures, the organic material is vaporized and burns, rapidly depleting available stoichiometric oxygen (supplied from the main burner), producing a short (approximately 5 min) transient event characterized by high emissions of carbon monoxide (CO), hydrocarbons (THC), and soot. The emissions from the RKIS are ducted into a flue gas cleaning system (FGCS) to destroy any unburned organic material, and remove acid gases and particulate matter.

### The Experimental Apparatus

The RKIS uses continuous emission monitors (CEMs) to measure the gas-

Figure 2. Data acquisition schematic.




phase species within the system. CEMs for oxygen ($O_2$), carbon dioxide ($CO_2$), CO, nitrogen oxides (NOx), and THC are used, in addition to several type-K thermocouples (TCs), a mass flow sensor for the main burner combustion air flow rate, and an orifice plate for the main burner natural gas flow rate. During the semi-batch type of experiments on the RKIS, many random factors come into play, such as whether the container falls in on its end or side, which can affect the magnitude and intensity of the puffs produced. This necessitates that many replicate experiments be performed for each given set of combustion conditions. It is obvious that a prodigious amount of data can be generated, which can rapidly become very unwieldy to analyze by hand. In the past, for example, a planimeter was used to integrate responses based on strip chart traces, requiring several days to analyze the data from a set of runs.

The transient nature of these experiments is ideally suited to computer-aided data acquisition, where large amounts of data can be manipulated in bulk, with various time-based techniques, such as integration or averaging. For example, $O_2$ deficiency is an integral function of CO and THC signals. In addition, mass emissions can be calculated and all results output in usable engineering units.

### System Considerations

Therefore the Combustion Research Branch (CRB) decided to add a data acquisition system to the RKIS facility. An existing system, based on an IBM XT clone, was fitted to the RKIS, but was found to be inadequate to the task of manipulating the large number of signals, plus was not easily re-configured for different experimental conditions. An appropriate data acquisition system needed to be purchased.

First, the needs of our research had to be defined. One consideration associated with making these types of combustion measurements is that different CEMs have different characteristic response times. The THC analyzers respond fairly quickly (< 1's) to changes in the flue gas concentrations, but the $O_2$, $CO_2$, and CO analyzers are slow (τ 10's) to respond to changes in the flue gas concentrations. Therefore it was necessary for the data acquisition system to be able to sample different analyzers at different rates, and write out multiple log files.

Another consideration for the system was that it be very easy to re-configure, depending on the experiments. This precluded the use of a procedural language, such as BASIC, since modifications to the acquisition setup could not always be planned until the testing was already underway, and coordination of sampling and analytical personnel left only minimal time for debugging and testing the data acquisition system. The use of an iconic-based data acquisition system appeared very attractive.

Yet another consideration for the system was the computer platform. Depending on the duration of the tests, the data files could become quite large. It was necessary that the data acquisition platform support the easy manipulation of large data files. Since these data files would frequently exceed the capacity of even a high density diskette, it would be desirable for the data acquisition computer to be able to be easily networked to CRB 's existing LocalTalk local area network (LAN), so that data files could be transferred to the investigators' desktop computers for further manipulation.

A final consideration had to do with the facility 's Resource Conservation and Recovery Act (RCRA) with a Research, Development, and Demonstration (RD&D) permit, which allows a wide variety of experiments to be performed on real or surrogate hazardous waste materials. The State of North Carolina and EPA's Region 4 require an emissions inventory from the RKIS to be reported, so it was important that the data could be date and time stamped. This date and time stamping would also be useful for cross referencing multiple data files taken simultaneously.

### Alternative Solutions

The user-friendly interface, networking capabilities, and linear memory addressing of the Apple Macintosh made it our preferred choice for the computing platform. Three different data acquisition systems were evaluated based on demonstration copies provided by the developers: National Instruments' LabVIEW, LabTech's LabTech Notebook, and Strawberry Tree's WorkBench PC. LabVIEW was regarded as the most powerful of the three systems, but the combination of its high price, steep learning curve, and our low budget eliminated it from the list. LabTech Notebook, though possessing some interesting features, had, in our opinion, a difficult-to-understand interface. We decided to use the WorkBench PC software, based on its moderately powerful feature list, and its simple, intuitive interface.

### The System

The data acquisition system was installed as shown in Figure 2. All CEMs are installed in a measurements and control room, located adjacent to the combustor. The clean, temperature controlled environment of the measurements and control room enhances the reliability of the analyzers. A MAC2/DA2 video signal splitter from Extron Electronics was installed, which enabled a satellite monitor to be placed next to the RKIS. The satellite monitor shows a duplicate of the image on the data acquisition computer.

Two Strawberry Tree ACM2-12-16 Nubus boards, providing 12-bit resolution on 16 analog input channels each, were installed in a Macintosh II. This setup enabled the measurement of up to 32 analog input signals. Table 1 is a list of the measurements taken and their sampling rates. The maximum possible sampling rate is 2.5 kHz on a single channel. An increase in the number of channels decreases the maximum sampling rate by a factor approximately equal to the number of channels.

An external material balance program written using MacApp is used to calculate the predicted flue gas concentrations and flow rates. The results from the material balance calculations (combustion gas flow rate and moisture content) are input as constants into the worksheet. These numbers are used to calculate mass emissions based on time-integrated CEM responses. Two external button functions supplied with WorkBench are used to reset the integrators and timers at the beginning of the day and at the beginning of each duplicate run.

Figure 3 illustrates an example of how the iconic data acquisition programming environment can be used to

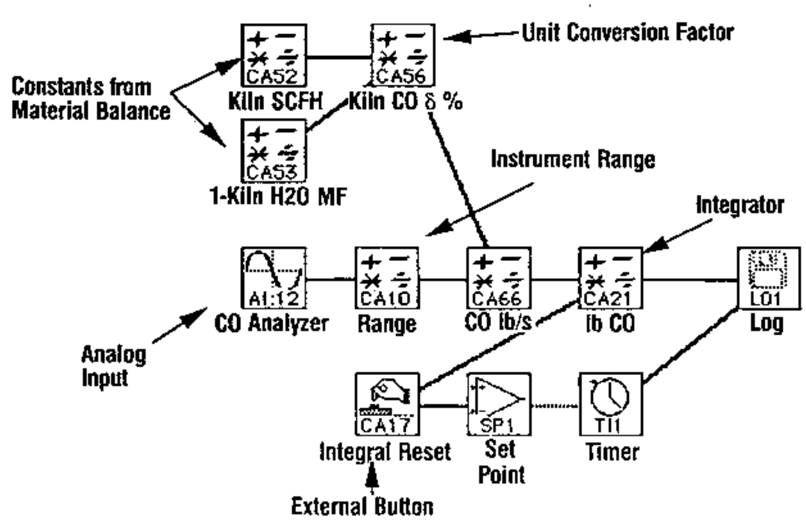
## Integrated Lab Systems

Table 1. Measurements and sampling rates.

| Measurement | Method | Signal | Sampling Rate (Hz) |
|---|---|---|---|
| $O_2$ | CEM | 0-1 V | 0.1 |
| $CO_2$ | CEM | 0-1 V | 0.1 |
| CO | CEM | 0-1 V | 0.1 |
| NO | CEM | 0-1 V | 0.1 |
| THC | CEM | 0-1 V | 2 |
| Temperature | Type K TC | * | 0.1 |
| Combustion Air Flow | Mass Flow Sensor | 4-20mA | 1 |
| Natural Gas Flow | Orifice Plate | 4-20mA | 1 |

*-Thermocouple signals are automatically put through an ice-point correction by the software.

Figure 3. Fragment of the data acquisition template.



measure signals from a CO analyzer, perform a real-time integration of the signal, convert to mass emissions, and log the results and the elapsed run time to disk.

All signals of interest are shown on the screen in the form of a real-time strip chart. This enables the investigators to visualize trends in the data while they are being acquired. In addition, equipment problems can be more readily identified and corrected. The satellite monitor enables the facility operators to see the same image that is present on the data acquisition machine.

Data are logged into three separate files: one with 0.1 Hz samples from the CEMs and TCs, one with the 2 Hz samples from the THC analyzers, and one with the hourly averages and total emissions, which is used for permit reporting purposes. All output files report data in engineering units, using the appropriate number of significant digits, and are output in tab-delimited ASCII files. As much as possible of the data reduction is done before the results are even written to disk.

The data files are copied over the LAN to the investigator's desktop machine at the end of a day's runs, for further analysis and plotting.

*This paper has been reviewed by EPA's Office of Research and Development and has been approved for publication. Approval does not signify that the comments necessarily reflect the views and policies of the U.S. EPA nor does mention of trade names or commercial products constitute an endorsement or recommendation for use.*

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