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Continuous Environmental Monitoring for Aqueous Effluents

W. W. Pitt, Jr.
G. Jones, Jr.

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CONTINUOUS ENVIRONMENTAL MONITORING
FOR AQUEOUS EFFLUENTS

W. W. Pitt, Jr. and G. Jones, Jr.

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CONTINUOUS ENVIRONMENTAL MONITORING FOR AQUEOUS EFFLUENTS

W. W. Pitt, Jr. and G. Jones, Jr.

ABSTRACT

An aquatic environmental monitor has been developed that will continuously monitor aqueous waste streams from coal processing plants. The monitor contains three different instruments: a continuous chemical oxygen demand monitor and two continuous-flow fluorometers with different excitation-emission characteristics. A prototype instrument was fabricated and evaluated for several different applications. The details of the instrument design and results of its evaluation are presented in this report.

1. INTRODUCTION

The development of continuous monitoring systems for sensitive on-site monitoring of dissolved aquatic pollutants constitutes a very practical, necessary approach to one facet of our growing concern for the perturbation in our environment caused by various anthropogenic energy sources. The anticipated increase in the utilization of coal to solve the nation's energy problems makes it clear that to avoid significant damage to our aquatic environment we must be capable of detecting environmentally hazardous compounds being discharged from coal handling and processing plants into receiving waters. Earlier studies have indicated that phenolic compounds and polynuclear aromatic hydrocarbons (PAHs) are two of the most environmentally significant classes of organic constituents likely to be released by coal conversion plants to the receiving waters and requiring monitoring.

This report describes the development of one such monitoring system through the design, fabrication, and evaluation of a prototype instrument. The system is a combination of two different instruments: (1) a continuous chemical oxygen demand (CCOD) monitor, which is particularly sensitive to phenolic compounds; and (2) a continuous-flow fluorometer with a wide dynamic range for monitoring dissolved PAHs. The CCOD and two of the flow fluorometers, with different excitation-emission characteristics,

were incorporated into a single system for continuous monitoring of waste streams from coal processing plants; the combined instrument is called an aquatic environmental monitor (AEM).

2. INSTRUMENT DESCRIPTION

The AEM is designed to accept either a small, continuous sidestream of a single effluent or a sequence of injected samples from several aqueous effluents; it will measure two characteristics of the aqueous samples in series: chemical oxygen demand (COD) and ultraviolet (uv) fluorescence. The instrument contains three continuous flow monitors, a continuous COD monitor, and two flow fluorometers (Fig. 1), with the response from each displayed on a strip chart. Provisions are made to allow periodic rezeroing and calibration of each monitor. A photograph of the prototype instrument is shown in Fig. 2.

Figure 1. Schematic of aquatic environmental monitor.

Figure 2. Photograph of aquatic environmental monitor.

2.1 Continuous Chemical Oxygen Demand Monitor

The CCOD monitor is based on cerate oxidimetry using perchloratoceric acid; that is, the measurement of the fluorescent cerium(III) resulting from the reduction of cerium(IV) by any oxidizable compound in the stream being monitored. Concentrations of cerium(III) from 10^{-8} to 10^{-4} M can be readily determined fluorometrically by exciting with uv light (254 nm) and measuring the light emission at 350 nm,¹ thereby measuring the COD of waters at levels as low as 100 $\mu\text{g}/\ell$. The CCOD monitor that was incorporated in the aquatic environmental monitor was a slightly modified version of one described previously.²

The key component of the system is the flow fluorometer, which has been described in detail elsewhere³ but is also briefly described here. The flow fluorometer, shown schematically in Fig. 3, consists of a fluorometer body, electronics chassis, and a high-voltage power supply. The fluorometer body (Fig. 4) is a machined aluminum block that contains a low-pressure mercury lamp, a 254-nm interference primary filter, a quartz-tube flow cell, two Corning 7-60 secondary filters, a photomultiplier tube and housing, and a photoconductor for compensation of changes in lamp intensity. In this situation, nature was exceptionally benevolent, because the excitation maximum for trivalent cerium is very close to the most intense emission line of the low-pressure lamp, 253.7 nm; the emission spectrum of cerium(III) corresponds almost precisely with the pass-band of the Corning 7-60 filters. These characteristics, plus the S-11 photo response characteristics of the photomultiplier, provided an exceedingly low background due to reflected light and allowed the construction of a very sensitive instrument from relatively inexpensive components.

The calibration curve for the flow fluorometer with Ce^{3+} solutions is shown in Fig. 5. Under the normal reaction conditions, it was determined that a stoichiometric reagent-to-sample ratio of 2.5 is required for maximal oxidation (see Fig. 6). Since the electrochemical stoichiometry for the complete oxidation of phenol to CO_2 requires 28 mol of Ce^{4+} per mol of phenol, the ratio of 2.5 shown in Fig. 6 is above normal stoichiometric ratio. This is dramatically illustrated in Fig. 7 where maximal response to phenol concentrations ranging from 1.1 to 10^{-5}

Figure 3. Schematic of flow fluorometer.

Figure 4. Exploded isometric view of flow fluorometer body.

Figure 5. Calibration curve for ORNL flow fluorometer.

Figure 6. Effect of reagent-to-sample stoichiometric ratio on the response of the continuous chemical oxygen demand monitor.

Figure 7. Effect of reagent concentration on the response of the continuous chemical oxygen demand monitor.

to 4.4×10^{-5} M is shown for a Ce^{4+} concentration of 2.5×10^{-3} M; in this case, the reagent-to-sample ratio ranges from 8 to 2. A dramatic falloff in response is shown for the same range of phenol concentration using 1.25×10^{-3} M Ce^{3+} . The amount of reagent is adequate for phenol at 1 $\mu\text{g}/\text{ml}$; however, at higher concentrations of phenol, the reagent-to-sample ratio is definitely suboptimal. Conversely, Fig. 7 also shows the quenching effect of Ce^{4+} on the fluorescence of Ce^{3+} where higher concentrations of the reagent were used.

Maximal response can be assured by using higher reagent-to-sample ratios for the oxidation but diluting the mixture prior to its entrance into the fluorometer. The reagent concentration and the ratio of reagent to sample thus are chosen so that no more than 40% of the cerium (IV) will be utilized. The mixture is then diluted with ultrapure water to a final cerium(III,IV) concentration of 2 mM or less to reduce self-quenching during measurement of the fluorescent trivalent cerium in the flow fluorometer.

Various combinations of reagent concentrations and sample, reagent, and diluent flow rates were utilized to measure the COD of sample streams containing 1 to 40 mg of phenol per liter. It was determined that sufficient sensitivity and adequate linear range could be obtained as long as the following constraints were met:

1. <2 mM Ce in the fluorometer, and
2. a stoichiometric reagent-to-sample ratio >3 .

To meet these constraints, the following operating conditions were chosen for the aquatic environmental monitor:

<u>Stream</u>	<u>Flow rate (ml/h)</u>	<u>Concentration</u>
Sample	10	1 to 30 mg COD/ ℓ *
Reagent	5	0.02 M Ce(IV)
Diluent	35	
Total	50	2 mM Ce

*By changing the relative flow rates of sample and diluent streams, COD concentrations outside this range can be measured.

The CCOD was tested in the discrete sample mode by injecting three or more samples of nine organic compounds (representing different classes) dissolved in triply distilled water and three polluted waters with a blank of triply distilled water between each sample. Periodically, a calibration standard containing a known amount of trivalent cerium in distilled water was injected. Quantities of each organic compound to produce about 10-mg theoretical COD per liter were dissolved in distilled water. At approximately 5-min intervals, the sample tube was placed into one of these solutions and a 1-min sample was withdrawn. During the remainder of the cycle the sample tube was inserted into distilled water. The COD of the sample was indicated by the height of a peak on the strip-chart recorder 10 min after the sample was withdrawn. The system was calibrated periodically with three 1-min samples of a cerium(III) solution of known concentration (1×10^{-3} to 2×10^{-3} M or 8- to 16-mg/l oxygen demand). An example of the recorder trace is shown in Fig. 8, and the results of several series of runs using the selected organic compounds and pollution samples are shown in Table 1.

The CCOD monitor was also evaluated using solutions containing known concentrations of phenol. Shown in Fig. 9 is the detector response

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Figure 8. Example of recorder trace from continuous chemical oxygen demand monitor when used as a discrete sample analyzer.

Table 1. Oxidation of organic compounds and polluted waters
by perchloratoceric acid COD method

Sample	Concentration (mg/l)	Number of determinations	Oxygen consumed (mg/l)		Percent of theoretical COD
			Average	Range	
Acetic acid	10	4	6.1	5.2-7.4	57
Acetone	8	5	3.2	3.0-3.3	18
Benzene	3.3	4	2.8	2.4-3.5	26
Ethanol	7.5	3	11.0	10.8-11.1	69
Glucose	14.5	4	17.4	15.9-17.9	112
Glycine	10	4	3.0	2.8-3.2	46
Linear alkyl sulfonate	5	5	6.9	6.3-7.4	105
Pyridine	10	6	3.5	3.2-3.6	16
Sodium lauryl sulfate	5	5	13.5	12.8-14.6	135
Sewage plant effluent (industrial plant), COD	19	5	16.5	14.8-18.1	
Secondary sewage plant effluent (Oak Ridge, Tenn.), BOD ₅	6	5	25.9	24.2-27.4	
Clinch River water, COD	8	3	7.8	7.5-8.0

Figure 9. Calibration curve for continuous chemical oxygen demand monitor.

(fluorometer adjusted to provide 1-mV output with 10 μM Ce^{3+} in the flow cell) as a function of the concentration of phenol in the flow cell.

2.2 Polynuclear Aromatic Hydrocarbon Monitor

Since most polynuclear aromatic hydrocarbons (PAHs) are strongly fluorescent when excited by uv light, two inexpensive, continuous-flow fluorometers were incorporated into the AEM to measure contamination by PAHs. Three types of fluorometers were used: (1) a commercial right-angle filter fluorometer (AMINCO Fluoro-Monitor, American Instrument Company, Silver Spring, Maryland); (2) a right-angle filter fluorometer, similar to the one described in Sect. 2.1, but with a different secondary filter; and (3) a bifurcated fiber-optics fluorometer, also designed and fabricated at ORNL. All three used a low-pressure mercury lamp as an

excitation source, either with a 254-nm interference filter or coated with phosphor emitting light at 360 nm. A Corning 0-53 filter was used as a secondary filter with the 254-nm excitation source, and a Wratten 2A filter was used with the 360-nm source. Since the performance of the two right-angle fluorometers was very comparable, they were used interchangeably. (The performance of the bifurcated fiber-optic fluorometer was disappointing; it was considerably less sensitive than the right-angle fluorometers without the expected increase in linear dynamic range.) A calibration curve for the commercial fluorometer ($\lambda_{\text{ex}} = 254 \text{ nm}$) using 2,3-benzofluorene as a PAH standard is shown in Fig. 10. The instrument has a measurable response to as little as $0.1 \mu\text{g}/\ell$ and a linear signal output from about 2 to $2000 \mu\text{g}/\ell$.

Figure 10. Calibration curve for commercial flow fluorometer.

2.3 Auxiliary Components

The prototype instrument incorporated several auxiliary components to minimize the need for external services, which are 110 V ac, and occasional filling of reagent reservoirs and emptying of the waste container.

2.3.1 Fluid-flow systems

Three controlled, steady flows are required: sample, reagent, and diluent. Sample flows were maintained at a given constant flow rate (10 to 20 ml/h) using an SP-1000 Saturn Teflon pump with a throttle valve (Fluorocarbon Co., Anaheim, California). Cerate reagent flow was maintained at a constant flow rate between 5 and 10 ml/h using a smaller SP-100 Saturn Teflon pump. Controlled diluent (tapwater) flow of between 20 to 60 ml/h was obtained by gravity flow through a length of small plastic tubing. All flows were measured continuously with small, precision-bore Flowrators (Fischer & Porter Co., Warmister, Pennsylvania) having sapphire ball floats.

2.3.2 Reactor

The heated reactor was simply a coil of Teflon tubing submerged in a 1000-ml round-bottom flask filled with water maintained at boiling with a Variac controlled heating mantle. Evaporation of water was minimized by use of an air condenser on top of the flask. The length of the reactor tubing was chosen so that the residence time of the mixture was about 10 min.

2.3.3 Mixers

Two fluid-stream mixers were used: one to mix the sample and reagent, the other to add diluent to the reaction mixture. To minimize the time for analysis, minimum volume mixers were required. These were made by blowing a small (5 mm diam), disc-shaped chamber in the center of an ~10-cm length of 2-mm-I.D. glass tubing and joining a 5-cm length of the same size tubing perpendicular to this chamber. A 3-mm length of nickel wire sealed in glass was used as the stirring bar. These mixers were mounted as inverted "T"s on a small magnetic stirrer, using the two

horizontal legs as inlets and the vertical leg as the outlet. The connecting Teflon tube was inserted inside the glass tubing (snug fit) to the mixing chamber, and sealed with heat-shrinkable tubing.

2.3.4 Reagent

The 0.02 N perchloratoceric acid reagent was prepared by diluting perchloratoceric acid (0.5 N cerium(IV) in 6 N perchloric acid) with 6 N perchloric acid. The water used for dilution must be organic free to minimize background fluorescence. Two liters of the reagent were prepared at a time and charged to the reagent reservoir (a 2-l Teflon bottle). This is sufficient to last for 1 week of continuous operation.

3. APPLICATIONS AND RESULTS

The AEM has been used to monitor the effectiveness of biological treatment in removing phenolics and PAHs from both synthetic waste and authentic coal hydrocarbonization wastewater. It was also used to compare the reduction of COD and fluorescence by activated sludge treatment of municipal wastewaters. The individual instruments in the AEM have also been used singly--the CCOD to monitor COD from an experimental anaerobic sewage treatment plant, and the PAH monitor to measure possible PAH contamination in drinking water. There are many other possible applications of the AEM and its associated instruments.

3.1 Coal Conversion Process Wastewaters

The AEM was primarily designed for monitoring the organic contaminants in the aqueous effluents from coal gasification and liquefaction processes. It has been established that the major classes of contaminants present in wastewater streams from different coal conversion facilities are phenolics, inorganic ions including trace elements, and PAHs. Table 2 shows the typical values found in untreated wastewater and the anticipated effluent regulations. Although many potential organic contaminants (particularly PAHs) are strongly fluorescent, most are only very sparingly soluble in water and their fluorescence intensity varies considerably. Thus, a qualitative study of the relative solubilities and fluorescences

Table 2. Pollutants in untreated wastewaters from CCP and anticipated regulations

Pollutant	Wastewater concentration (mg/l)	Anticipated regulations ^a (mg/l)
Phenols	3,000 - 10,000	0.03 - 0.3
NH ₃	1,000 - 7,000	0.8 - 5
NO ₃	3,000 - 12,000	1 - 10
COD	3,000 - 20,000	20 - 350
PAH	~10	<0.05

^aData taken from ref. 4 in this report.

of several PAHs was made in the following manner. Each compound was initially dissolved in methanol, and this solution was diluted (beginning with a twofold dilution) with distilled water until no precipitation occurred. The fluorescences of the resulting solutions were measured with a fluorometer using 254-nm excitation and a 0-53 Corning filter as the secondary filter (see Table 3).

It is apparent that the wastewaters generated in coal conversion processes (CCP) must be treated before release to the environment, and the AEM can be used to measure the effectiveness of the treatment for COD, phenols, and PAHs. One proposed method for CCP wastewater treatment is biological oxidation in a fluidized-bed bioreactor.⁵ A prototype AEM was installed in Building 2528 at Oak Ridge National Laboratory (ORNL) to continuously monitor clarified effluent from a bioreactor used to treat synthetic CCP wastewaters, as well as authentic wastewater from a coal hydrocarbonization process. Shown in Fig. 11 are three sections of the AEM recorder chart, indicating its response to different bioreactor changes. Trace A shows the startup transient of the bioreactor, which indicates that after about 12 h (needed for accumulation of biomass) the effluent from the bioreactor is essentially free of phenolics and PAHs. Trace B shows the transient associated with replacement of a large fraction of the active biomass with clean solid support. As would be expected, the effectiveness of the bioreactor is reduced, but it quickly

Table 3. Qualitative solubilities and relative fluorescence of polycyclic aromatic hydrocarbons

Compound	Initial methanol solution ^a (mg/l)	Solubility in water using methanol as carrier (mg/l)	Relative fluorescence ^b (λ_{ex} , 254 nm, λ_{em} 320 nm)
Pyrene	500	5	1.0
Phenanthrene	500	5	0.6
3,4-Dimethylphenol	200	100	0.05 ^c
Naphthalene	500	250	0.22 ^c
2,3-Dimethylnaphthalene	1000	10	0.70
2-Methylnaphthalene	1000	500	0.50 ^c
Adamantane	200	0	
2,3-Benzofluorene	100	50	2.8
Triphenylene	500	15	0.008
Retene	320	10	0.05
2,3-Benzindene	900	25	0.56
Fluorene	900	5	2.2
Fluoranthene	250	1	0
Biphenyl	500	250	0.8 ^c
Chrysene	25	0	
Dibenzofuran	750	0	
Rubrene	25	10	0.1 ^c
Perylene	10	5	1.8 ^c
1,2-Benzofluorene	100	50	4.2 ^c
Anthanthrene	100	50	0 ^c
1,2-Benzanthracene	500	100	0.75
1-4-Dibenzanthracene	50	5	2.0 ^c
3,4-Benzopyrene	75	15	1.1
2,3,6,7-Dibenzanthracene	20	10	0.2

^aValues <100 mg/l represent approximate solubility of compound in methanol.

^bPyrene chosen as standard (1 mg/l = 1 mV detection response).

^cBackground fluorescence of methanol subtracted.

Figure 11. Examples of aquatic environmental monitor recorder traces.

recovers and starts producing clean effluent. Trace C shows the effect of augmenting the wastewater with nonbiodegradable phenolic compounds. The AEM detects their presence as COD in the effluent.

3.2 Effluent from Municipal Activated Sludge Treatment Plant

The AEM was used to determine the level of pollution of secondary sewage effluent from the Oak Ridge East Waste Treatment Plant before and after chlorination. The effluent contained 9- $\mu\text{g}/\text{ml}$ COD both before and after chlorination, but the native fluorescence was reduced $\sim 20\%$ by chlorination (Table 4).

Table 4. Organic contamination in the Oak Ridge East Waste Treatment Plant secondary effluent

	COD (mg/l)	Fluorescence (mV) ^a
Before chlorination	9	38
After chlorination	9	30

^a1 mV corresponds to the fluorescence of 1×10^{-5} M Ce(III).

3.3 Other Applications

Two other applications of components of the AEM briefly investigated were the use of the flow fluorometer as a monitor for PAHs in drinking water, and the use of the CCOD for routine analysis of COD before and after an experimental wastewater treatment.

Because of the carcinogenicity of some PAHs and their rather ubiquitous nature, a need was perceived for an inexpensive, continuous monitor for PAHs in drinking water. Consequently, the PAH monitor portion of the AEM was evaluated for this purpose.

The ORNL flow fluorometer (λ_{ex} - 254 nm; λ_{em} - 320 nm) was adjusted to the most sensitive settings, which had a noise level of <1% of full scale with a sample flow of 2 l/h. Under these conditions, instrument drift was less than 1% per day, and 250 $\mu\text{g/l}$ of phenanthrene could be detected at a signal-to-noise ratio of 2. Monitoring of ORNL process water gave no indication of PAH contamination.

In response to a recognized need for major near-term decreases in the energy intensiveness of conventional technologies for treating wastewaters, ORNL has been engaged in the development and demonstration of a wastewater treatment technology based on an anaerobic, fixed-film bioreactor (ANFLOW).⁶ As part of the supporting research for this technology, ten bench-scale bioreactors were operated under identical conditions except for hydraulic residence times, which were 2, 4, and 12 h. Feed and effluent samples were analyzed for COD on a routine basis using the CCOD portion of the AEM. Ranges of COD removal efficiencies for each of the residence times are shown in Fig. 12.

Figure 12. Measured chemical oxygen demand removal efficiency of anaerobic bioreactor as a function of residence times.

4. SUMMARY

An instrument capable of continuous monitoring of aqueous streams for contamination from coal conversion processes has been assembled and tested. The monitor was shown to be capable of measuring contamination by phenolics in the range of 1 to 10 mg/l and PAH contamination at concentrations below 100 µg/l. These concentrations are about the levels of the existing or anticipated discharge regulations. Tests with several actual effluents show the versatility and utility of the instrument.

5. REFERENCES

1. W. A. Armstrong, D. W. Grant, and W. F. Humphreys, *Anal. Chem.* **35**, 1300 (1963).
2. W. W. Pitt, Jr., S. Katz, and L. H. Thacker, "A Rapid, Sensitive Method for the Determination of the Chemical Oxygen Demand of Polluted Waters," *AIChE Symp. Ser.* **129**, 69 (1975).

3. L. H. Thacker, "Improved Miniature Flow Fluorometer for Liquid Chromatography," J. Chromatogr. 136, 213 (1977).
4. J. A. Klein and R. E. Barker, Assessment of Environmental Control Technology for Coal Conversion Aqueous Wastes, ORNL/TM-6263 (July 1978).
5. D. D. Lee, C. D. Scott, and C. W. Hancher, "Fluidized-bed Bioreactor for Coal Conversion Effluents," J. Water Pollut. Control Fed. 51(5), 974 (1979).
6. R. K. Genung, D. L. Million, C. W. Hancher, and W. W. Pitt, Jr., "Pilot-Plant Demonstration of an Anaerobic Fixed-Film Bioreactor for Wastewater Treatment," Biotechnol. Bioeng. Symp. 8, 329 (1978).

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