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The Addition of Powdered Activated Carbon to Anaerobic Digesters: Effects on Methane Production

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THE ADDITION OF POWDERED ACTIVATED CARBON TO ANAEROBIC DIGESTERS: EFFECTS ON METHANE PRODUCTION

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Recent renewed interest in the anaerobic digestion process as a source of methane has been a consequence of shortages and increased costs of natural gas. The technology and economics of resource recovery from sewage sludge digestion, as well as digestion of agricultural and municipal solid waste organics, have been the subjects of several research programs.

Although anaerobic digestion has a long history of use, it has a reputation for poor process stability and has never been universally accepted as an effective wastewater sludge handling technique. In addition, the rate of anaerobic decomposition is relatively slow. For digesters operating in the mesophilic temperature range (30-37°C), a retention time of 10-30 days is generally required. In an effort to improve the digestion process, several researchers have conducted tests of powdered activated carbon in the anaerobic digestion process. The results seem to indicate that carbon is responsible for increased gas production, accelerated digestion and decreased detention times, and greater process stability. However, the experimental studies, some dating back to the 1930's, have not been performed in continuous flow units with adequate variation in carbon dosage and controls.

The purpose of this research was to conduct a systematic laboratory study. Both batch and semi-continuous experiments were performed over a four month period. Carbon (Hydrodarco C-ICI United States, Inc.) doses of 0, 500, 1000, 2000, and 4000 mg/l were maintained in four liter laboratory digesters. An additional control unit, containing 2000 mg/l of Bentonite clay, served as a sixth digester. All normal measures of digester performance were monitored, including gas production and composition, volatile solids reduction, filtrate volatile acids and chemical oxygen demand, pH, and alkalinity.

The study was intended to determine as far as possible the validity of the postulated effects of powdered activated carbon on well controlled digesters. While the study was not successful in testing all the postulates, the results are of considerable interest since they clearly show an effect of carbon addition.

Experimental

Each digestion apparatus included a four liter glass reaction vessel. The single stage digesters were continuously mixed, and were maintained at 35 ± 1°C. Gas produced in each digester was collected in 1.5 liter plexiglass columns by displacement of an acidified saturated salt solution.

Feed sludge was procured from the Richland, Washington sewage treatment plant. Influent to the plant consisted almost entirely of domestic sewage. In the batch study, both raw and digested sludge were required. For the semi-continuous studies, raw sludge was fed to the digesters. Sludge was stored in the laboratory to provide for periodic feeding of the digesters. To retard biological degradation of the organic matter and thus provide a more uniform feed, the sludge was frozen. As required for addition, a quantity of sludge was removed from the freezer and allowed to reach ambient temperature prior to its addition to the digesters to minimize thermal shock. Units were fed once a day for the 10 day solids residence time (SRT) study, and twice a day for the 5 and 2.5 day SRT studies.

In the first experiment, the digesters were operated on a batch basis. Each of the six units was filled with 2300 ml of raw sludge and 1200 ml of digested sludge. The digesters were then monitored for 30 days. During the test, samples from the digesters were periodically analyzed for pH, alkalinity, soluble COD, volatile acids, total solids, and volatile solids. Gas production was continuously monitored and gas composition routinely analyzed. In addition, the sludge at the end of the test was subjected to a vacuum filtration test to determine its dewatering characteristics. Sodium bicarbonate was added to each digester on the sixth day of the test run to raise the pH and increase the buffering capacity of the sludge. Further chemical additions were not required, as the pH and total alkalinity remained at satisfactory levels during the remainder of the experiment.

In subsequent experiments, the digesters were operated on a semi-continuous mode. Sludge was periodically withdrawn from the system and fresh sludge then added in equal quantity. A 10 day solids residence time in the digesters was chosen for initial study. Digesters were initially charged with 2300 ml of raw sludge and 1200 ml of digested sludge, and the appropriate amounts of powdered activated carbon and Bentonite clay. Raw sludge, containing the desired concentrations of carbon and clay, was then fed to the units for 20 days prior to a 10 day experimental period used for data analysis. A 5 day SRT study was conducted next. The experiment was started using the digested sludge remaining from the 10 day study. The units were operated for 13 days preceding a 5 day period during which test data was collected. The final study involved operation at a 2.5 day SRT. Initially, the digesters contained sludge remaining from the 5 day SRT study. The units were operated for 6 days prior to a 2.5 day data collection period. During each experiment the same carbon or clay concentrations were used as the batch study. Also, analyses were performed for the same parameters as in the batch study. Sodium bicarbonate additions were generally made every one or two days. Doses were calculated to maintain total alkalinity levels between 4000 and 5000 mg/l as $CaCO_3$.

Results

A plot of cumulative gas production versus time is presented in Figure 1 for the batch study. Gas production rates in all of the digesters had significantly decreased at the end of 30 days. The digesters containing activated carbon generated about nine liters of gas per liter of sludge, while the control units produced slightly over three liters of gas per liter of sludge. Thus, the carbon appeared to account for nearly a threefold increase in total gas production. The total gas production for the carbon dosed units was about the same, the production rates varied with higher rates for the first 14 days and lower rates after that. Therefore, it seems that the rates of gas production and of the digestion process were increased by the presence of the carbon. Volatile solids reduction for the carbon dosed digesters generally ranged between 30 and 40 percent, while corresponding values for the control units were approximately 15 to 20 percent. Final volatile acid concentrations were less than 800 mg/l in the carbon dosed units, but greater than 3000 mg/l in the control units. Thus, digestion in the control units was not complete at 30 days. The experiment showed a clear effect of powdered activated carbon, but it could not be determined whether the carbon enhanced digestion or whether the carbon allowed digestion to proceed normally, increasing in some way the process stability in the batch process.

The semi-continuous feed studies were intended to test for enhancement of the digestion process. For each of the retention times investigated, the carbon dosed units generated gas at a higher rate than the control digesters. Also, the production rates increased as the carbon concentration increased. In Figure 2 the rates of gas production during the 10 day SRT study were three to four times higher for the digester containing the highest carbon concentration than for the control units. Like gas production, volatile solids destruction also improved as the carbon concentration increased. For the 10 day and 5 day SRT studies, the destruction of volatile solids in the carbon dosed digesters generally ranged between 40 and 50 percent. Destruction in the control units was less than 35 percent, and volatile acid concentrations were consistently higher in the controls than in the carbon dosed units. For the 2.5 day SRT study, volatile solids destruction was less than 30 percent in all digesters. As observed in the batch study, the digesters containing carbon produced gas having a higher percentage of methane.

It is evident that the digesters dosed with powdered activated carbon performed more efficiently than the control units in all tests. However, the control digesters never achieved normal operating efficiency during any of the studies. In both the batch and semi-continuous studies, volatile solids destruction in the control digesters was less than 35 percent, and volatile acid concentrations remained high, usually in excess of 2000 mg/l as acetic acid. The percent methane in the gas from the control units was generally below 50 percent. The operating characteristics for the carbon dosed units largely paralled those normally expected in conventional digestion systems. It may be that the effect observed in this research was due merely to the poor performance of the control digesters. However, since consistent environmental conditions were maintained in all of the units, the variation in digester performance can be attributed to the presence of activated carbon. An increase in process stability in the semi-continuous feed tests and a decrease in time for complete digestion in the batch tests are the unequivocal effects of powdered activated carbon in the study. The other postulated effects, enhanced net production of methane and decreased required residence time, may occur. In the experimental study with time limitations on the tests, the control units were not operated at good steady state, and the postulates were not critically tested.

The mechanism of the effect of powdered activated carbon has also been the subject of considerable interst. Several theories have been proposed: 1) carbon provides sites for the anaerobic reaction to occur; 2) carbon adsorbs toxic materials which may inhibit the digestion process; 3) alkaline carbons increase the buffering capacity of the digestion system; and 4) carbon adsorbs volatile acids which are more rapidly destroyed by bacteria after adsorption. In the study, data do not indicate that increased alkalinity could account for the effects. The paper includes results relating to the other proposed mechanisms, but the study does not identify the actual mechanism.

Summary

1. A 2-4 fold increase in gas production was achieved in digesters dosed with small amounts of powdered activated carbon. The concentrations of carbon used in this investigation ranged from 500 to 4000 mg/l. Enhancement appeared to be proportional to the carbon concentration.

2. Anaerobic digesters dosed with powdered activated carbon produced gas having an increased percentage of methane.

3. The addition of powdered activated carbon promoted the destruction of volatile solids.

4. The carbon dosed digesters generally exhibited improved dewatering characteristics.

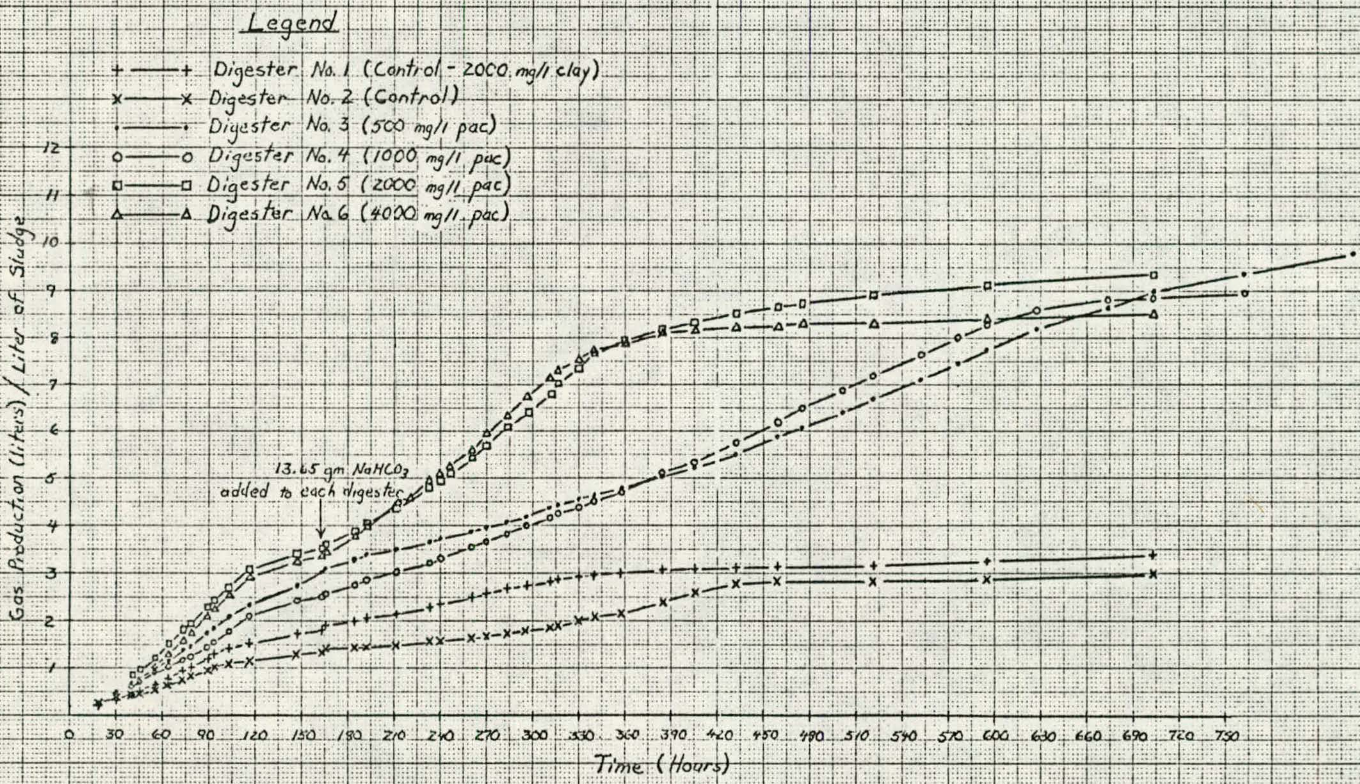

Figure 1. Cumulative Gas Production for Batch Study

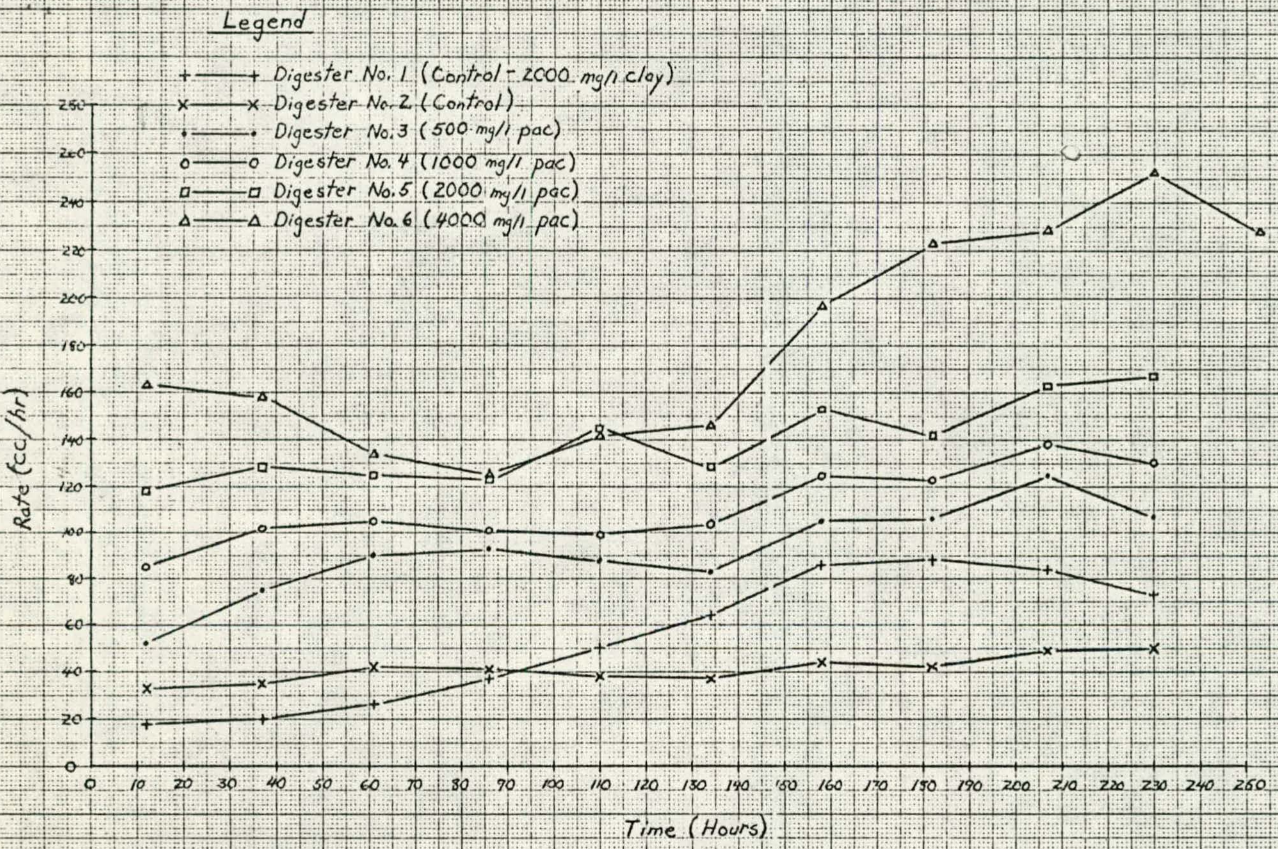

Figure 2. Rates of Gas Production for 10-Day SRT Study