Thermophilic Aerobic Digestion of Activated Sludge; Reduction of Solids and Pathogenic Microorganisms

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ABSTRACT: *In the temperature range of 10 to 80 ºC and in a batch digester, a typical activated sludge was digested aerobically. Reaction rate constants were determined by measuring the amounts of volatiles removed from the suspended solids at different time intervals during the process. The maximum value of the reaction rate constant (0.45 d^{-1}) occurred in the temperature range of 55-60˚C. Removal of indicator organisms (pathogens) in the sludge, during the batch digestion, was also studied. Sludge digestion at 60 ºC provided a noticeable difference in reduction of the indicator organisms as compared to digestion carried out at 55 ºC. Optimum thermophilic aerobic digestion for high rate removal of volatile suspended solids and effective inactivation of pathogens happened in temperature range of 60-65 ºC.*

KEY WORDS: *Activated sludge, Thermophilic aerobic digestion, Volatile suspended solids, Pathogen inactivation.*

INTRODUCTION

Typical disadvantages of anaerobic digestion such as: very slow growth of methanogenic bacteria, low limit of ultimate biosolids removal, poor process stability, and requirements for further treatment of decanted supernatant, have caused the present widespread attention to the aerobic digestion of activated sludge [1]. Also sufficient academic and industrial evidences are available showing that thermophilic aerobic treatment of wastewaters and thermophilic aerobic digestion (TAD) of sludges, have clear advantages over their conventional mesophilic analogous [1-3]. Obvious improvements in the rates of biomass and pathogen removal have been seen by many investigators when TAD process was applied on activated sludges [4-9].

Strains of thermophilic bacteria (12 aerobic species) found in sewage sludge are able to grow in the

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temperature range of 40 to 80 ºC [10, 11]. At the temperature of optimum growth, thermophilic aerobic bacteria, through bio-oxidation processes, demonstrate their maximum ability in conversion of organic materials into carbon dioxide, water, and ammonia. Also, like all kinds of fuel oxidation, a considerable amount of sensible heat will be released during the biological process resulting in the possibility of operating the process in autothermal condition [1,3,12].

Since the thermophilic temperature range of bacterial life is relatively wide (80 – 40 = 40 ºC), operation of the sludge in the most active range is strictly necessary. This range is required to obtain the satisfactory level of stabilization factors; i.e. volatile suspended solids (VSS) removal and pathogen inactivation. However, no analytical or experimental study exists focusing on the simultaneous effects of temperature on these two most important aspects of the sludge stabilization. This paper, through an experimental approach, examines the effects of temperature on the stabilization factors of a typical activated sludge during the aerobic digestion process.

EXPERIMENTAL

Activated sludge

Undigested aerobic wastewater treatment sludge (activated) was collected from one of the clarifiers bottom in the Delhi Jal Board sewage treatment plant located at Okhla near New Delhi, India. The sludge had a total solids (TS) concentration of 8.0 g/l, total suspended solids (TSS) of 7.6 g/l, total dissolved solids (TDS) of 0.4 g/l, total volatile solids (TVS) of 6.1 g/l, volatile dissolved solids (VDS) of 0.1 g/l, and volatile suspended solids (VSS) of 6.0 g/l. The raw sample showed a sludge volume index (SVI) equal to 44 (ml/g), pH of 6.7, and a chemical oxygen demand (COD) of 8700 ± 45 mg/l. Tests of indicator organisms on one liter of the original raw sludge resulted in existence of 4.8×10^8, 1.0×10^8, and 2.7×10^7 colony forming units (CFU) of *Total Coliforms* (TC), *Fecal Coliforms* (FC), and *Fecal Streptococcies* (FS) respectively. Solids analysis, COD, SVI, pH, and tests for indicator organisms were carried out according to the Standard Methods [13].

Batch aerobic digester

A batch glass digester (2.5 liters in total and filled for 1.5 liters sludge) designed and set up for performing the aerobic digestion experiments. Controlled electrical energy via a heating tape surrounded around digester's body was used to prepare different thermal condition.

Kinetics of aerobic digestion

Non-biodegradable part of the sludge was estimated experimentally by prolonged aeration of the sludge having initial TS concentrations of 10, 30, and 60 g/l at 60 ºC. The rate of removal of biodegradable volatile suspended solids was considered to be first order with respect to the concentration of biodegradable VSS present at any instant with a reaction rate constant of k. For estimation of the reaction constant (k), sludges having TS of 10 and 60 g/l were digested aerobically at different temperatures (10 to 80 ºC) by streams of air (300 ml/min).

Pathogen inactivation

Experimental investigations of the removal of indicator organisms were performed separately on digesting sludge (initial TS of 8.0 g/l) in the temperature range of 10 to 80 ºC. TC, FC, and FS as standard pathogen indicators, were counted using CFU technique during the digestion [13].

RESULTS AND DISCUSSION

The kinetics

The rate of degradation of the sludge during the endogenous respiration has been widely accepted to be a first order function of the concentration of the biodegradable biomass present, known as biodegradable volatile suspended solids [14, 15]:

$$\frac{d(bVSS)}{dt} = -k(bVSS) \tag{1}$$

Where

bVSS : biodegradable VSS remains after batch time (g/l)

k : digestion rate constant (d^{-1})

t : aeration time (d).

Eq. (1) after integration, takes the following form:

$$\frac{VSS_t - nbVSS}{VSS_0 - nbVSS} = \exp(-kt) \tag{2}$$

Where nbVSS is non-biodegradable VSS and subscript "0" refers to the initial concentration of the variable VSS. The profiles of VSS concentrations during

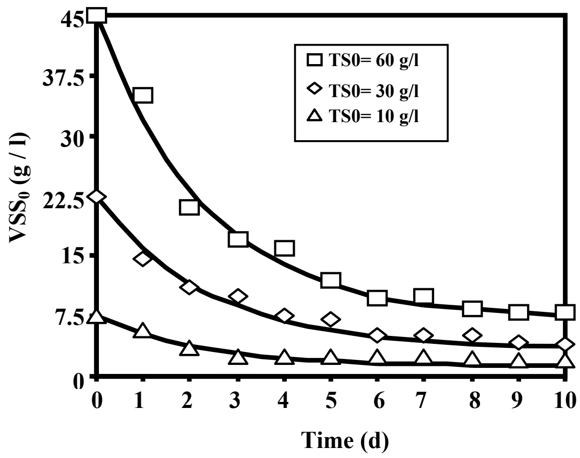

Fig.1: VSS reduction during aerobic sludge digestion at 60 ºC.

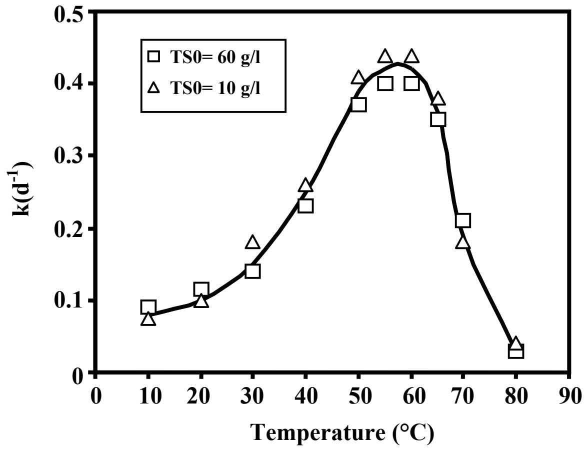

Fig. 2: Sludge digestion rate constants at various temperatures.

the course of the experiments (aeration at 60 ºC) at various sludge initial concentrations are plotted in Fig.1. Each curve finally ends in a horizontal line that represents the amount of nbVSS of the relevant sludge sample. This amount will not be changed further by aeration with time. After 10 days of thermophilic digestion, 16.5, 17.0, and 16.5 % of the initial VSSs remained for three sludge samples having initial TS of 60, 30, and 10 g/l respectively. Fig. 1 shows that during the last days of the process, curves become horizontal and get almost parallel to each other. Therefore, a fixed amount of 16.5% of initial VSS was assumed to be the amount of nbVSS part of the sludge in the present work.

Using data of nbVSS and the kinetic model, the curve of rate constants (k) could be plotted. Initial TS of 10 and 60 g/l were used to find the reaction constants at different temperatures. Fig. 2 gives the results of the kinetic study in terms of the digestion rate constant at temperatures ranging from 10 to 80 ºC (using Eq.(2)). The highest kinetic rate constants were observed at a temperature range of 55-60 ºC and had values between 0.40 to 0.45 d^{-1}.

As Fig. 2 shows, rate constants (k) at temperatures between 55 to 60 ºC are close to each other and an average equal to 0.42 d^{-1} can be taken for this range. The kinetic rate constant, k, for endogenous decay which was observed to increase with digestion temperature, follows an Arrhenius relationship $k_{(T)}=k_{20ºC} \cdot \theta^{(T-20)}$, with θ varying from 1.02 to 1.07 in the mesophilic range [16]. Matsch and Drnevich [17] showed this relationship to be applicable in the thermophilic range also. However, a value of 1.04 for θ provides the least error from the kinetic rates below 60 ºC presented in this work.

Inactivation of pathogens

Figs. 3, 4, and 5 show the inactivation concentration profiles of standard indicator organisms (TC, FC, and FS) at different temperature conditions on original secondary sludge (TS = 8.0 g/l) aerated by air for 100 hours. Temperatures of 65 to 80 ºC were very effective in pathogen inactivation; almost all indicator organisms were inactivated within few hours at these temperatures. At 60 ºC the number of the indicators dropped down to under detectable level within around 12 hours. Although it has been found that thermophilic digestion removes pathogens very effectively compared to stabilization under mesophilic conditions, sludge digested shortly at 55 ºC could not be counted as a pathogen free product completely safe for disposal. In this work, clear difference between pathogens inactivation at 55 and 60 ºC was observed (Figs. 3, 4, and 5). Around 60 hours treatment at 55 ºC was necessary for achieving the same level of coliforms removal as that occurred at 60 ºC in 12 hours.

CONCLUSIONS

The following conclusions can be drawn based on the data generated in this experimental work.

With thermophilic digestion and in the temperature range of 55 to 60 ºC, endogenous respiration of a typical secondary wastewater treatment sludge reaches to its maximum rate, which is much higher compared to that under mesophilic conditions.

Sludge digestion in the range of 60 to 65 ºC provides a noticeable difference in reduction of pathogenic organisms as compared to the digestion process at the range of 55 to 60 ºC. Among the indicator organisms

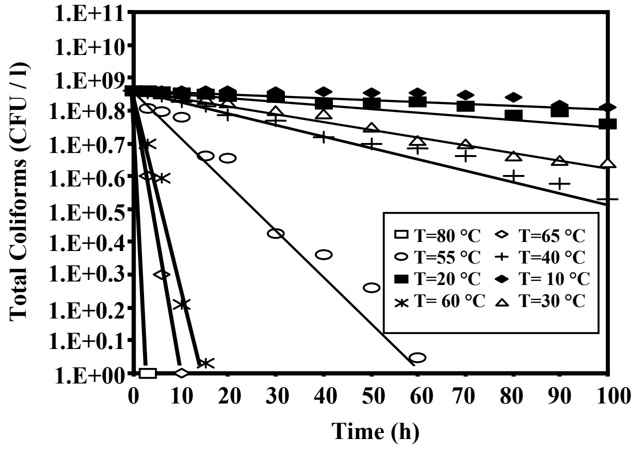

Fig.3: Thermal inactivation of Total Coliforms at various temperatures.

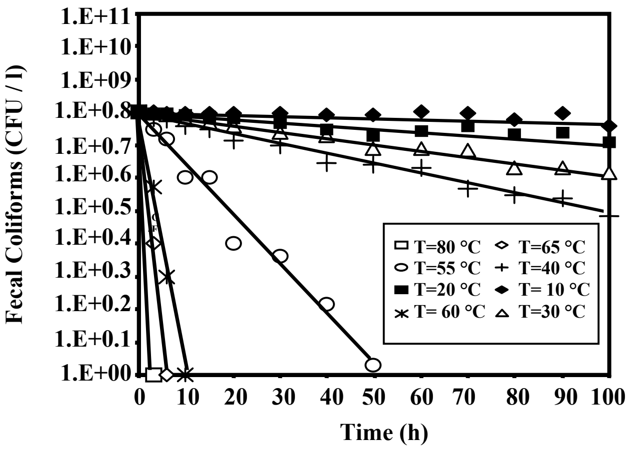

Fig.4: Thermal inactivation of Fecal Coliforms at various temperatures.

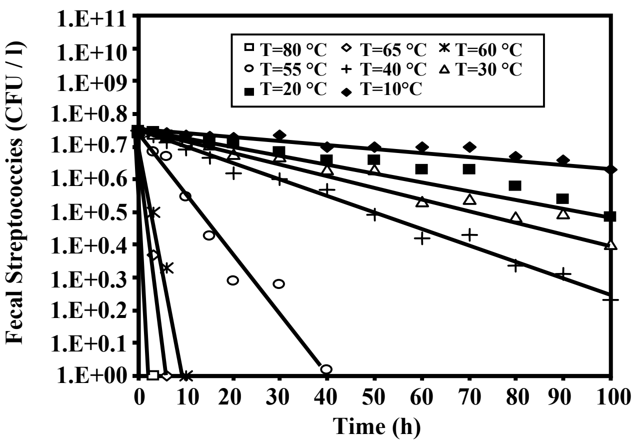

Fig.5: Thermal inactivation of Fecal Streptococcies at various temperatures.

tested in the present study, *Fecal Streptococcies* were the fastest to be eliminated from the system.

The results of this study shows that the temperature in which thermophilic digestion reaches to its maximum rate (55 ºC) is not necessarily the suitable temperature for pathogen inactivation. In other word, after a high rate solids removal in 55 ºC, still plenty amounts of pathogenic organisms will be remained in the disposed sludge. Temperature elevation more than 65 ºC (like 80 ºC) will inactive all indicating bacteria (pathogens), but as Fig.2 shows, does not result in a good rate for aerobic digestion because of a significant decrease in k. Therefore, for having a good solid removal and effective pathogen inactivation, an appropriate range of 60 to 65 ºC should apply.

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