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Project Summary

Performance of Activated Sludge – Powered Activated Carbon – Wet Air Regeneration Systems

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The investigation summarized in this report was undertaken to evaluate the performance of powdered activated carbon (PAC) technology used in conjunction with wet air regeneration (WAR) at municipal wastewater treatment plants. Excessive ash concentrations accumulated in the mixed liquor suspended solids (MLSS) at all facilities that relied on the WAR unit blowdown for ash control. A variety of ash control methods have been implemented and are documented. The nitric acid test for PAC was shown to substantially overestimate PAC concentrations. Previous claims that PAC losses through WAR are 5% or less were based on selected use of the nitric acid test. PAC losses across WAR or the desirability and economics of recovering the volatile suspended solids. (VSS) exiting the WAR reactor could not be quantified. Other areas covered in the report include adsorptive capacity of the recycled material, tertiary filter performance, metals accumulation, oxygen transfer, operation and maintenance concerns and economic considerations. The report includes Appendices submitted by the system manufacturer that dispute many of the report conclusions and provide alternative explanations for some of the data obtained.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Addition of PAC to activated sludge systems is a proven technology for wastewater treatment. The use of wet air oxidation for the treatment of non-PAC sludges, such as primary and secondary sludges, is also an established technology. Eleven municipal facilities in the United States have been built using these combined technologies, with the wet air oxidation process, which is commonly called WAR, used for oxidation of excess biological solids and regeneration of spent PAC.

Nearly all municipal systems designed for PAC addition in the United States have included WAR. A majority of these systems received Federal funding under the innovative technology program. The evaluation summarized in this report was undertaken to document the performance of the PAC/WAR technology at municipal plants. The information on plant operation and performance reflects data available on or before August 1988.

Technology Description

Figure 1 illustrates a flow diagram for a typical municipal system incorporating the PAC/WAR technology. Virgin PAC is added to the activated sludge system influent as a make-up dosage. A slip stream from the the secondary clarifier underflow, which is composed of an activated sludge/PAC mixture, is thickened before being pumped to WAR. Effluent filters, at one time considered optional (1), were installed in nearly all of the municipal systems.

The purposes of the WAR systems are to destroy excess biomass, regenerate PAC and provide a means of controlling ash build-up.

High pressure feed pumps are used to pump the activated sludge/PAC mixture to the WAR system and to sustain an operating pressure of approximately 800 psi. Air is injected into the sludge/PAC stream by means of multiple-stage high-pressure compressors. Heat exchangers are included for the mutual functions of reducing the temperature of the treated material and increasing the temperature of the incoming material. The air/sludge/PAC mixture reacts in a vessel (reactor) for a period of 25 to 50 min before being discharged through the heat exchangers. Steam boilers are used at he beginning of each operating cycle to raise the system temperature. The oxidation reaction generally provides most of the heat required to sustain the reaction temperature between 230°C to 245°C. Material exiting the WAR system consists of a mixture of PAC, other VSS, nonvolatile suspended solids (NVSS), and a large component of soluble organics (which are formed in the for the process). In accordance with the claims process (2), the WAR reactor blowdown stream was the only means of controlling ash in the original design approach. This stream was to be mixed with plant effluent and a return stream from a parallel plate settler underflow before flowing to the settler for separation of the PAC and ash materials. The settler overflow, containing recovered PAC, was to be returned to the process. A portion of the settler underflow, containing settled ash, was to be wasted.

Study Procedures

Initially, discussions were held with personnel at the operating facilities, U. S. Environmental Protection Agency (EPA) regional offices, and the process

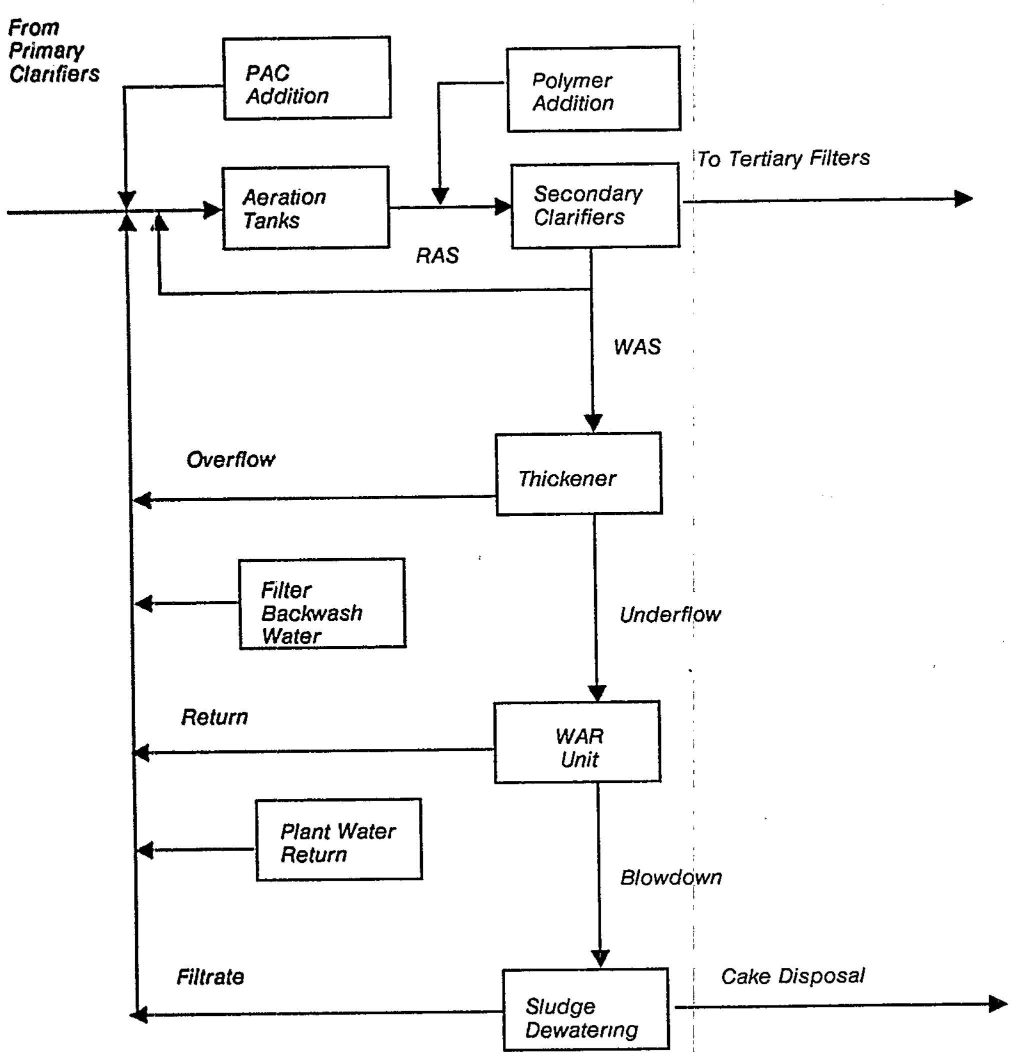

Figure 1. *Flow Diagram of Typical System with PAC/WAR.*

manufacturer (Zimpro Inc.) to gather background information. Typical process data were collected from the various facilities and reviewed. Site visits to five facilities were made to review the intended versus the actual operation, and the types of plant records maintained and analyses performed; a thorough plant inspection documented locations of sampling points and sidestreams. Following a preliminary analysis of the data and assessment of the PAC/WAR process, an interim meeting was held (12/87) with personnel from Zimpro, EPA and the assessing contractor to review and discuss the preliminary findings. Information and discussions from this meeting were used by EPA to determine steps needed to complete the evaluation. Subsequently, two more facilities were visited to gather additional data. Supplemental conversations were then held with people at the various operating plants to confirm information or secure missing data. This information was analyzed along with other published data to complete the technology evaluation.

A summary of the results was presented and discussed during a final meeting (8/88) with several EPA personnel, Zimpro personnel, and the contractor team. Discussions during the final review meeting and subsequent communications with Zimpro Inc., have clearly indicated a difference of opinion as to the appropriate interpretation of much of the assembled data. For this reason, comments from Zimpro Inc., are provided in two appendices to the final report so that their viewpoints will also be available to the reader.

Plant Summary

The municipal PAC/WAR facilities that were reviewed are summarized in Table 1. Color reduction, nitrification, limited space availability and toxics removal were the predominant factors given for selecting this technology. Effluent permit limits range from typical 30/30 mg/L for BOD5 and total suspended solids (TSS) (with and without nitrification) to summer limits at Kalamazoo of 7/20/2/1 mg/L for BOD_5/TSS/NH_3-N/Total Phosphorus. The current status of municipal facilities indicates that all have, in some way, modified the original design and/or of their systems.

Ash Accumulation and Control

Mixed liquor ash accumulation was a common problem at all full scale PAC/WAR facilities listed in Table 1. when they were operated as originally designed. The size and specific gravity of the ash and PAC particles were found to be similar, and effective separation would not occur. As a result, ash was returned to the process from the Lamelle settler along with the PAC. Mixed liquor ash levels of from 60% to 80% were observed at facilities that relied solely on WAR unit blowdown for ash control. This led to the loss of excess TSS from the secondary loadings on the tertiary filters.

A variety of methods were initiated for ash control. Vernon discontinued PAC addition for several months at a time, but continued to run the WAR system. Mixed liquor was occasionally purged to the primary clarifiers for disposal with the primary sludge. PAC addition was recently reinitiated to control effluent color. Mount Holly discharges a portion of the WAR unit effluent to the primary sludge dewatering system for disposal. East Burlington practices direct dewatering of a WAR reactor effluent slip stream. PAC addition at South Burlington has been discontinued, and the plant currently operates as a conventional activated sludge facility. Kalamazoo purged mixed liquor for ash control before constructing a differential sedimentation and elutriation (DSE) system to separate ash. Bedford Heights switched to addition of a nonactivated carbon (NAC), which is used on a throw-away basis (no WAR system operation). The NAC costs $0.16/lb, which is roughly half the cost of a typical PAC, and is maintained at the minimum concentration needed for satisfactory plant operation. Medina County is operating a modified DSE system and is dewatering the ash with the primary sludge. North Olmsted experimented with several operating modes, with and without WAR unit operation and with and without PAC or NAC addition. They recently switched to conventional activated sludge operation but plan to convert back to the use of NAC. Sauget added PAC during start-up, but a catastrophic failure of a heat exchanger made it impossible to operate their WAR system. The initial PAC dose has since been wasted from the plant. El Paso is wasting a slip-stream of sludge upstream from their WAR reactor to anaerobic digesters.

Differential Sedimentation and Elutriation (DSE)

Zimpro Inc., conducted a number of standardized pilot plant studies of the DSE process to estimate the requirements for full-scale ash removal facilities. On average, the results indicated that 37% ash removal and 90% VSS recovery would be reasonable expectations. Four of the PAC/WAR systems either have or are in the process of installing DSE systems.

A slip-stream of the WAR unit effluent is blended with softened water in an approximately 1:4 volumetric ratio. Dispersants, such as sodium hexametaphosphate or metasilicate, and an anionic polymer are then added before an upflow elutriation tank. VSS (including PAC) are concentrated and removed in the underflow, and the ash fraction is concentrated and exits in the overflow. Cationic polymer addition flocculates the ash, and this stream is sent to a clarifier for separation. A filter press is the normal mode for dewatering the concentrated ash underflow. East Burlington has a full scale DSE system but, because of the low PAC dosage required for satisfactory wastewater treatment, does not consider it cost effective to operate. Instead a slip stream of WAR reactor effluent is sent to a dedicated filter press for dewatering. The system at Jessup, MD, was not in operation at the time this technology evaluation was conducted. A full scale system at Kalamazoo was brought on line in June 1988. Data from the modified DSE system at Medina were unavailable for incorporation in this evaluation.

Ash Balances and Accumulation

East Burlington and Kalamazoo maintain extensive plant records and also monitor internal sidestreams. Material balances for several parameters (e.g., TSS, VSS, and NVSS) around their aeration basins and WAR units were developed from the operating records at these plants. An excellent TSS balance was developed for 1 yr of record at the East Burlington plant. The recycled ash (NVSS) from the WAR unit constituted 83% of the ash entering the aeration basins.

Figure 2 illustrates the buildup of various MLSS components that was experienced over a 273-day period at the Kalamazoo facility. This operating period was selected because it does not include the removal of 4 million gallons of mixed liquor from the aeration basins for temporary ash reduction, which occurred in the last quarter of 1986, nor does it include the period of sustained high effluent TSS, which occurred in the last quarter of 1987. The mixed liquor carbon volatile suspended solids (PAC) concentration was measured by a nitric acid digestion procedure discussed in the next section of this summary. During the periods when effluent quality was reasonably satisfactory (April through

Table 1. *Summary of Municipal PAC/WAR Facilities Reviewed*

Facility	Flow, mgd Current/ Design	PAC/WAR Status*	Reason for PAC**	Permit Limits BOD$_5$, mg/L	TSS, mg/L	NH_3-N, mg/L
Vernon, CT	4.2/6.5	MA	C	10	20	–
Mt. Holly, NJ	2.4/5.0	MA	C,S	30	30	20
E. Burlington, NC	7.0/12.0	MA	C,N,T	12-24	30	4.0-8.0
S. Burlington, NC	6.8/9.5	AS	C,N,T	12-24	30	4.0-8.0
Kalamazoo, MI	25/54	MA	C,N,T	7-30	20-30	2.0-10.0
Bedford Hts., OH	3.4/3.5	NAC	N,S	10	12	5.1
Medina Co., OH	7/10	MA	N	10	12	1.5-8.0
N. Olmsted, OH#	6/7	AS	N,S	10	30	2.3-6.9
Sauget.IL	16/27	AS	T	20	25	–
El Paso,TX	4.5/10	MA	N,O	SD##	SD	SD

*MA = Modified operation and/or design for ash control.
AS = Converted to conventional activated sludge.
NAC = Converted to the use of nonactivated carbon without regeneration.
**C = Color Removal, S = Space, N = Nitrification, T = Toxics, O = Organics.
#Plan to convert to NAC without regeneration.
##SD = Secondary Drinking Water Standards.

mid-September), there was a continuous increase in ash concentrations.

PAC Measurements and Loss

Analytical Procedures

Attempts to construct mass balances for PAC from plant records were unsuccessful. Determination of the PAC content in the mixed liquor is an important process control parameter, and the inability to perform PAC balances was deemed significant. This led to a review of the nitric acid test method used to determine the PAC fraction of the MLSS in PAC/WAR systems.

The MLVSS measured in PAC/WAR system aeration tanks may be presumed to include active biomass, residue, nondegradeable VSS in the entering wastewater, recycled and virgin PAC, organics bound to the PAC (which are measured as VSS), and any inert VSS formed in and/or not oxidized or solubilized in the WAR process. PAC/WAR plants have traditionally classified all VSS in the aeration basin as either PAC or biomass, with the PAC concentrations measured on an ash free basis. The analytical method provided to the facilities to differentiate between these two classes of VSS assumes that all non-PAC VSS are dissolved by nitric acid digestion.

According to Zimpro personnel (3), the nitric acid digestion technique was developed at Zimpro to attempt to quantitatively determine the biomass and powdered carbon in a mixture. A number of claims concerning the accuracy and appropriateness of the test are documented in the report.

Plant Operating Results

In addition to using the nitric acid test procedures for process control, several operating facilities also use the nitric acid techniques to measure the PAC losses across the WAR unit. The individual measurement results from three facilities where these data were available are summarized in Table 2.

Nine months of data from both East Burlington and Kalamazoo were analyzed in attempts to establish PAC balances for these facilities. The results of this analysis are presented in Table 3. These material balances show that Kalamazoo measures daily losses and accumulations of PAC that exceed the PAC addition rate by a factor of four. East Burlington measures daily PAC losses that are five times higher than the mass of daily PAC addition. Since measurement of the PAC addition rate does not depend on the nitric acid procedure and has been verified through comparison with plant purchase and use records, the average rate of PAC addition is known. Therefore, the nitric acid procedure substantially overestimates PAC concentrations, making the measured value of this parameter of no quantitative significance.

A steady state mass balance was also developed for East Burlington to evaluate aerator PAC concentrations as a function of PAC loss in WAR and in effluent and waste solids. The results indicated that the PAC concentrations measured in the aerator with the nitric acid test were higher than could be present. A comparison of the measure value with computed values for various assumed oxidation losses in the WAR unit indicated that even with no PAC oxidation in WAR, the measurement error [(measured value-true value) true value] would be 67%.

Results of previous VSS destruction studies on wet air oxidation of sludges not containing PAC are summarized in the report and show that most, but not all, of the VSS are oxidized or solubilized. A small portion of VSS does not go into solution and, as shown in Figure 1, nondegradeable VSS entering the plant that are neither oxidized nor solubilized by WAR must cycle in the system until escaping in the plant effluent or until being removed in a waste stream. Part or all of the gradual buildup in MLVSS at Kalamazoo, as shown in Figure 2, can be attributed to this type of material. Biomass destruction through WAR (measured by the nitric acid test) at Kalamazoo decreased from greater than 96% shortly after start-up in 1985 to an average of 83% during the first 5 mos. of 1988.

The characterization of the VSS existing WAR (as measured by the nitric acid test) at three facilities are summarized in Table 4. The accumulation of this "biomass" material contributes to the falsely high values for the measured PAC concentrations.

The absence of a correlation between PAC addition and PAC levels (as measured by the nitric acid procedure) at Kalamazoo is apparent in Figure 3. Ten-day moving averages of PAC addition minus the estimated daily PAC loss calculated from the effluent VSS values and the measured PAC percentage in the aeration basins) are shown along with the measured 10-day moving average values of mixed liquor PAC concentrations in the aeration basins. There is a gradual rise in the measured PAC concentrations that, on a long term basis, is independent of the PAC addition rate.

PAC Loss by WAR

The data summarized in Table 2 indicate PAC losses across WAR units to be in the range of 30% to 40% per regeneration. As shown in Table 3, however, the magnitude of the PAC loss exceeds by four to five fold the amount of PAC added; this shows that the absolute values of the PAC concentration measured by the nitric acid digestion technique are meaningless. Whether or not the relative change of 30% to 40% represents the actual percentage loss per WAR cycle cannot be determined from the data available.

In previous pilot studies of PAC systems with WAR, Zimpro reported low PAC losses through WAR. For example,results reported from Back River (4) stated that the WAR unit operated with PAC recovery efficiencies in excess of 95%. In an attempt to ascertain the reason for the large variations between the Back River results and those observed at the three facilities summarized in Table 2, a detailed analysis of the Back River report was undertaken. The reasons for the apparent differences are related to the selected use of the nitric acid procedure and are detailed in the final report.

Tertiary Filtration

Tertiary filters were installed in nearly all of the municipal PAC/WAR facilities even though several facilities have an effluent TSS limit of only 30 mg/l. Solids capture in secondary clarification was not adequate at East Burlington or Kalamazoo to consistently meet the discharge permit indicating the key role played by the tertiary filters at these locations. In addition, polymer assisted clarification was normally used at the various facilities. Typical polymer costs were estimated at $21,000/yr/MGD based on an applied dosage of 2.75 mg/l and a unit costs of $2.50/dry lb.

Recycle Loadings

PAC systems have a high mass of organics, nitrogen and phosphorus in the WAR reactor effluent. The WAR return stream can represent a significant portion of the loading applied to the secondary process. Organic (BOD_5) recycle loading at E. Burlington and Kalamazoo ranged from 11% to 29% of the primary effluent loading and the NH_3-N loading ranged from 54% to 120%.

Kalamazoo monitors total phosphorus in the WAR return stream. The concentration is high and represents 730% of the mass loading from the primary clarifier. This facility has a phosphorus limitation and adds alum to the secondary system for its precipitation. The precipitated phosphorus compounds and those resulting from cellular destruction by WAR have concentrated as an insoluble, inert recycled material.

Adsorptive Capacity of Recycled PAC

It is difficult to characterize the adsorptive capacity of the material exiting the WAR system. Attempts to characterize the regenerated PAC from the Sauget pilot study (5) showed that the COD adsorption capacity was too low to measure. That study concluded that comparison of virgin and regenerated PACS was not an appropriate indicator of performance.

Recktenwalt (6) reported that PAC subjected to multiple regenerations does not retain significant capacity for adsorption of low molecular weight compounds such as 2,4-dinitrophenol. On the other hand, methylene blue adsorption after regeneration was essentially the same as that for virgin PAC. Materials that have adsorptive properties similar to methylene blue should adsorb as well to the recycled VSS as to virgin PAC.

Metals Accumulation

Activated carbon will adsorb some heavy metals. This removal mechanism could help reduce the toxicity to biological functions in PAC/activated sludge systems. One facility (Bedford Heights) experienced operating and

Table 2. *Measured PAC Losses Across WAR by Nitric Acid Digestion*

Location	*Period*	*Measured PAC Loss per WAR Cycle, %*	*Number of Samples*
Kalamazoo	*2/88-5/88*	*40.6*	*46*
E. Burlington	*1/87-2/88*	*30.8*	*31*
Mt. Holly	*1/87-7/87*	*32.1*	*48*

Table 3. *PAC Balances*

Parameter	*Kalamazoo, lb/day*	*East Burlington, lb/day*
Input		
*PAC Added**	*3,704*	*404*
Total	*3,704*	*404*
Loss + Accumulation		
*PAC Accumulation**	*1,277*	*0*
*PAC in Final Effluent***	*1,056*	*232*
*PAC Destroyed in WAR***	*11,452*	*1,596*
*PAC Removed in Filter Press Solids***	*0*	*344*
Total	*13,785*	*2,172*

**Reported on an ash-free basis.*
***Based on nitric acid test procedure.*

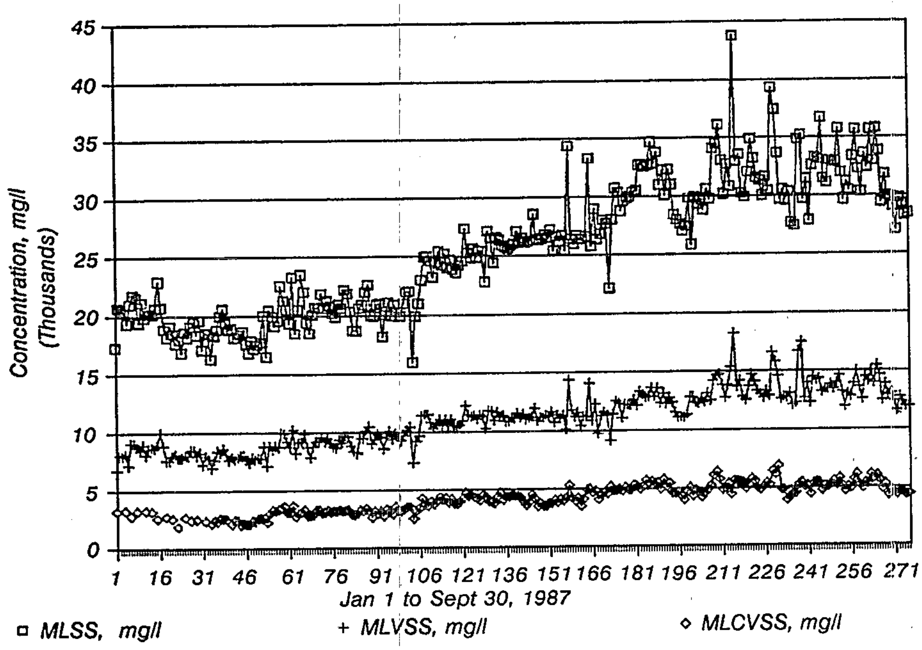

Figure 2. *Aeration basin suspended solids components at Kalamazoo, MI.*

effluent quality problems that were attributed to heavy metals accumulation. This facility later controlled ash and ash associated heavy metal accumulations by substituting NAC for PAC and abandoning attempts at media recovery.

The Vernon facility noted high metals concentrations in the blend of primary and waste secondary sludge fed to the vacuum filters and conducted an EP Toxicity Extraction to determine the Resources Conservation Recovery Act (RCRA) status of the sludge. Results of the EP Toxicity Extraction analyses indicated that the metals did not leach appreciably under conditions of the test.

Operations and Maintenance Considerations

A WAR unit is composed of high temperature and high pressure components. Operating temperature/ pressure conditions require that repairs (such as welding) be performed by certified craftsmen and that all repairs be completed in such a manner that the pressure and temperature rating certifications are maintained.

Operations of a WAR system requires a working knowledge of boiler water chemistry. Several facilities experienced coil failures in their WAR system boilers that were reported to be the result of inadequate deoxygenation of boiler feed water. Other facilities experienced frequent failure of high pressure valves that required replacement of trims and seats. A design modification to utilize ceramic components has decreased the failure rate at some facilities. Kalamazoo and Mount Holly have located alternative suppliers which has resulted in valve component increased service life and reduced cost. North Olmsted had difficulty in obtaining replacement components, some of which had a 52-wk delivery schedule because of the special nature of the alloys specified by the system manufacturer.

Scale formation in the WAR reactor reported by several facilities. Formation was severe at some plants, resulting in limited throughput capacity and decreased operating temperature. Scale formation continued to occur in some plants that regularly acid cleaned their WAR systems. Manual removal of scale with water lasers has been required at some facilities.

Significant scum accumulation on the surface of secondary clarifiers was experienced at three facilities. The cause (s) for these accumulations has not been determined.

Additional O & M considerations included frequent maintenance on the last stage of multi-stage air compressors, abrasion-related repairs to slurry transfer pumps, and check valve problems on high pressure feed pumps.

Economic Considerations

A few facilities maintained separate records of the costs associated with WAR system, O & M. Average monthly O & M costs in 1986 (parts, electricity,fuel oil cleaning and labor) for one facility that processed an average of 42,000 gpd, containing 26,300 lb/d of TSS, through their WAR unit averaged $21.86/1,000 gal or $35.13/1,000 lb of TSS processed through the WAR unit. Another plant that also maintained separate cost records computed 1986 WAR processing costs (fuel, water, electric @ $.07/Kwh, repairs, and labor) to be $27.68/1,000 gal or 50.88/1,000 lb of TSS.

Bedford Heights maintained detailed records of WAR operating costs. For an

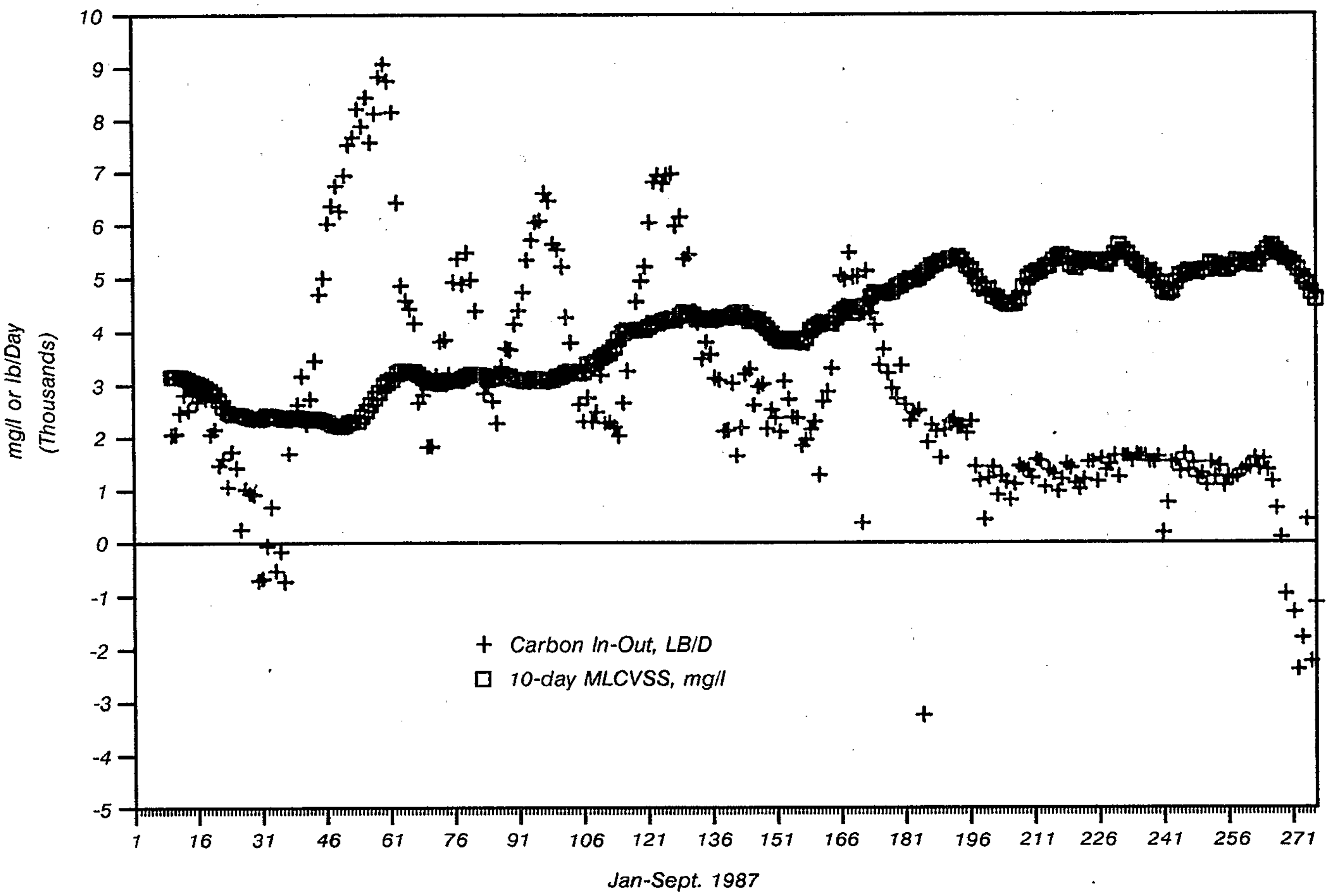

Figure 3. *Ten day moving average of PAC addition less loss and measured aeration basin levels at Kalamazoo, MI.*

11-mo period in 1986, the WAR unit processed 2.58 million gal at an average cost $42.00/1,000 gal (labor, natural gas, electricity, water lubricants, and repairs). The cost was equivalent to $75.58 per 1,000 lb processed. Bedford Heights also operates a low pressure oxidation (LPO) unit for primary sludge conditioning. The 1986 LPO operating costs (labor, utilities, repairs) were $15.00/1,000 gal conditioned in this unit.

Bedford Heights considered installing a DSE system during their cost effectiveness analysis of options to address ash buildup problems. Instead, they chose to substitute NAC for PAC and waste the excess biomass/NAC mixture to the primary clarifiers. The combined sludge is now conditioned in the LPO unit and the WAR unit is no longer operated as such. They have proposed to convert the WAR unit to an additional LPO unit.

The economic analysis performed for the retrofit DSE system at Kalamazoo assumed that all VSS that exited the WAR system were PAC (7). Based on the nitric acid procedure, the PAC content is only 68% of the total VSS (Table 4). Based on the mass balances presented earlier, however, it is clear that the actual PAC concentration is substantially less than that measured by this testing procedure. Since there is no analytical procedure available for the determination of true PAC content, the cost effectiveness of the Kalamazoo DSE system cannot be accurately determined on the basis of the reported value of the PAC that is recovered by the system.

Table 4. **Characterization of VSS from WAR**

Facility	*% PAC**	*% Biomas**
E. Burlington	*79.0*	*21.0*
Kalamazoo	*67.7*	*32.3*
Mt. Holly	*79.2*	*20.8*

**As measured by the nitric acid procedure*

Operating costs for DSE systems include those associated with water, water softening, dispersant and dual polymer application, power and labor. Manufacturer pilot studies were used to project these costs to be approximately $20/1,000 gal of material processed. Given the inaccuracy of the estimates of PAC content, it is difficult to determine the benefit of a DSE system operation over that of direct wasting of a fraction of the material, as is practiced by several facilities.

The full report was submitted in fulfillment of EPA contract No. 68-03-3429 by James M. Montgomery Consulting Engineers, Inc. under the sponsorship of the U.S. Environmental Protection Agency.

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The complete report, entitled "Performance of Activated Sludge-Powered Activated Carbon-Wet Air Regeneration Systems," (Order No. PB 90-188889/AS; Cost: $17.00, subject to change) will be available only from:

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