Use of Thermophilic Biological Aerobic Technology for Industrial Waste Treatment

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ABSTRACT
Thermophilic aerobic treatment systems offer unique advantages for treatment of high strength organic waste streams and slurries/sludges. These systems combine the best features of conventional aerobic and anaerobic processes that include rapid biodegradation kinetics and low biological solids production, respectively. Application of these processes can result in substantial economic benefit by reducing residuals processing and disposal costs. These systems have not been widely applied for industrial waste treatment, therefore the goal of this paper to show the advantages of applying thermophilic aerobic treatment to these streams. Also included in the paper is a discussion of the process benefits along with design/application considerations and different industrial case histories.

KEYWORDS
Aerobic liquid waste treatment, high-strength organic waste, industrial waste, sludges, thermophilic process

INTRODUCTION

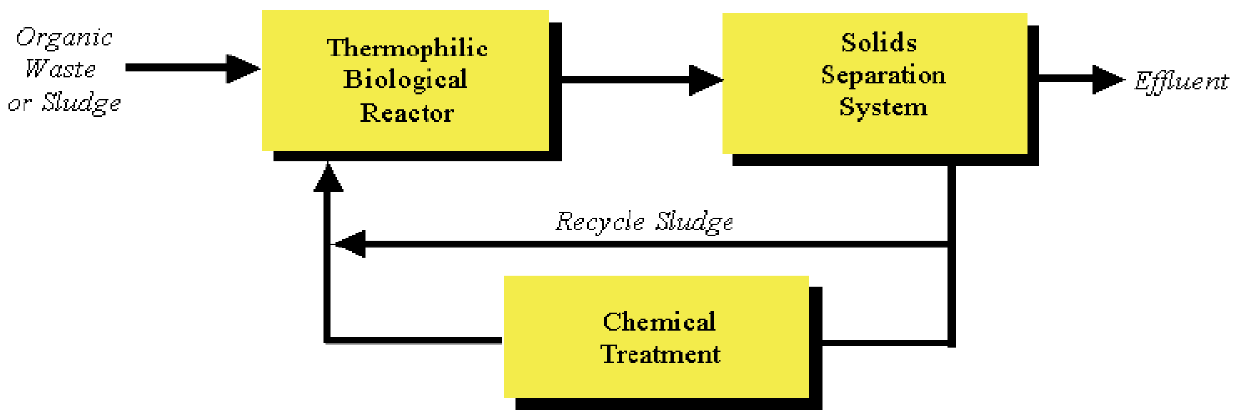
Aerobic thermophilic biological treatment systems are often viewed as a relatively novel waste treatment technology or process. These systems were first developed in the 1970s and were referred to as "fluidized composters" because they can be considered to be a hybrid of static pile aerobic composting and fluidized biological treatment. The purpose of this paper is to present the operational experience for aerobic thermophilic treatment systems that have been applied for industrial waste treatment. There are many thermophilic systems that have been designed for sludge and treatment. ATAD (autothermophilic aerobic digestion) systems are applied in many locations for the treatment of sludges. The primary focus of these systems is to achieve pasteurization of the target sludges so that these sludges can be land applied.

Overview of Thermophilic Aerobic Treatment

Thermophilic aerobic treatment is a promising process technology for treating high strength organic waste streams and sludges that result in a highly efficient rate of organic destruction with little or no generation of residual sludges commonly associated with most biological processes. The technology combines the advantage of low biomass yields and rapid kinetics associated with high temperature operation and stable process control of aerobic systems into one process flow scheme.

A modification of thermophilic aerobic treatment, the AFC℠ process, is presented in Figure 1. The waste streams are introduced to a self-heating, completely mixed, thermophilic (45-65 ^{o}C) reactor for treatment. Effluent from this reactor is sent to a solid separator (e.g., ultrafilter, dissolved air flotation, or other appropriate solid separation device). A portion of the separated solids is returned to the thermophilic reactor while the remaining solids go to a small chemical treatment unit prior to being sent back to the thermophilic reactor for further digestion and destruction.

Figure 1 - Modified Thermophilic Aerobic Treatment System



Results from several bench-, pilot-, and full-scale systems had shown that the technology can cost effectively reduce organic residuals by approximately by 90% with a potential to achieve 100% destruction. The high destruction efficiency is achievable because the high temperature characteristics of the thermophilic process facilitates the biodegradation of organic components that are more soluble at high temperature and therefore more efficiently converts up to 99% of the soluble organics to carbon dioxide and water. Residual organics or organic solids resisting biodegradation are "softened" in the chemical treatment step and then converted to carbon dioxide and water upon re-entering the thermophilic reactor. This technology has successfully been applied to a variety of waste streams including, but not limited to: High strength organic acids, fermentation wastes (spent mycelia), solvents, high salt waste streams (3%-8% salt), viscose fiber sludges, waste activated sludges, phenolic streams, high strength methanol streams, high strength nitrate streams, cosmetic wastes with high fats, oils and greases (FOG), dairy wastes with high FOG, metal stamping oils and greases, and food processing wastes.

Advantages of Thermophilic Aerobic Treatment

Thermophilic systems are rarely deliberately applied or considered as technology for liquid waste treatment. Mesophilic aerobic systems or anaerobic technology are usually applied instead. Thermophilic aerobic processes can offer substantial performance benefits over other biomass systems. Many aerobic thermophilic treatment systems evolved inadvertently in cases where mesophilic aerobic systems were designed without sufficient sensitivity to heat generation and accumulation issues. These "inadvertent thermophilic" systems were devised using retrofit approaches on existing mesophilic systems. In some cases, thermophilic operation (operating temperature approximately 38 °C and higher) was maintained while in other cases, operational modifications were implemented to facilitate a return to mesophilic operations (operating temperatures less than 38 °C).

Aerobic thermophilic processes offer several advantages over mesophilic aerobic or anaerobic systems. Performance advantages of thermophilic systems include:

- *Lower waste sludge production* – Thermophilic aerobic systems have characteristically lower biomass yields, which results in lower sludge production. Some commercial systems are engineered, which virtually eliminate waste organic sludge production.

- *Enhanced COD Removal* – Thermophilic aerobic units have been observed to realize high levels of COD removal than mesophilic systems. The system discussed in this paper is fed influent COD concentrations of 30,000 mg/L and produces an effluent with a COD of approximately 20 mg/L. This is a COD removal efficiency of 99.9%.

- *High Loading Rate Capability* – Thermophilic aerobic systems can be engineered to have very high loading rates in comparison with mesophilic aerobic treatment systems. Loading rates of 14 kg COD/m^3/day have been demonstrated on fermentation broths resulting from pharmaceutical production activities.

- *Enhanced Biodegradability Capability* – Thermophilic aerobic systems have the biokinetic capability of aerobic systems and are much more kinetically robust then anaerobic systems.

Design and Operational Issues

Experience has shown that aerobic thermophilic treatment systems present challenges for engineers and operators. Key design issues surrounding any high rate thermophilic aerobic application involve the aeration system, solids separation, and foam control.

- *Oxygen transfer* – Increased operating temperatures which lower dissolved oxygen saturation values and higher chemical oxygen demand (COD) loading necessitate an increased focus on the design of the oxygen transfer or aeration system. Typically to meet the high oxygen transfer requirements of the process, aggressive aeration systems are specified (e.g., jet aeration) and reactor water depths are increased above conventional applications.

- *Solids separation* – A thermophilic biomass can not be separated using gravity settling and biomass yields are very low (i.e., less than 0.05 kg per kg of COD removed), therefore the system requires more aggressive methods of solids separation. Field experience has shown that ultrafiltration, dissolved air flotation, and rotary drum thickeners are effective in providing high capture efficiency of the thermophilic biomass.

- *Foaming* – Both high biomass concentration in the bioreactor (over 30,000 mg/L of suspended solids) and high temperature are conducive to foaming incidents. The high solids operation results in accumulation of high level of biological surfactants. Transitions to thermophilic operation (shifting microbial populations from mesophilic to thermophilic) or cycling between thermophilic and mesophilic operation also result in spurious foam production. Foaming can be controlled by adding antifoam agents or designing mechanical foam breakers.

Periodic foaming events are often interpreted as indicative of an unstable treatment system or unstable operation; however, these events are inherent with any biological process that is operated at high biomass concentrations (greater than 10,000 mg/L).

Due to the thermophilic nature of the process, heat and energy balancing are also extremely important design considerations. A component of the design effort has to include a focus on reactor heating characteristics so that appropriate considerations for insulating and/or cooling the biological reactor are addressed.

Cost-Effective Biological Alternative to Incineration

Current approaches for handling high strength industrial waste streams include off-site disposal to other treatment facilities (including land disposal) or on-site treatment via biological, physico-chemical or thermal (incineration) processes. Off-site treatment is by far the most commonly used method where wastes are hauled to private or public disposal facilities. This method of disposal carries a high premium and increased liability associated with the transportation and the ultimate fate of the waste stream. As more and more regulations both in the USA and in Europe prohibiting land disposal of wastes, more facilities are considering onsite treatment of their high strength wastes. Physical and chemical treatment processes tend to be expensive and are prone to generating large quantities of chemical sludge, which can be very costly for off-site disposal. Incineration provides a total destruction alternative at high cost and strong public opposition.

Of the biological processes, aerobic systems tend to be more resilient to a variety of waste streams and variable loading conditions. Anaerobic systems on the other hand, produce much less sludge and have lower operating costs due to lower energy requirements. A modified thermophilic aerobic system such as the AFC℠ system is an aerobic biological treatment process operating in the anaerobic range of sludge production, therefore combining the best features of both processes. The process still requires a high level of aeration, but the extremely high kinetic rates coupled with resistance to shock loads and low residual sludge production make it an attractive process to treat high strength industrial waste streams.

CASE HISTORIES

Four case histories of full-scale thermophilic aerobic treatment systems are presented. In all cases, the minimization of sludge production was a major consideration for process selection. Other factors such as waste biodegradability and salt concentration mitigated against the use of anaerobic processes. The full-scale operating experience demonstrated that modified thermophilic aerobic systems with an integral chemical treatment step can achieve the goal of zero-net organic sludge production.

Case History 1 - Treatment of High Strength Groundwater

A remedial investigation of the site found groundwater that contained CODs ranging from 80,000 to 200,000 mg/L. Ancillary hydrogeological data and plant production records indicated the site contains as much as 150,000 M^3 of the high-strength material. A detailed feasibility investigation was performed to evaluate various alternatives for treatment and disposal of the impacted groundwater. Results of the study showed that on-site treatment with discharge to a municipal treatment system was more cost-effective than off-site disposal, which cost as high as $US0.26 per liter.

A review of on-site treatment options showed that a modified thermophilic treatment process was the most cost-effective process. Successful bench and pilot testing led to the implementation of a full-scale treatment system that started operation in October 1995. The treatment system is designed to treat 1,100 kg/day COD. The system includes two groundwater collection systems: high COD deep bedrock groundwater and low COD, benzene-impacted shallow groundwater. These streams are combined to yield a final COD of 30,000 mg/L with a non-volatile dissolved solids level of 2.5% in a 38 M^3 balance tank. From the balance tank, the groundwater is pumped to a 400 M^3, insulated and covered, thermophilic biological reactor. This unit is mixed and aerated using a jet aeration. The reactor is piped to a ultrafilter that is used to separate the thermophilic biomass from the treated effluent. The separated biomass is returned back to the thermophilic reactor while the treated effluent from the ultrafilter is combined with a portion of the shallow groundwater to lower the temperature to < 32 ºC and the effluent dissolved solids to < 2% prior to entering a 110 M^3 extended aeration package plant designed for treatment polishing. Final effluent from the package plant is discharged via gravity to the local sewer. The extended aeration package plant was never needed because of superior performance of the thermophilic system.

System performance to date has been excellent. The system began discharging to the local municipal treatment system 45 days ahead of schedule. Effluent quality has been within discharge permit requirements for all parameters. BOD and COD treatment efficiency has been greater than 99% through the thermophilic reactor, thus eliminating the need to operate the extended aeration package system. The overall treatment process produces less than 5% sludge per mass COD removed, thus minimizing the need and cost for off-site disposal of hazardous solids wastes.

Case History 2 - Treatment of Specialty Chemical Wastes and Waste Activated Sludge

A specialty chemical manufacturer makes adhesives, aircraft coolants, and assorted phenolic-based products. Wastewaters generated during the production of these specialty chemicals are treated by an on-site biological activated sludge system. The above processes generate approximately 23 M^3 of combined primary sludge and secondary waste-activated sludge at a COD concentration of 200,000 mg/L and a solids concentration of 8% to 10%. The high organic-strength sludge had all been hauled off-site for disposal at an annual cost of over $1,000,000. The plant decided to install a modified thermophilic aerobic treatment system to realize more efficient waste treatment and to reduce sludge disposal costs.

An economic benefits analysis for implementing a modified thermophilic sludge treatment process indicated potential substantial cost savings. Based on the favorable economic benefits analysis, continuous-flow bench-scale testing was performed over a three-month period on a combined sludge grab sample. Results of the testing showed 85% total COD destruction via thermophilic biodegradation. An integral chemical treatment step showed that enhanced net solids destruction could be achieved.

Follow-on pilot testing verified bench-scale test results, defined sludge waste characteristics, refined chemical treatment procedures, optimized cost-effective solids separation equipment, and defined solids disposal characteristics.

The system construction was completed April 1998. Performance to date has yielded greater than 80% organics material destruction with reduced excess sludge disposal. One complicating factor, which impacted performance, was the chronic discharge of high levels of inorganic iron sludge into the system. This material accumulated in the reactor and hampered solids separation (ultrafilter) efforts. The plant has subsequently halted the discharge of iron sludge to the system and noted a marked improvement in system performance. Despite the interference in process operations caused by inorganic sludges, annual operating costs estimated at $450,000 per year were still achieved.

Case History 3 - Treatment of High Salt Specialty Chemical Wastes

A chemical company recently expanded a specialty chemical production facility in the Eastern U.S. Wastewater generated by the expanded facility consists of three waste streams: heavy, light, and oligomer. All wastewater currently generated at the site is being hauled off-site for disposal. A modified thermophilic aerobic treatment system was selected for pretreatment of the final wastewater prior to discharge to the local municipal treatment plant.

The raw wastewater characteristics are flow rate = 60 M^3, COD = 120,000 mg/L, non-volatile dissolved solids = 80,000 mg/L, toluene = 400 mg/L, and chlorides = 4,000 mg/L. Key effluent requirements are BOD < 300 mg/L and toluene < 0.028 mg/L

The system includes wastewater equalization, pH adjustment, a thermophilic aerobic reactor, ultrafiltration, and an ancillary chemical treatment process. The goals of the system are to remove COD, BOD, and toluene to within pretreatment permit requirements while minimizing the production of excess biological solids requiring processing and off-site disposal.

The system start-up had the usual assortment of equipment and process issues. Once stable operation was achieved, the system demonstrated high COD destruction of around 90% with no net sludge production. The interesting aspect of this system is that solids separation is achieved with an ultrafilter. Consequently, there is no way for solids to be "lost" from the system such as what occurs with anaerobic reactors that are "zero sludge" because they lose 300 to 600 mg/L of biomass in the effluent. Extended aeration activated sludge plants can also be "zero sludge" because of solids losses from the secondary clarifier. The modified thermophilic plant at this installation with the use of the chemical treatment step demonstrated that the system could achieve zero net sludge production after long term operation. It was also interesting to note that non-volatile solids did not accumulate in the system. These materials exited the ultrafilter as dissolved solids.

Case History 4 - Treatment of Food and Grease Wastes

A processing plant operates a chicken and fish food product production facility. Wastewater generated by various production lines is sent to an oil and grease trap prior to discharge to an industrial park wastewater treatment system. Under revised local permitting requirements, the facility was required to upgrade its existing pretreatment system to remove BOD, COD, oil and grease, and suspended solids. The design parameters for the new system were flow rate = 400 M^3/day, BOD = 5,000 mg/L, COD = 10,000 mg/L, TSS = 5,000 mg/L, and oil and grease = 1,800 mg/L. Effluent requirements were BOD < 500 mg/L, COD < 700 mg/L, and TSS < 600 mg/L.

The owner of the facility selected a modified thermophilic process in order to treat the target waste and to minimize the need for off-site sludge disposal. The proposed system included wastewater equalization, pH adjustment, a thermophilic aerobic reactor, and an ancillary chemical treatment process. The goals of the system were to remove COD, BOD, and TSS to within pretreatment permit requirements while minimizing the production of excess biological solids requiring processing and off-site disposal.

The system has been on-line since January 1998 and has been in compliance with all permit requirements since March 1998. To date, no excess sludge disposal has been required.

A summary of nominal design and performance characteristics for all four systems is provided in Table 1.

Table 1 - Nominal Design and Performance Summary for Modified Thermophilic Aerobic Treatment Systems

Parameter	Case 1	Case 2	Case 3	Case 4
Design Flow, M^3/d	40	25	95	400
Design Influent COD Concentration, mg/L	30,000	200,000	120,000	10,000
Design COD Loading, kg/d	1,140	4,500	11,400	4,500
Design OUR, mg/L/hr	125	166	200	150
Max Observed OUR, mg/L/hr	125 <	200 <	500 <	200 <
Reactor Size, M^3	400	1,200	1,600	475
COD Removal, %	99	85	90	94
Sludge Production, Kg VSS/d	8	650 (3)	None (1)	None (1)
Operating Temperature Range, ºC	46 – 52	43 – 52	53 – 65	53 – 63
Key Treatment Requirements	COD < 750 mg/L BOD < 300 mg/L	Reduced sludge by 90%	BOD < 300 mg/L Toluene < 0.028 mg/L (2)	SS < 300 mg/L COD < 600 mg/L
Actual Treatment Performance	COD < 50 mg/L BOD < 5 mg/l	Sludge reduced by 75% (3)	BOD < 200 mg/L Toluene < 0.010 mg/L	SS < 200 mg/L COD < 400 mg/L
Years in Service	6	3.5	1.5	4

Notes:
(1) As of August, 2001
(2) Influent Toluene = 400 mg/L
(3) Impacted by high levels of inorganic iron sludge in feed

SUMMARY

The purpose of this paper was to introduce the conceptual and operational application of a modified thermophilic aerobic biological treatment process for treating high strength organic wastes and sludges/slurries generated by industry. This process offers a significant economic advantage over conventional aerobic and anaerobic technologies. The process is very flexible as proven by operational experience and should be considered for applications where treatment and residuals minimization are a priority. Full-scale systems showed that the technology has significant economic and environmental advantages over other technologies used to treat difficult to degrade wastes and sludges resulting in higher than 90% reduction in organic sludge disposal and costs. It can thus be viewed as a cost-effective biological alternative to incineration.

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