refractory organics without the generation of sludges or residues. This technology is being widely applied to treat contaminated ground water.

Some of the advantages in the application of advanced oxidation methods include substantial reduction in Chemical Oxygen Demand (COD), Total Organic Carbon (TOC) and toxicity. The mechanism of removal in the peroxide oxidation is based on the formation of very reactive radical species, which is remarkably higher in oxidative capacity in comparison to other oxidants. Further more, the peroxide oxidation process leaves lesser residues at the end of the treatment.

In recent times considerable amount of work on rejuvenation of polluted soils and lake sediments has been reported in literature using various peroxides. Among them the use of hydrogen peroxide for oxidation of organics from liquids as well as solids is prominent. A brief review of the information about the chemical oxidation is included in this report such that future work can be programmed with this background information.

H₂O₂ contains oxygen in a state of oxidation midway between molecular oxygen and water. It is one of the most powerful oxidizers known - stronger than chlorine, chlorine dioxide, and potassium permanganate. And through catalysis, H₂O₂ can be converted into hydroxyl radicals (OH) with reactivity second only to fluorine. Despite its power, H₂O₂ is a natural metabolite of many organisms, which decompose the H₂O₂ they produce into oxygen and water. H₂O₂ is also formed by the action of
composting experiments or even direct use by dilution with soil. Therefore it can be concluded that secondary sludge is more suitable than the primary sludge for further experiments.

Chapter III presents an overview of the various oxidants, their relative oxidizing power and the advantages and disadvantages of oxidation. The physical, chemical and thermodynamic properties, advantages and environmental applications of hydrogen peroxide along with the mechanism of Fenton's reagent and its advantages are also discussed. The mechanism behind using ozone, perozone, calcium and magnesium peroxide along with the photochemical methods like photocatalysis as an oxidant are discussed in this chapter.

Chapter IV presents a review of earlier reports on the application of various advanced oxidation methods for detoxification of hazardous wastes and the experimental procedure for the oxidation of sludges with hydrogen peroxide, calcium peroxide and Fenton's Reagent.

Advanced Oxidation Processes (AOPs) - AOPs represent the newest development in H₂O₂ technology, and are loosely defined as processes that generate highly reactive oxygen radicals without the addition of metal catalysts. Typically, this means combining H₂O₂ with ozone or ultraviolet light. The result is the on-site total destruction of even
refractory organics without the generation of sludges or residues. This technology is being widely applied to treat contaminated ground water.

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In recent times considerable amount of work on rejuvenation of polluted soils and lake sediments has been reported in literature using various peroxides. Among them the use of hydrogen peroxide for oxidation of organics from liquids as well as solids is prominent. A brief review of the information about the chemical oxidation is included in this report such that future work can be programmed with this back ground information. H₂O₂ contains oxygen in a state of oxidation midway between molecular oxygen and water. It is one of the most powerful oxidizers known - stronger than chlorine, chlorine dioxide, and potassium permanganate. And through catalysis, H₂O₂ can be converted into hydroxyl radicals (·OH) with reactivity second only to fluorine. Despite its power, H₂O₂ is a natural metabolite of many organisms, which decompose the H₂O₂ they produce into oxygen and water. H₂O₂ is also formed by the action of
sunlight on water - a natural purification system for our environment. Consequently, H₂O₂ has none of the problems of gaseous release or chemical residues that are associated with other chemical oxidants. Industrial strength H₂O₂ is a strong oxidizer and as such requires special handling precautions. The fact that H₂O₂ is used for seemingly converse applications proves its versatility. For example, it can inhibit microbial growth (as in the biofouling of water circuits) and encourage microbial growth (as in the bioremediation of contaminated groundwaters and soils). Similarly, it can treat both easy-to-oxidize pollutants (iron and sulfides) and difficult to oxidize pollutants (solvents, gasolines and pesticides). The reason why H₂O₂ can be used for such diverse applications is the different ways in which its power can be directed -- termed selectivity. By simply adjusting the conditions of the reaction (e.g., pH, temperature, dose, reaction time, and/or catalyst addition), H₂O₂ can often be made to oxidize one pollutant over another, or even to favor different oxidation products from the same pollutant.

Two other oxidants being used in recent times are calcium and magnesium peroxide called solid peroxygens (classified Oxidizers) which slowly decompose to release oxygen at a "controlled" rate. Calcium peroxide is an ecologically pure substance, which can be used in different fields of industry and agriculture. In environmental protection it is used for treating wastewater and remediation of groundwater, for
decontaminating soil and to purify and disinfect drinking waters and process waters, and to destroy trace organics in industrial effluents.

Oxidation experiments with Hydrogen peroxide and Calcium peroxide were carried out by taking 100 gms of sludge samples in 500 ml Erlenmeyer flasks and adding 30% (w/v) hydrogen peroxide at a concentration range of 100-500 mg of hydrogen peroxide per gram of sludge and 100-600 mg of calcium peroxide per gram of sludge to establish the optimum concentration and contact time. Samples were removed at various time intervals between 0-6 hours and analyzed for Total Organic Carbon (TOC) to establish the optimum contact time required for the maximum removal of TOC.

Reduction in TOC was 27% at H₂O₂ concentration of 100mg/gm. The maximum TOC reduction values obtained were 39%, 75%, 81% and 90% respectively at H₂O₂ concentration of 200, 300, 400 and 450 mg/gm. It was observed that after 6 hours of contact time, there was no change in the reduction TOC with any of the concentrations. At concentration greater than 450mg/gm of hydrogen peroxide, the reduction in TOC was not significant hence the concentration of 450 mg/gm is considered to be the optimum value. The TOC removal at optimum H₂O₂ concentration is 90% with 6 hours contact time, which may have occurred due to the formation of hydroxyl and hydroperoxyl radicals during the reactions.
The TOC reduction using calcium peroxide was studied over concentration ranges of 100-600 mg/gm of CaO$_2$. Reduction in TOC was 25% at 100% mg/gm CaO$_2$ concentration. TOC reduction values increased to 35%, 69%, 69%, 70% and 72% at CaO$_2$ concentrations of 200, 300, 400, 500 and 600 mg/gm respectively. But at ranges higher than this there was no reduction in TOC indicating that 600 mg/gm CaO$_2$ was optimum concentration showing the inefficiency of this oxidant in the oxidation of the highly complex wastes.

Oxidation experiments with Fenton’s reagent are performed by taking 100 gms of sludge samples in 500 ml Erlenmeyer flasks with pH adjusted to 3 by adding H$_2$SO$_4$. This is followed by addition of FeSO$_4$ in the concentration ranges of 0.05 to 0.5 ppm. Finally, 90 ppm of H$_2$O$_2$ (30% w/v) is carefully added to start the Fenton’s reaction. The oxidation reaction releases gases (mostly CO$_2$ and small organic molecules). The samples are withdrawn at 30, 60, 90, 120, 150, and 180 min. and immediately analyzed. Samples are removed at various time intervals between 0-6 hours and analyzed for Total Organic Carbon (TOC) to establish the optimum contact time required for the maximum removal of TOC.

For analysis samples are withdrawn and 1M NaOH is added to stop the oxidation reaction (pH 12) as Fenton reaction cannot happen at pH>10. The Total Organic carbon analysis was performed using a TOC
TOG analyzer. TOC reduction gradually increased with variation in time and FeSO₄ concentration and reached maximum of 94% at a concentration of 90 mg/gm of hydrogen peroxide and 0.5 mg/gm of FeSO₄ in 180 mins. In these experiments the pH values dropped from an initial value of 3 to 2.4. This decrease in pH values may have been caused by the generation of CO₂ or H⁺.

Experiments with varying acidity and temperature with acids like perchloric, nitric and varying the dosages of oxidants with heat are also performed and their results are also presented. The application of advanced oxidation methods for the treatment of PETL-CETP primary and secondary sludge are examined.

**Primary Sludge**

The available organic matter in the sludge was about 230 mg/gm. Briefly the observations in the reduction of organic matter is given below: When the sludge was treated with H₂O₂ the reduction in organic matter was about 16%; when treated with Ca₂O₂ it was about 10%; when treated with H₂O₂ along with heat at 80°C the reduction in organic matter was about 79%; when treated with Ca₂O₂ and heat the reduction was about 67%; when treated with H₂O₂ and HNO₃ the organic matter reduction was about 13% and when treated with Ca₂O₂ and HNO₃ it was about 9%; when treated with H₂O₂ and HNO₃ along with heat at 80°C the organic matter reduction was about 91% and under the same conditions when
treated with Ca$_2$O$_2$ it was about 83%; when treated with H$_2$O$_2$ and HClO$_4$ the reduction in organic matter was about 81% and in case of Ca$_2$O$_2$ the reduction was about 71%; when treated with H$_2$O$_2$ and HClO$_4$ along with heat at 80° C the organic matter reduction was about 92% and in case of Ca$_2$O$_2$ it was about 87%; when treated with H$_2$O$_2$, HNO$_3$ and HClO$_4$ the reduction in organic matter was about 90% and in case of Ca$_2$O$_2$ it was about 88%. When treated with H$_2$O$_2$, HNO$_3$ and HClO$_4$ along with heat at 80° C the reduction in organic matter was about 95% and in case of Ca$_2$O$_2$ it was about 91%.

**Secondary Sludge**

The available organic matter in the secondary sludge was about 265 mg/gm; when the sludge was treated with H$_2$O$_2$ the reduction in organic matter was about 14%; when treated with Ca$_2$O$_2$ it was about 9%; when treated with H$_2$O$_2$ along with heat at 80° C the reduction in organic matter was about 77%; when treated with Ca$_2$O$_2$ and heat the reduction was about 76%; when treated with H$_2$O$_2$ and HNO$_3$ the organic matter reduction was about 10%; when treated with Ca$_2$O$_2$ and HNO$_3$ it was about 8.5%; when treated with H$_2$O$_2$ and HNO$_3$ along with heat at 80° C the organic matter reduction was about 92% and under the same conditions when treated with Ca$_2$O$_2$ it was about 84%; when treated with H$_2$O$_2$ and HClO$_4$ the reduction in organic matter was about 82%; in case of Ca$_2$O$_2$ the reduction was about 76%; when treated with H$_2$O$_2$
and HClO₄ along with heat at 80°C the organic matter reduction was about 89%; in case of Ca₂O₂ it was about 88%. When treated with H₂O₂, HNO₃ and HClO₄ the reduction in organic matter was about 91%. And in case of Ca₂O₂ it was about 83%. When treated with H₂O₂, HNO₃ and HClO₄ along with heat at 80°C the reduction in organic matter was about 95%. And in case of Ca₂O₂ it was about 86%.

Both the primary and secondary sludges have high organic matter and need to be stabilized by reducing the organic matter. This was achieved by applying chemical oxidants like H₂O₂ and Ca₂O₂ and Fenton’s reagent. It can be observed from the results that effective reduction of the organic matter is observed in case of both the peroxides used, however Fenton’s reagent is better when compared to hydrogen peroxide and calcium peroxide. Application of peroxide in the presence of heating conditions showed about 90% reduction in organic matter in both the cases. Addition of perchloric and nitric acid also showed reduction of about 85% however oxidation under acidic condition might be cost-intensive. It was also observed that the primary sludges showed better reduction of the organic matter than the secondary sludge however this result needs to be further validated.

Chapter V discusses various stabilization and solidification methodologies currently in use. Stabilization methods like Microencapsulation, Macroencapsulation, Precipitation, Detoxification,
Absorption, Adsorption, Polymer microencapsulation and Solidification methods like Cement, Pozzolans, Polyethylene extrusion, Ground granulated blast-furnace slag, flyash, clay plasticizers, Bituminisation, Vermiculite, Vitrification are described along with a review of the literature on the various methods.

The experimental studies are performed using primary sludge from PETL and clay. The properties of primary sludge and clay along with the preparation of block are described, followed by the preparation of clay and sludge mixtures. The clay and sludge mixtures were then introduced into brick molds. Wet bricks were then dried in the drying chambers of a local factory at approximately 150°C for 85 hrs. The molded mixtures were then fired in a continuous kiln with temperatures from 150°C to a peak temperature of approximately 985°C over a 12-h period. The bricks were then soaked at 985°C for about 14 h. Finally they were cooled by thermal regulation of the kiln for 16 hrs to ambient temperature. These bricks are then tested for compressive strength, water absorption, linear firing shrinkage, weight loss on ignition (LOI), and bulk density to determine the usability of bricks for construction purpose.

The compressive strength of 8.6 N/mm² was comparable to ordinary red (clay) bricks (IS 3495 (Part I): 1992. However, bricks with more than 30
wt% sludge are not recommended because they were brittle and easily broken even when handled gently.

The results of the water absorption test for different proportions of sludge in the mixture shows that the water absorption of the bricks increases with increased sludge addition and therefore leads to decreased resistance to weathering. With the addition of sludge, the plastic nature of the mixture is lowered and the bonding ability of the mixture is also decreased. When the mixture contains high amounts of sludge, the adhesiveness of the mixture will decrease and the internal pores of the brick will increase. As a result, the quantity of water absorbed increases.


Firing shrinkage did not increase but decreased with higher sludge addition. A decrease in firing shrinkage of bricks utilized up to 50 weight % fired sludge. Hence, the decreasing trend obtained here may be due to the non plasticity of the dried sludge amended into the clay bricks, which had a more profound effect on the bricks after being subjected to firing in the kiln. Further more, this study used dried sludge where the moisture had been driven out during the drying process, prior to it being mixed with clay. The water content was therefore largely derived from the clay. As the amount of dried sludge increased, the amount of clay used decreased and hence the amount of water content also decreased. Thus, this will contribute to the decrease in the linear firing shrinkage. The firing
shrinkage values obtained for all control and amended bricks are considerably below the desirable firing shrinkage limits of 6% to 8%.

The brick mixtures with 30% sludge and below, met the given criteria for weight loss on ignition after firing. Esthetically, the surface texture of the bricks was uneven with the appearance of many pores, thereby ruling out their use as facing bricks. This was due to the increase in the degree of surface roughness of the bricks with sludge addition. They were, however, attractive because they appeared to be light red in color. It was expected that the formation of the rough texture was mainly due to organic matter being burnt off during the firing process. Upon the addition of sludge in the mixture, the loss of weight apparently increased due to the contribution of the organic matter in the sludge as well as inorganic substances found in both the clay and sludge.

At 10% weight of sludge, the density of the bricks is 2.43 g/cm³ and is reduced by 0.33 g/cm³ for 40 wt% sludge bricks. This downward trend may be due to the associated loss of constitutive water and organic matter from the incorporated sludge in the bricks that are subjected to firing in the kiln, thus creating pores or voids. With higher sludge addition, more voids are created in the brick after firing.

The leachability of toxic metals like Arsenic, Lead, Chromium and Cadmium at varying sludge proportions and varying pHs is also studied. These bricks are subjected to extreme environmental conditions
conducted at pH 3, 5, and 9 in order to quantify their post
manufacturing metal leachate losses. Though As and Pb are not present
in PETL primary sludge samples, the clay used contains these metals
and as such the leaching tests are conducted. The leachate losses of As,
Cd, Cr, and Pb, at pH 3, 5, and 9 are far below the US-EPA regulatory
limits that are 5 ppm, 100 ppm, 1 ppm, and 5 ppm, respectively. Other
leached metals are of insignificant concern. Overall, it appeared that the
contained metals are believed to be locked inside the fired bricks. This
behavior is apparently related to a silicate-based physico chemical
containment mechanism, and possibly due to fusion of the ash residue
within a glassy (crystalline) matrix after subjecting the bricks to high
firing temperature. Obviously, the firing process makes the metal less
leachable.

By taking the water absorption, compressive strength, and heavy metal
leaching results, into consideration it can be concluded that an apparent
sludge amendment of up to 40 wt% in clay bricks can be used for
different application purposes as cited in Indian Standard IS 3952:1998.
Bricks made form sludge and clay will be resistant in this environment
and these bricks are also cheap, superior in structural and aesthetic
qualities. This work has provided a viable option for utilization of 40-50%
of primary sludge of PETL.
Chapter VI reviews the basic concepts about composting, various changes occurring during composting and the various technologies available as well as the factors governing the process of composting like C: N ratio, particle size, moisture content, temperature, turning frequency, aeration, pH and microorganisms. The Chapter also reviews types of composting, the parameters used to assess compost maturation and the innovative uses of compost. It also presents a review on literature on the current trends in composting and various methodologies adopted in composting along with the various types of composting technologies like windrow composting, aerated composting, lab scale reactors, and drum composter. The detailed analytical procedures like cation-exchange capacity, enzyme assay and measurement, germination index, and humic substances are also discussed.

The primary and secondary sludges are classified based on the nature of organic and inorganic constituents and the microbial activity present. It is observed that microbial activity is comparatively less in primary sludges than secondary and that the concentration of the non-biodegradable pollutants was also high. It was observed from the microbial characterization studies that secondary sludge was rich in microflora (Direct total microbial Count) and biodegradable organics. Composting which is one of the widely accepted and most suitable option for Indian conditions is adopted in this study. Stabilization of sludges using bioremediation technologies like aerobic composting in which a
biologically stable product is produced while reducing both sludge mass and volume is attempted in this study.

On-Site preliminary composting studies with both primary and secondary sludges of PETL with, and without amendments and their results are presented. The results of the experiments showed that due to the lack of microbial activity in primary sludge composting is not effective even after adding amendments.

Hence the lab-scale experiments were performed only with secondary sludge by varying the turning frequency, moisture contents, C/N ratio and then composting under optimum conditions in which all the compost maturity indices are assessed.

First set of experiments were performed with variation in turning frequency of the piles. The changes in physical (temperature), chemical (pH and, concentrations of NH₄-N) and biological (GI) properties revealed that composting with a 2 or 4-day turning frequency had a faster composting rate than turning the pile with a 7-day turning frequency.

The second set of experiments were performed with variation in moisture contents. Three piles A, B and C with initial moisture contents of 50, 60 and 70 % were set up and the various composting parameters were assessed. The higher moisture content in pile C resulted not only in a
lower microbial activity during the thermophilic stage of composting, but also a delay in reaching peak values of temperature.

This suggests that the decomposition process in pile C is slower. The differences between piles A and B were minimal, indicating that the microbes were adapted well to between 50 and 60% moisture, which can therefore be considered, as the optimum moisture content for an efficient composting.

The third set of experiments were set up with variation of C/N ratio. Two piles were setup with an initial C/N ratio of 30 and 15. Composting of secondary sludge at an initial C/N of 30 resulted in the compost reaching maturity after 49 days of composting. While composting in Pile B required a composting period of more than 63 days.

Finally composting was performed under optimum conditions of Turning frequency – once in 4 days, moisture content-55%, and C/N ratio of 30. The composting pile was setup with sludge, poultry manure and sawdust in the ratio of 2:1:2. The composting process lasted for a period of 14 weeks, including four stages such as the initial phase, the thermophilic phase, end of thermophilic phase and the mesophilic phase. Under optimum conditions temperature variation during composting followed a pattern similar to many other composting systems. There was a steep increase in temperature upto 58° C due to the availability of
comparatively more degradable organic matter and hence intense microbial activity. The thermophilic phase lasted for nearly 7 weeks.

The intense microbial activity and organic matter degradation during the first weeks of thermophilic phase led to the formation of ammonia as a consequence of ammonification of organic nitrogen. The solubilization of ammonia led to the formation of ammonium and an increase in the pH values in the composting mixtures from an initial of 6.7 to 8.2.

The total nitrogen content increased during composting from an initial value of 1.65% to 1.76%. This increase is probably due to a concentration effect caused by the decrease of the substrate carbon resulting from CO₂ lost as a consequence of the degradation of non-nitrogenous organic matter.

After 14 weeks of composting the organic matter decreased from 48% to 21% respectively. The C/N ratio decreased due to the mineralization of the organic matter. The Carbon/Nitrogen decreased from an initial value of 29.5 to 11.9 at the end of the process.

The NH₄⁺ -N content in the pile increased from 658 mg/kg to 725 mg/kg during the thermophilic phase. This increase could be due to conversion of organic N to NH₄⁺ -N via the ammonification process and then the NH₄⁺ - N content decreased to 144 mg/kg towards the end of maturation phase. This decreasing trend guaranteed that ammonification was ending and can be used as a criterion of compost maturity. The ammonia
produced during the thermophilic phase is oxidized to NO$_3^-$ - N and thus the concentration of ammonia decreases with the increase in NO$_3^-$ - N.

The NO$_2$ concentration was negligible in both the pile, indicating that aerobic conditions prevailed during the composting process.

Appreciable amounts of NO$_3^-$ - N could be observed in the pile. The values increased from 0.01% to 4.5%, which were reached after maturation. A NH$_4^+$ / NO$_3^-$ ratio in favour of the oxidized form is considered desirable for a mature compost. The NH$_4^+$ / NO$_3^-$ ratio was 0.03 towards the end of composting.

Water-soluble organic carbon is the most biologically active compound in composts applied to soils. Water-soluble organic carbon level gradually increased from 2.02% to 2.41% in the 7$^{th}$ week and then gradually decreased to 1.32% towards the maturation phase. A decline in water-soluble carbon is often used as an indicator of compost maturity. The Water-soluble Nitrogen decreased from 13.5% to 5.0%.

Humic substances comprise the most important fraction of organic matter because of their unique properties, such as the capacity to interact with metal ions, the ability to buffer pH, and the ability to act as a potential source of nutrients for plants. The quantities of Humic acids, Fulvic acids and non-humic fraction in composting mixture at various stages of the composting process represent the humification process.
Total humic substances increased from 31% of organic matter to 52% of organic matter after 7 weeks, stabilizing at this value till the end of the process. The fulvic acid gradually decreased from 8.2% of organic matter to 5.4% in mature compost. The humic acids increased from 5.2 to 21.9% in the mature compost.

During composting, humic acids increased, whereas fulvic acids decreased slightly. The non humic fraction increased rapidly from 18% to 30% of organic matter for the first 7 weeks of composting, and then decreased to 12% in the mature compost may be due to decomposition and humification of the break down products and presence of easily biodegradable organic matter during the maturation stage. Humification index in the pile remained steady at 0.6-0.8 for the first 4 weeks and increased sharply to 1.8 in the seventh week and slowly increased to a final value of 4.0 towards maturity of compost. The changes in humification index reveal that Fulvic fraction and non humic fraction extracted from sediment contain relatively high levels of biodegradable organic matter that was mostly decomposed during first 7 weeks of composting. The humification ratio increased from 0.4 to 1.04.

The determination of Cation-exchange capacity in an organic amendment is of great value because it shows the stability degree of the amendment. Several studies accomplished with different kinds of compost have demonstrated that CEC increases with the stability degree of the
compost. On the other hand, this parameter gives an indication of the amendment's capacity for catching nutrients and immobilizing phytotoxic substances as well as for buffering unforeseen pH changes. The obtained results showed that the CEC increased from an initial value of 55.3 to 68.6 cmol kg⁻¹. This value was higher than the minimum recommended for mature compost (67 cmol kg⁻¹) thus indicating that the compost is mature. The compost mineralization index is expressed as Ash content/Oxidizable Carbon. In the initial stage of composting (about 7 weeks) the intense mineralization process takes place, which is manifested by a considerable decrease in carbon and increase in ash content. The ash content increased from 49.4% to 61.9% and the oxidizable carbon decreased from 20.4% to 14.1% and the compost mineralization index increased from 2.5 to 4.65.

Sorption Capacity Index is represented as the Cation Exchange Capacity/organic carbon and the ratio reflects the degree of maturity of specific humic compounds and can be connected with the increase of the functional groups during humification process. The cation exchange capacity increases and organic carbon decreases with composting. At the end of the active phase the pile had a sorption capacity index value of 3.2 which was greater than 1.7, the lowest limit for describing well humified manures.
The Germination Index values increased during the composting process due to decomposition of the phytotoxic organic compounds. These phytotoxic compounds, which were present in raw waste or produced during the first days of composting as intermediate products of microbial metabolism, were degraded during the process, giving mature composts which could safely be used with plants. The sample taken from the pile had a GI of 95 which is greater than 80 and indicates a phytotoxic-free compost.

The hydrolases monitored in the present work are BAA-Hydrolysing Protease, Urease, β-glucosidase, Dehydrogenase and Phosphatase which represents a good index of qualitative fluctuations of substrate during composting since they are substrate-inducible enzymes. The high initial activity of these enzymes reflected the high microbial activity. The presence of a high content of degradable compounds in the pile might have stimulated enzyme synthesis. As substrate decreased, the enzyme activity decreased as well.

β-Glucosidase and BAA-hydrolyzing protease which are enzymes involved in C and N cycles, respectively showed a sharp decrease during the first 7 weeks, and then stabilized as a consequence of decrease in available organic substrates.

Urease activity is closely related with the nitrogen cycle and it is involved in the hydrolysis of proteins to ammonium hydrolyzing urea-type
substrates. Urease activity decreased until week 7 and then remained more or less stable till the terminal phase of the composting process.

Phosphatase is a key enzyme in the phosphorus cycle, which is induced by the substrate. Its activity is largely dependent on microbial biomass. Phosphatase activity showed a sharp increase during the thermophilic phase followed by a gradual decrease. The increase observed during the thermophilic phase can be associated to high microbial activity, which occurs during this stage. After a slight decrease during the first week phosphate activity stabilized at about 200 μ mol PNP g⁻¹ h⁻¹ in the pile.

Dehydrogenase activity in soils and other biological systems has been used as a measure of the overall microbial activity since it is an intracellular enzyme related to the oxidative phosphorylation process. The initial high dehydrogenase activity recorded might have been the result of high microbial activity due to the high water soluble carbon concentration. After two weeks, dehydrogenase activity decreased until the end of composting.

The direct total microbial count is a representative of the total microbial load in the sample and this was observed to be very high at 312 x 10⁴ CFU/ml (Colony forming units) at the beginning of composting and slowly decreased to 83 x 10³ CFU/ml by day 60 which further decreased to 17 x 10² CFU/ml by day 126 showing that the rise in temperature
during composting destroyed the microbial population and can be compared with other fertilizers.

No faecal coliforms were detected in the mixture analyzed during the stabilization phase even though temperatures in the piles were near the ambient levels, indicating that high temperature killed the coliforms.

This chapter also discusses the composting economics and provides background information on the options and trade-offs involved in the design and day-to-day operation of industrial waste sludge composting facilities and also describes the prototype facilities for which cost estimates are presented. It also outlines the assumption made in computing the cost of constructing and operating prototype facilities and presents the cost analysis of various types of facilities.

Conclusions

1 Data on characterization of the sludges for toxic hazardous compounds and their tentative impact on further stabilization studies indicate that the total Volatile Solids are less in primary sludge indicative of complex organic compounds. The secondary sludge shows more since it is from biological treatment and indicative that it may be amenable for further biodegradation. About 28 percent of chemically oxidisable material is present, showing the possibility of
little biological oxidation in the primary sludge while 32 percent is biologically oxidisable from the secondary sludge.

2 Phytotoxic studies using primary and secondary sludges on fifteen varieties of seeds indicate secondary sludges are less phytotoxic than primary sludges.

3 Seed germination was observed in 5% and 10% primary and secondary sludge samples. Plant growth rate were analyzed in these samples. Secondary sludge samples of 5% and 10% were found to be suitable than the primary sludge. Amongst the fifteen varieties of seeds in *Zea mays*, *Phaseolus aureus*, *Luffa acutangula*, plant growth rate was faster in 5%, 10% secondary sludge samples than the 5%, 10% primary sludge samples.

4 Growth of different plants, both flowering and otherwise has been found to be satisfactory by dilution of the mixed sludge with soil in proportion of less than 10%.

5 In order to reduce the organic and toxic load of the raw sludges chemical treatment using advanced oxidation methods are tested. The treatment with peroxides rendered the sludges more suitable for composting and final product had good nutrient and manurial properties.
Advanced Oxidation methods: Both the primary and secondary sludges have high organic matter and need to be stabilized by reducing the organic matter. This can be achieved by applying chemical oxidants like H$_2$O$_2$ and Ca$_2$O$_2$. Effective reduction of the organic matter can be achieved in case of both the peroxides used, however hydrogen peroxide was slightly better in comparison with calcium peroxide. Application of peroxide in the presence of heating conditions showed about 90% reduction in organic matter in both the cases. Addition of perchloric and nitric acid also showed reduction of about 85%. However oxidation under acidic condition might be cost-intensive. It was also observed that the primary sludges showed better reduction of the organic matter than the secondary sludge. At a concentration of 450 mg/gm hydrogen peroxide a maximum of TOC removal upto 90% with 6 hours contact time can be achieved. The TOC reduction using calcium peroxide over concentration ranges 100-600 mg/gm is 72% after 6 hours of contact period. Using Fenton's reagent all experiments are performed at pH 3 in presence of 90 mg/gm of hydrogen peroxide and 0.5 mg/gm of FeSO$_4$. The results show that the Fenton's reagent is the most effective oxidant when compared to the other two. Fenton's oxidation is successful in increasing both the extent and rate of oxidation.

The applicability of stabilization and solidification methodologies like conversion into bricks for the sludges is tested. Parameters such as
Compressive strength, water absorption, linear firing shrinkage, weight loss on ignition (LOI), and bulk density were studied to determine the usability of bricks for construction purpose. The leachability of toxic metals like Arsenic, Lead, Chromium and Cadmium at varying sludge proportions and varying pHs was also reported. By taking the water absorption, compressive strength, and heavy metal leaching results, into consideration, sludge amendment of up to 40 wt% in clay bricks can be used for different application purposes as cited in Indian Standard (IS 3495 (Part I): 1992). Bricks made from sludge and clay will be resistant in this environment and these bricks are also cheap, superior in structural and aesthetic qualities.

Bio Stabilization: The sludges from the CETP are found to be biodegradable waste and can be used as biofertilizers or organic manure. The primary and secondary sludges are classified based on the nature of organic and inorganic constituents and the microbial activity present. It is observed that microbial activity is comparatively less in primary sludges than secondary and that the concentration of the non-biodegradable pollutants was also high. None of the heavy metals encountered in the sludges are in significant concentrations to cause any toxicity to any of the organisms. Composting with a 2 or 4-day turning frequency had a faster composting rate than turning the pile with a 7-day turning frequency. For an efficient composting the
suitable moisture content in the pile is between 50 and 60%. The compost was alkaline, pleasantly earthy in smell and dark brown in color. According to the results obtained, compost showed a C/N ratio of 11.9 which shows that there was a considerable decrease in organic matter. There was decrease in water soluble carbon and nitrogen, increase in CEC values, showing a higher concentration of carboxyl and hydroxyl-phenolic groups which are mainly responsible for the higher value of CEC. Thus these hydrolytic and dehydrogenase activities are sensitive indicators of the state and evolution of the organic matter and the overall quality of the compost. The macronutrient contents were above the minimum recommended (0.5% P_2O_5; 0.3% K_2O; 0.3% K_2O; 0.3% MgO; 2.0% CaO). Heavy metals present, in all the composts, were below the maximum values permitted for each element.

The composting of the CETP sludges is found to be an economically viable treatment process. Further studies on the regulatory standards of the composted product can validate the applicability of these stabilized sediments for successful application as biosolids.