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Secondary Sludge Treatment and Disposal in Pulp & Paper Industry

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Contents

LIST OF ABBREVIATION

AC	:	Aerobic compost
AF&PA	:	American Forest and Paper Association
AOX	:	Adsorbable organic halides
cc	:	cubic centimeter
C/N ratio	:	Carbon to nitrogen ratio
DSVI	:	Diluted sludge volume index
EOX	:	Extractable organic halides
ID	:	Internal diameter
I-TEQ	:	International toxic equivalent
kg	:	kilo gram
kW	:	kilo watt
mg	:	mili gram
µg	:	micro gram
l	:	liter
lph	:	liter per hour
MLSS	:	Mixed liquor suspended solids
MLVSS	:	Mixed liquor volatile suspended solids
mv	:	milivolt
ng	:	nanogram
PAC	:	Poly aluminum chloride
PCDD	:	Polychlorodibenzo-p-dioxin
PCDF	:	Polychlorodibenzofuran
pg	:	picogram
POX	:	Purgeable organic halogens
RT	:	Retention time
SS	:	Secondary sludge
SVI	:	Sludge volume index
t	:	tonne
TCDD	:	Tetrachlorodibenzo-p-dioxin
TCDF	:	Tetrachlorodibenzofuran
TVC	:	Total viable count
USEPA	:	United State Environment Protection Agency
VC	:	Vermicompost
VS	:	Volatile solids

EXECUTIVE SUMMARY

Pulp and paper mills generate significant amount of biodegradable sludge during the biological treatment of wastewater. The disposal of sludge from wastewater treatment systems is a global concern and it is more difficult for pulp and paper mills because the biosludge falls under the category of hazardous material due to presence of AOX compounds. The present study was aimed to characterize the biosludge from treatment of wastewater generated during different bleaching sequences and to find out suitable dewatering process prior to various treatments like composting, incineration and anaerobic stabilization of sludge. The study was also targeted for characterization of sludge after treatment and its beneficial use.

The biosludge samples were collected form 5 mills in India where two mills were based on ECF bleaching whereas rest three were using elemental chlorine in the first stage of bleaching. The organochlorine contamination was higher in latter samples compared to samples from mills based on ECF bleaching process. Presence of 2,3,7,8 TCDD was detected in the secondary sludge and concentration was up to 16-31 pico gram per kg of dry secondary sludge from chlorine based bleaching sequence. The same was below detection limits in secondary sludge from ECF based bleaching sequence. The essential metals (micro nutrients) and other heavy metals were also present in all the samples and concentration was below the EC Directive

Decanter centrifuge was found to be suitable to dewater secondary sludge to a solid concentration of 18% using 3.1-3.7 kg cationic polymer per ton of secondary sludge with >99% solid capture in the cake. The dewatered sludge from mill based on partially chlorine dioxide substituted chlorine bleaching was composted. There was 14-23 % loss in weight of material during 90 days of vermicomposting depending upon the composition of the secondary sludge mixture. Concentration of AOX compounds remained same or slightly less in composted material after 90 days of time but based on reduction of quantity of absolute material, 15-26% (I^{st} trial) and 19-24% (II^{nd} trial) decomposition/removal of AOX compounds was observed depending upon composition of the secondary sludge mixture during vermicomposting. There was reduction in PCDD and PCDF during vermicomposting of sludge and level was less than the prescribed limit given by EU.

Wheat and onion crops were selected to check the growth pattern of crops and transformation of halogenated compounds from compost to plant. Growth of crops and fruit were better on vermicomposted material in comparison to that with natural compost from cow dung. The transformation of AOX compounds and chlorophenols was below detection limit in crop as well as fruit. PCDD and PCDF were detected in wheat crop cultivated using compost from cow dung as well as secondary sludge. The level of PCDD and PCDF was

higher in the wheat cultivated with the latter one. In both the two cases, concentration was higher than those reported in a few European countries.

Traces of few chlorophenolic compounds were observed in flue gases even after incineration at 1100 ^{0}C. Anaerobic stabilisation of biosludge was feasible. The anaerobic degradation of sludge resulted in 42.4 and 33.4 % reduction in MLVSS and MLSS concentration of sludge respectively while the retention time was 15 days. The anaerobic stabilization was also effective for mineralization of organochlorine compounds. There was 37-55% reduction in AOX compounds, chlorophenolic compounds were below detection limit and substantial reduction in PCDD and PCDF compounds was observed.

1. BACKGROUND

Paper mills, and integrated pulp and paper mills generate significant amount of biodegradable sludge (34 and 105 kg/t product in large and small paper mills respectively) during the biodegradation of organic substances coming out of the papermaking and pulp making stages. The disposal of sludge from wastewater treatment systems is a global concern not a unique problem to the pulp and paper industry.

Among the four major modes of sludge disposal; sea discharge, landfill, incineration and land application, there is a continual shift from the first three to the last one. According to the recent estimate carried out by the U.S. Environmental protection agency (US-EPA) half of the 6500 municipal landfill sites has been closed by the end of the last century and another 54% of the remaining landfills will be closed within next five years. In Western Canada, these same pressures affect municipalities, the agricultural industry, and increasingly the pulp and paper industry.

To cope up with the problem, the United States undertook a long term research and demonstration programme involving all segments of society, from regulators to farmers for the utilization of biosolids for gainful purposes and to find a long term solution. The US-EPA estimates that 49% of the biosolids generated from sewage treatment plants are now being used for land application and other beneficial applications. Of the remainder, 35% is disposed of by land filling and surface disposal and 15% by incineration. Similar is the trend in European Union.

The pulp and paper industry throughout the world is slow to react to these changes for techno-economic reasons. As per a survey conducted in 1997 in the province of Quebec (Canada), primary and secondary sludges in paper mill contribute about 17.4 and 0.5% of the total biosolids generated whereas, that by the sewage sludge is only 2.3%. In North America, paper mill primary sludge is mainly disposed of by landfill. Two factors viz., continued decrease in availability of landfill space and increase in energy cost in incineration, have forced the American Forest and Paper Association (AF&PA) to look for the land application of the same, low cost disposal method. Earlier, US-EPA put restriction on land use of paper mill sludges for the dioxin and dibenzofuran contamination.

By the persuasion of AF & PA to protect the interest of the member paper mills, US-EPA and the American Forest and Paper Association in 1994 signed a Memorandum of Understanding on the voluntary environmental stewardship programme for the land application of primary and secondary sludges from kraft and sulphite mills using chlorine or chlorine-derivative bleaching process. Under the agreement, individual mill will undertake periodic monitoring of dioxin and dibenzofuran concentration and report to US-EPA and the

AF&PA will also collect the information on an annual basis from mills that undertake the land application of the sludge materials for submission to US-EPA.

Waste sludge management in Indian Pulp and paper industry requires some improvement. Presently, the primary sludge is either sold to the vendors for board making or landfill.

Mills mostly avoid the dewatering and treatment of secondary sludge as it is difficult to dewater and disposal of primary sludge through vendors becomes difficult once it is mixed with secondary sludge which is estimated to be 2,19,150 t/year for the large and small scale pulp and paper industry.

TCIRD carried out a preliminary study on the characterization of secondary sludge of two integrated pulp and paper mills in the recent past. But detailed study on the characterization of different mills in the country is warranted. No systematic work has so far been reported on the dewatering and treatment of secondary sludge for useful application.

Mills are in need of suitable technology for handling and disposal of secondary sludge maintaining the applicable environmental norms.

2. OBJECTIVES

Though the scale of operation in Indian pulp and paper sector is relatively low in comparison to North American, European and even South Asian paper mills, it is continuously under pressure in the globalized economy; environmental management in the pulp and paper sector will be a major issue in the years to come. Keeping these things in mind, the objectives of the present study have been framed and given as follows:

- To characterize the secondary sludge in detail including the level of contamination of dioxin and dibenzofuran
- To study the anaerobic decomposition of the secondary sludge
- To find out suitable flocculants for the secondary sludge (treated or untreated)
- To select the appropriate equipment amongst vacuum filtration, belt press filtration and decanter centrifugation for the dewatering of secondary sludge
- To study the treatability of the secondary sludge with composting and vermicomposting
- To characterize in detail including the dioxin and dibenzofuran contamination of the anaerobically treated/composted secondary sludge
- To study the beneficial/adverse impact of the treated secondary sludge on the forest based plantation and agricultural crop

3. IMPORTANCE OF THE STUDY

Secondary sludge is basically biological material and presently it is mere a waste. Because of the non-availability of appropriate technical solution, this is being wasted causing damage to the aquatic water bodies and land. The treated material is expected to be useful as manure in the forestry plantation and agricultural application if the contaminant level can be brought down to the acceptable level.

4. MATERIALS and METHODS

4.1 Materials

Secondary sludge samples from four mills were collected; first one from BILT Shree Gopal (sample designated as SGU-SS1), second from J K Paper Mill, Raygada (sample designated as JKPM-SS1), third sample from ITC, Bhadrachallam (sample designated as ITC–SS1) and the fourth from APPM at Rajamundry (sample designated as APPM–SS1). One more set of samples was collected in middle of 2010 for characterization of organochlorine compounds which were designated as SS2 preceded with the abbreviated name of the mill. Secondary sludge samples from Star Paper Mill (Star-SS), Saharanpur was also collected for characterization of organochlorine compounds.

For dewatering studies, the chemicals were collected from commercial suppliers and BILT Unit Shree Gopal.

For vermicomposting experiments, secondary sludge was dewatered with solid-bowl centrifuge (Humboldt Wedag India Ltd, Kolkata). The biosludge was taken from secondary sludge thickener in BILT-Unit Shree Gopal for dewatering studies. Saw dust was collected from BILT Unit Shree Gopal and dried in sun light to reduce the moisture. Further the saw dust was sieved in chips classifier with 3 mm porosity tray. The later step was repeated two times for removal of coarse size saw dust. The worm culture (species - Eisenia foetida) was collected from Krishi Vigyan Kendra (ICAR) TEPLA, Ambala. The enriched culture of aerobic organisms was procured from Naisargic Agro Products, Navi Mumbai, for aerobic composting of sludge.

Three different species of mushroom viz., Agaricus bisporuus, Pleurotus sajor-caju and Calocybe were collected from National Research Centre for Mushroom, Solan, HP. Vegetative cells (mycelium) of each species were grown in the autoclaved composted material.

The incineration experiments were performed in quartz furnace (supplied by Thermoelectron, USA). The combustion experiments were performed at 800 and 1100 ^{0}C under flow of oxygen.

The anaerobic seed sludge for anaerobic reactors was collected from sewage treatment plant, Yamuna Nagar.

4.2 Methods

For mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS), 100 ml of mixed sludge sample was centrifuged at 6000 rpm and washed with distilled water and centrifuged again before transferring to pre-weighed silica crucible. The

sample was oven dried at 105 ^{0}C for overnight. Dried material was taken as MLSS, the same crucible was ignited at 550 ^{0}C and loss in weight was taken as MLVSS.

Total carbohydrate content, filament count and characterization of filamentous organisms were performed as per Jenkins et al., 1993. Carbon, hydrogen and nitrogen content were characterized using CHN analyzer at CPPRI, Saharanpur.

The sludge samples were digested with nitric and perchloric acid and filtered through Whatman no. 42. The filtrate was used for characterization of sulphur content (APHA method 4500-SO_4^{-2} D), phosphorus content (APHA method 4500-P E) and various metals using atomic absorption spectrophotometer. The trace elements were analysed on furnace AAS and rest were analysed on flame AAS. The hydride forming elements were analysed using hydride generator.

The kjeldhal nitrogen content was measured as per IS 5960 (part 1), 1996. Zeta potential of sludge sample was measured with Mutek SZP06 zeta potential analyser whereas, the dissolved charge of chemicals was measured with Mutek PCD03.

EOX content in sludge was estimated as per EPA method 9023 and manufacturer's manual whereas, for estimation of purgeable organic halide (POX), 0.1 to 1 g (on oven dried basis) as such sludge was taken in POX bottle and suspended in 80 ml water. The sample was heated for 30 min at 60 ^{0}C and stripped with oxygen at a flow rate of 150 ml/min. The gases were fed into combustion apparatus and halides were detected by microcoulometric titration (DIN, 1989; EPA, 1992). Dichloromethane (DCM) was used as a standard for the determination of POX compounds.

The AOX content was estimated as per DIN (1989) with modification for dispersion of sludge. As such wet sample (50-100 mg on OD basis) was taken in glass beaker. The sample was dispersed in acidified water (1.5-2.0 pH using nitric acid) and kept overnight. The sample was sonicated instead of drying and grinding for dispersion. Sonication was carried out with probe sonicator under ice bath for one-minute duration and process was repeated 3-4 times. Disintegrated sample was transferred in 100 ml volumetric flask and volume made up to the mark with acidified water. The sample was further processed for estimation of AOX compounds as per DIN (1989).

The chlorophenolic compounds in solid samples were estimated as per NCASI method CP-85.01. For extraction of chlorophenolic compounds, wet sludge (1 g on OD basis) was taken in glass bottle and homogenized by sonication under ice bathe. 25 µl of internal standard was added followed by 2 ml of potassium carbonate under agitation. The sample was sonicated for 4 times for 1 minute duration and 2 ml of acetone was added under agitation and again sonicated for 2 times for 1 minute duration. 1.5 ml of acetic anhydride was added under

agitation followed by 2 minutes of sonication. 0.5 ml of acetic anhydride was added prior to the addition of 5 ml hexane to break the foams. Finally the sample was sonicated for 2 minutes and centrifuged at 12000 rpm and 4 ^{0}C to extract hexane. The extracted sample was analysed on GC (Make Varian 450-GC) using capillary column (VF-1ms) and ECD detector.

For PCDD and PCDF content, the samples were characterized at ALS Laboratory Group, Czech Republic. Similarly for various pathogenic organisms, the sludge and composted materials were characterized at Microtech Laboratory, Nashik, India.

5. RESULTS AND DISCUSSION

5.1 Physico-chemical characterization of secondary sludge

The collected secondary sludge samples were characterized for various physical and chemical characteristics (Table 1). ITC-SS1 was having the maximum MLSS and MLVSS concentration (8.0 and 5.7 g/l respectively) whereas the same were lowest in JKPM-SS1. All secondary sludge samples were negatively charged; JKPM-SS1 was bearing highest negative charge. Though highest organic content was with APPM-SS1, JKPM-SS1 was richest in total carbohydrate content. ITC-SS1 was having the highest C and S content of 37.58 and 1.20% respectively. Highest H and N contents were with JKPM-SS1. Highest P was with SGU-SS1. All the sludge samples were rich in organic, C, H, N and S content. On an average C/N ratio was 6.29:1.

All the sludge samples of four mills had high concentration of Na, Ca, Mg, K and Al (Table 2); The source of these elements might be the raw material, process chemicals, washing and leakage in the plant, and addition of alum/PAC for flocculation of sludge. Whereas Ca, Mg were beneficial for land application; excessive discharge of Na and Al were not desired in respect of ion exchange.

Among the heavy metals Fe was present in very large amount from 1468- 4594 mg/kg (Table 3). There might be several sources for Fe build-up in the secondary sludge; it might come from dissolution of Fe from steel pipe lines, iron in alum etc. Mn and Zn were also present in high amount. Higher amount of Pb in APPM-SS1, Cr and Cu in JKPM-SS1 were observed. Reasons and source of the higher amount of these elements need to be investigated in the mill level.

5.2 Characterisation of secondary sludge for organochlorine compounds

Different organochlorine contaminants like Adsorbable organic halides (AOX) and Extractable organic halides (EOX) in the sludges were analysed (Table 4). AOX values ranged from 451 to 5140 mg/kg dry solids. Highest amount of AOX and EOX values were observed in APPM-SS1 and JKPM-SS1 sludge samples respectively possibly due to usage of higher amount of elemental chlorine in the bleaching process. Both AOX and EOX were present in low amount in ITC-SS1 due to elementary chlorine free bleaching process adopted by the mill.

For second batch of samples, a sun-dried secondary sludge sample was received from JK Paper Mill, Rayagada (JKPM-SS2) and from other mills secondary sludge samples were collected in semi-solid form. Concentration of AOX compounds was lowest in ITC-SS2 sample whereas it was highest in JKPM-SS2 sample (Table 5). The concentration of AOX

compounds in APPM-SS2 was lower in comparison to that in APPM-SS1due to change in bleaching sequence from elemental chlorine based to ECF bleaching.

The secondary sludge samples were also characterized for 12 chlorophenolic compounds identified by USEPA. The concentration of these compounds was lowest in ITC-SS2 followed by APPM-SS2 (Table 6). Dioxins and dibenzo furans were also tested in the sludge samples. ITC-SS1 contained extremely low concentration of 2,3,7,8-TCDD whereas the same in APPM-SS2 was below detection limit. APPM-SS2 had the least amount of total dioxins and dibenzo furans whereas the first sample of APPM (APPM-SS1) had higher concentration of PCDDs and PCDFs. The ECF bleaching (second sample) resulted in very low generation of these compounds. The highest concentration of these compounds was observed in JKPM-SS2 (Table 7).

5.3 Morphological characterization of secondary sludge

Gram staining, Neisser staining, 'S' test coupled with microscopical examination of the sludge samples indicated that the ITC-SS1 was rich in floc forming bacterial mass whereas, rest three samples were rich in filamentous organisms. Dominant filament species were *Nocardia spp. and Nostocoida limicola I* in all the sludge samples whereas, *Microthix parvicella* was present in all sludge samples except ITC-SS1 (Table 8). Some amount of Cell type – 1851 filament was present in ITC-SS1. The filamentous organisms were characterized morphologically (Figures 1-19, Table 9). The filament length, count, diameter and other characteristics of all sludge samples were as per Table 10.

5.4 Pathogen contamination in secondary sludge

Pathogen contamination level in all the four sludge samples was assessed (Table 11). *E. coli* and Salmonella were abundant in all four secondary sludge samples (least and highest concentration of *E. coli* was present in SGU-SS1 and JKPM-SS1 respectively; similarly least and highest concentration of Salmonella was present in APPM-SS1 and ITC-SS1 respectively). Both typhoid and cholera causing pathogens viz. *Salmonella typhi* and *Cryptosporidium parvum* respectively were absent in all the four secondary sludge samples. The source of E. coli and Salmonella might be sewage or the pulping raw materials.

5.5 Settling and dewatering characteristics of secondary sludge (SGU-SS1)

All the secondary sludge samples were anionic in nature; the zeta potential was in the range of –17.6 to –39.0 mv. Secondary sludge of BILT-SGU was used for the experiment due to its easy accessibility to TCIRD and further downstream treatment plan of the dewatered materials. Various inorganic and organic coagulants and flocculants were characterized for their dissolved charge (Table 12). Settling characteristics of secondary sludge were studied

with organic flocculants viz., zetag 7653, DK Set C 715 HN, and with inorganic coagulants viz., $FeCl_3$ and PAC coupled with different organic flocculants viz., OP 5925, zetag 7653, DK Set C 715 HN, OP 5540 etc. (Figure 20).

Cationic inorganic coagulants settled the sludge but impaired filterability when carried out with vacuum filter. The same behaviour of the secondary sludge was also observed with cationic inorganic coagulants and polymeric flocculants. Anionic polymeric flocculants were neither effective for settling nor filterability of secondary sludge. Cationic flocculants viz., zetag 7653 and DK Set C 715 HN offered good settling and filterability of sludge. It was observed that 2.5-3.0 kg flocculant polymer was required per tonne of secondary sludge to capture more than 98% of the suspended solid particles of the slurry and to have 150 – 200 mg/l TSS in the filtrate.

5.6 **Dewatering characteristics of SGU- SS with decanter centrifuge**

Secondary sludge (SGU-SS) was dewatered with decanter centrifuge (Figure 21); the design specification of centrifuge were as per Table 13. Dewatering of the sludge was studied with two cationic polymeric flocculants (Suyog K– 30 and Nalco 9914) (Table 14 and 15) which were similar to Zetag 7653 and DK Set C 715 HN. Between two flocculants Nalco 9914 was relatively better with respect to higher solid consistency and solids capture in the cake at a lower dose of flocculant. Solid consistency of ~18 % was achieved with 3.1-3.7 kg of flocculant dosage per ton of the secondary sludge with more than 99% solids capture.

5.7 Vermicomposting

Treatment of the secondary sludge was required to stabilize the biodegradable organics and to reduce the contaminant level including pathogenic organisms. The ultimate goal of the treatment was to convert the waste secondary sludge into a state where it can find a gainful outlet. Secondary sludge dewatered with decanter centrifuge at BILT- Shree Gopal Unit was used for vermicomposting. Three batches of secondary sludge were composted to confirm the feasibility for vermicomposting of sludge. Initially secondary sludge dewatered with and without flocculant was composted to check the impact of the dewatering aid on worms. The worms were found to be adaptable with sludge dewatered with flocculants. No external addition of N and P was done during vermicomposting.

5.7.1 Set-up for vermicomposting

Vermicomposting experiments were performed in plastic trays (2 x 1.5 x 1 feet dimension) (Figure 22). Dewatered secondary sludge was mixed with inert material in different proportions in order to maintain the moisture content and reduce the toxicity level, if any, of the secondary sludge for the adaptation of worms (Table 16). The worm culture was spread

(Figure 23) at the top of mixed layer (1 kg worms/ 10 kg dry material). No external addition of N and P was done during vermicomposting. pH, temperature and moisture were maintained in the range of 7.5-8.5, 27-30 ^{0}C and 60-75% respectively throughout the period of study.

5.7.2 Characterization of constituents of vermicomposting

Carbon content in saw dust was highest (44.3-45.7%) whereas it was 20.1-26.9 % in secondary sludge and worm culture. The nitrogen content in secondary sludge varied from 3.3 to 5.8% (Table 17). The AOX content of secondary sludge was 2155-2232 mg/kg whereas, other two constituents contained negligible amount of AOX compounds.

5**.7.3 Effect of vermicomposting on nature of sludge**

The worms became 30-35% heavier during 60 days of vermicomposting. The height of the compost pile reduced upto the extent of 12-40% and worms penetrated upto the bottom within 60 days of time (Table 18). It required 90-100 days to stabilize the secondary sludge.

In Batch 2, the initial organic content of material was 46.7-67.4% (Table 19) and it reduced to the extent of 14-23% during vermicomposting depending upon the composition of the secondary sludge mixture (Figure 24). The C/N ratio in the vermicomposted material varied from 9.4 to 19.0 depending upon the composition of the secondary sludge mixture (Table 20). The values were indicative of the suitability of the composted material for plantation and agricultural application.

In Batch 3, the initial organic content of material was 45.8-79.8% (Table 21). It reduced to the extent of 8-15% (Figure 25) during 90 days of composting depending upon the composition of the secondary sludge mixture. Worms used nitrogen and phosphorous present in the secondary sludge mixture for the growth. In the process organic nitrogen and phosphorous were reduced after vermicomposting. The bulk density of composted material was 0.51 & 0.60 g/cc (set-2 and set-3) whereas the same was 0.62 g/cc for aerobic compost from cow dung.

The vermicomposting also facilitated the reduction of contamination of pathogenic organisms. Concentration of E coli was also reduced by vermicomposting (Table 22).

5.7.4 Effect of vermicomposting on organochlorine compounds

Decomposition/removal of AOX compounds took place during vermicomposting, though the concentration of AOX compounds remained more or less same in the composted material after 90 days of time (Table 23) but based on reduction in absolute amount, 15-26 and 19-24% decomposition/removal of AOX compounds were observed in Batch 2 and 3 respectively depending upon composition of the secondary sludge mixture.

The concentration of 12 chlorophenols was measured in mixed sludge before and after composting (Table 24). There was substantial reduction in concentration of organochlorine compounds after composting (Table 25). The concentration of PCDD and PCDF compounds was far below (Table 26) than European Commission Directives for composted sewage sludge (0.100 ng I-TEQ/g dm). Only objectionable contaminants in the secondary sludge and compost material were 2,3,7,8 TCDD and 2,3,7,8 TCDF. As per Stockholm Convention, 2000, in which India is a signatory; presence of these two compounds should be below detection level.

5.7.5 Distribution of metals in constituents and compost

Common metals like Na, K, Mg, Al, Ca and Fe were in very high concentration in all the three constituents. Na, Mg and K were highest in worm compost whereas rest common and heavy metals were highest in secondary sludge (Table 27). The source of these metals in secondary sludge might be pulping raw materials, pulping and bleaching chemicals, paper fillers, chemicals for sizing and paper broke processing. After composting the metal concentration increased in all the sets due to loss of organic material (Table 28-30) but concentration of metals were far below the limit recommended in EU and USEPA Directives.

5.8 Aerobic Composting

Dewatered secondary sludge was used for aerobic composting. The aerobic composting was also performed in plastic containers (Figure 26). It was mixed with saw dust in different proportions (Table 31) in order to maintain the moisture content between 75-80%. No external addition of N and P was done during the entire period of aerobic composting. Naisargic BTM-COM, an enriched aerobic culture supplied by Naisargic Agro Products, Navi Mumbai was used for the aerobic composting. 5 ml of bacterial mixture was diluted to 100 ml, sprayed and thoroughly mixed with the sludge material. The material was mixed thoroughly once in a day with spreader. Moisture content during aerobic composting was maintainted within 75-80%.

Like the vermicomposting, aerobic composting was also slow process; it took more than 90 days to stabilize the organic matter. About 16 to 22% organic matter was decomposed by the aerobic organisms depending upon the composition of secondary sludge and wood dust (Table 32). Both C and N contents reduced during the composting though the reduction of the latter was slightly higher (Table 33). This had resulted in the marginal increase in C to N ratio, though it was much lower than the recommended value of 20:1. The composted material was very hard in nature.

AOX compounds were reduced appreciably during composting from 21 to 39.5%. Highest reduction was observed in the case when secondary sludge was used as the sole substrate (Table 34).

The composted material was rich in Ca and Mg content and low in Na content. This aspect was favourable for the compost to be used in land application (Table 35). Heavy metals content was far below the European Commission Directive.

5.9 Crop cultivation

Wheat and onion crops were selected to check the transformation of halogenated compounds from compost to plant. Three sets of experiments were carried out with the compost from set-2 (68% secondary sludge), set-3 (45% secondary sludge) of Batch-3 and natural aerobic compost from cow dung. The compost material was mixed with sand in 1:3 ratio. For set-2 (A) and set-3 (B) wheat and onion were cultivated in triplicates while for control using natural compost (C) wheat and onion were cultivated in duplicate (Figure 27).

Initial length of onion plants was 21-22 cm and wheat was germinated on 12-13 day in all the sets. Growth of both the crops was better in composted material from secondary sludge. Both height and weight of crops after 60 and 90 days were higher in case of crops cultivated with composted material from sludge (Table 36-38). The height and weight of spikes of wheat crop grown with compost material from sludge was 37 and 125% higher respectively than those in crops grown with natural composted material.

5.9.1 Transformation of chlorophenolic compounds

The different part of crops were analysed for AOX and EOX content. The concentration of AOX compounds was below detection limit (2 mg/kg) in control samples as well as samples cultivated with compost material from sludge. The whole plant samples were also analysed for 12 classified chlorophenolics when none of the compounds was detected in all the samples. The wheat spikes were also characterized for PCDD and PCDF and concentration was slightly higher in sample cultivated on composted sludge (Table 39); trace concentration of PCDD and PCDF compounds has also been reported in cereals and food from different parts of the world (Table 40).

5.9.2 Cultivation of mushroom in the composted material from secondary sludge

A mushroom is the fleshy, spore bearing fruiting body of a fungus, typically produced above ground on soil or on its food source. The standard for the name "mushroom" is the cultivated white button mushroom, Agaricus bisporuus. Many people are intrigued by mushrooms' nutritional and medicinal properties, in addition to their culinary appeal. Mushrooms contain many essential amino acids for example white button mushrooms; contain more protein than kidney beans. As a group, mushrooms also contain some unsaturated fatty acids; provide several vitamins B, and vitamin D. Some even contain significant vitamin C, as well as the minerals potassium, phosphorus, calcium, and magnesium.

Three mushrooms species are cultivated in India viz., white mushroom (Agaricus bisporuus), paddy-straw mushroom (Volvariella volvacea) and oyster mushroom (Pleurotus sajor-caju). Mushroom cultivation is again dependent upon the season of the year; generally the following schedule is maintained throughout the year:

Mid November to mid March: Agaricus bisporuus

February to mid April : Pleurotus sajor-caju

Mid June to Mid September: Volvariella volvacea

September to November: Pleurotus sajor-caju.

Mushroom production is completely different from growing green plants. Mushrooms do not contain chlorophyll and therefore depend on other plant material (the "substrate") for their food. The part of the organisms that we see and called mushroom is really just the fruiting body. Unseen is the mycelium—tiny threads that grow throughout the substrate and collect nutrients by breaking down the organic material. Generally, each mushroom species prefers a particular growing medium, although some species can grow on a wide range of substrates.

Steps for the cultivation

- Choosing a growing medium
- Pasteurizing or sterilizing the medium
- Seeding the beds with spawn (material from mature mushrooms grown on sterile media)
- Maintaining optimal temperature, moisture, and other conditions for mycelium growth and the conditions that favor fruiting (This is the most challenging step)
- Harvesting, packaging, and selling the mushrooms
- Cleaning the facility and beginning again

The selected species of mushroom was cultivated in the lab with vermicompost and aerobic compost materials. One set of control was also run using compost from cowdung. The mycelium of different species propagated in all the compost material for the entire period of incubation which was nearly 4 months (Figure 28-29). Amongst the three species Calocybe grew in much higher proportion. Between the two composts, vermicompost was better for the growth of the selected species. Though, mycelium grew significantly, fruiting bodies did not form properly which might be due to the laboratory physical condition or texture of the compost material. The laboratory scale experimentation on mushroom growth demonstrated

that the composted material (vermicompost or aerobic compost) were not toxic for the growth of the mushroom.

5.10 Incineration of secondary sludge

The secondary sludge samples from pulp and paper industry were rich in organic content and had moderate calorific value. The SGU-SS2 and Star-SS samples had calorific value of 3268±86 and 3658±163 kcal/kg respectively. For incineration study, the sludge samples from different mills were dried in sun light, hot air (45 ^{0}C) and oven dried (103 ^{0}C). The drying of samples altered the volatile organochlorine compounds. During drying there was reduction in AOX compounds due to release of POX compounds (Table 41). 24-30% reduction in AOX compounds was observed during drying in sunlight; highest reduction was observed at higher temperature (105 ^{0}C).

The incineration experiments were performed with sludge collected from BILT-SGU. 5 g sample was incinerated in 3 cm dia and 30 cm long quartz tube at 800 and 1100 ^{0}C (Figure 30). After incineration, the flue gases were passed through different solvents to trap organochlorine compounds and analysed for AOX content. The concentration of AOX in flue gases was <0.2 mg/kg of sludge. For chlorophenolic compounds, two impingers containing dimethyl glycol and water (25 ml each) were used. Even after incineration at 1100 ^{0}C, presence of a few chlorophenolic compounds was observed in flue gases (Table 42).

5.11 Anaerobic stabilization of sludge

5.11.1 Reactor set-up

The collected seed sludge was screened through 12 no. mesh wire sieve and acclimated in anaerobic conditions at 37 ^{0}C for 3-5 days. Three batch reactors (Figure 31) were set-up containing 3.82 l of mix sludge (2 l of seed sludge & 1.82 l of secondary sludge) with MLSS of 112.6 g and MLVSS of 46.8 g (Table 43) and operated at different retention time of 10, 15 & 20 days. A continuous mode reactor (Figure 32) was also run to study the anaerobic stabilization but due to low volume (24 l) and heterogeneity of material, it was not possible to get interpretable results out of the study in the continuous reactor.

5.11.2 Anaerobic degradation of biomass

At the end of above mentioned retention time, certain amount of mixed sludge was withdrawn from each reactor assuming 50% reduction in MLVSS of secondary sludge and fresh secondary sludge was added. The mixed sludge removed from the reactor was equivalent to the amount of undigested secondary sludge. After a period of 60 days, the maximum reduction in quantity of secondary sludge was observed in case of 15 days retention time.

There was 42.4 and 33.4 % reduction in MLVSS & MLSS concentration of added sludge respectively (Table 44-45).

5.11.3 Effect of anaerobic stabilization on organochlorine compounds

After 60 day period, the samples were analysed for AOX and chlorophenolic compounds. Significant reduction in AOX compounds was observed (Table 46). The presence of chlorophenolic compound was below detection limit in seed and anaerobically stabilized sludge. One sample (15 day RT) was also checked for the contamination level of PCDD and PCDF compounds and the concentration was very low in treated sample (Table 47). The upper bound I-TEQ from PCDD/Fs was 8.6 in treated sample whereas the same was 54 pg/g dm in SGU-SS.

5.11.4 Effect on dewatering property of secondary sludge

Anaerobic treatment of sludge attributed better dewatering property to the sludge due to reduction in surface charge. Filterability and dryness were improved when the sludge was digested for a retention time of 15 days (Table 48). Being negative in charge, cationic flocculant were found to be suitable for settling and dewatering. The filterability study was also carried out with Buckner funnel (7.3 cm ID) at 300 mm of Hg vacuum without addition of flocculant. The raw secondary sludge contained excessive filamentous organisms and DSVI value was > 400 ml/g. The settling characteristics of anaerobically treated sludge were very good and morphological characterization revealed lowering in filamentous organisms in anaerobically digested sludge (Figure 33).

5.11.5 Impact of ozone assisted disintegration on anaerobic stabilization

The secondary sludge was disintegrated at two different ozone doses (i.e. 20 and 40 mg/g of MLSS) and subsequently treated anaerobically with retention time of 15 days for 5 cycles.

For the study, three batch reactors (A, B & C) were set-up having 2 l of seed sludge with MLSS of 45.1 g/l or MLVSS of 15.0 g/l and 1 l of secondary sludge having MLSS of 7.60 g/l or MLVSS 4.65 g/l.

After 75 days all the batch reactors were analyzed for reduction in MLSS, MLVSS, and AOX content (Table 49). Maximum reduction in biomass was observed in reactor B (O_3 dosage of 40 mg/g) and it promoted the maximum generation of biogas in the same reactor. The least reduction of sludge was observed in control reactor (reactor C). Considerable reduction in AOX was also observed in all the reactors; maximum reduction of 51.5 % in reactor B followed by reactor A and C. The presence of chlorophenolic compounds was below detection limit in anaerobically stabilized sludge.

6. CONCLUSIONS

Dewaterability and filterability of the secondary sludge are dependent upon the nature of the sludge. Sludge containing excessive filamentous organisms can be dewatered upto 18% dryness level with 3.1-3.7 kg of cationic flocculant dosage per ton of the secondary sludge with decanter centrifuge.

Secondary sludge can be treated by aerobic composting, vermicomposting or anaerobic treatment. The latter two treatment methods stabilize the organic matter in the sludge and remove the organochlorine pollutants to the great extent. Dioxins and dibenzofurans which are the typical contaminants in secondary sludge of pulp and paper industry utilizing partially chlorine substituted bleaching can be reduced to the level where it can be applied as organic manure. No apparent adverse effect has been observed in the growth of wheat and onion crops when vermicomposted secondary sludge was used as manure. Secondary sludge of pulp and paper mills based on elementary chlorine free bleaching which is almost free of 2,3,7,8 TCDD/Fs contamination can safety be utilized as manure after vermicomposting or anaerobic treatment. Mills need to modify the bleaching sequence either to ECF or substitute initial chlorination with higher amount of chlorine dioxide to eliminate the formation of 2,3,7,8 dioxin and 2,3,7,8 dibenzofuran completely. This will lead to secondary sludge with no contamination of these two prohibited compounds

Incineration at a temperature above 1100 ^{0}C can be considered as a technical option for the secondary sludge having very traces of chlorophenolics or PCDD/Fs contamination.

7. RECOMMENDATIONS

The anaerobic stabilization of sludge should be carried out at pilot scale with bulking and flocculating sludge. The study will establish the following aspects:

- Effect of bulking of sludge on stabilization
- Design of reactor
- Necessity of additional pretreatment of sludge
- Characterization of produced gas

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9. REFERENCES

1. Greenberg A.E., Clesceri L.S., Eaton A.D., Standards methods for the examination of water and wastewater, 18th ed., American Public Health Association, Washington, 1992
2. Brinton W.F., (2000). Compost quality standards & guidelines. Woods End Research Laboratory , Inc., USA
3. Cooper, J.S. (1994). Sludge - The final frontier. Tappi J., 77(5),12-14
4. Camberato, J.J., Vance, E.D., Someshwer, A.V., (1997). Composition and land application of paper manufacturing residuals, ACS Symp. Ser. 668 (Agricultural Uses of Byproducts and Wastes), 185-202
5. Drolet J.Y. and Baril P., (1997). A review of constraints and opportunities for the land application of paper mill sludges and residues. Pulp & Paper Canada, 98(6), 63-66
6. Fiedler H., Hutzinger O., Welsch-Pausch K., Schmiedinger A., (2000). Evaluation of the occurrence of PCDD/PCDF and POPs in wastes and their potential to enter the food-chain, University of Bayreuth, Bayreuth
7. Jenkins D., Richard M.G., Daigger G.T., Manual on the cause and control of activated sludge bulking and foaming. 2nd Edition, Lewis Publication Inc., USA, 1993
8. Kanters M.J., Nispen R.V., Louw R., Mulder P., 1996. Chlorine input and chlorophenols emission in the lab scale combustion of municipal solid waste. Environ. Sci. Technol. 30 (7), 2121-2126
9. Kato M., Urano K., Tasaki T., (2000). Development of semi and nonvolatile halogen as a new hazardous index of flue gas. Environ. Sci. Technol. 34, 4071-4075
10. Macyk, T.M., (1996). Research relative to land application of pulp mill wastes in Alberta. Pulp & Paper Canada, 97(3), 48-52
11. Matthews, P., (1996). A global atlas of wastewater sludge and biosolids use and disposal, Scientific and Technical Report No.4, International Association on Water Quality, London, UK.
12. NCASI method CP-85.01, NCASI methods for the analysis of chlorinated phenolics in pulp industry wastewater. National Council of the Paper Industry for Air and Stream Improvement, New York, USA
13. Pickell J. and Wunderlich R., (1995). SIudge disposal: Current practices and future options, Pulp & Paper Canada, 96(9), 41-48
14. Puhakka J.A., (1992). Anaerobic treatment of kraft pulp mill waste activated sludge: Gas production and solids reduction. Bioresour. Technol., 39, 61-68
15. Rantala P.R., Vaajasaari K., Juvonen R., Schultz E., Joutti A., Makela-

Kurtto R., Composting of forest industry wastewater sludges for agricultural use. Proc. 6th IAWQ Symp. Forest-Industry Wastewaters, 6-10 June, 1999, Tampere, Finland, 181-188

16. Ratnieks E., Gaylardeb C.C., (1997). Anaerobic degradation of paper mill sludge. Int. Biodeterior. Biodegrad. 39 (4), 287-293

17. Thacker W.E. and Vriesman R. (1984). The Land Application and Related Utilization of Pulp and Paper Mill Sludges, National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin No: 439, New York, USA

18. USEPA Report: Proposed regulation of land application of sludge from pulp and paper mills using chlorine and chlorine derivative bleaching processes. Federal register, 56 (91), 40 CFR. Part 744, OPTS-62100; FRL 3873-2.

19. Veillette A.X. and Tanguay M.G. (1997). Agricultural land application of pulp and paper mill sludges in the Donnacona area, Quebec: Chemical evaluation and crop response. ASTM Spec. Tech. Publ., STP 1275 (Testing Soil Mixed with Waste or Recycled Materials), 141-154.

20. Velema G. (1999). Domtar Papers' land application: Experience at Cornwall. Pulp & Paper Canada, 100(3), 42-45

Table 1: Physical and chemical characteristics of secondary sludge samples

Parameter	SGU-SS1	JKPM-SS1	ITC-SS1	APPM-SS1
MLSS (g/l)	5.3	3.2	8.0	4.1
MLVSS (g/l)	3.8	2.0	5.7	3.2
Organic (%)	70.9	63.1	71.9	78.0
Total carbohydrate (g/kg)	83.4	99.5	42.5	56.2
Carbon (%)	32.8	35.1	37.6	36.5
Hydrogen (%)	5.2	5.6	5.5	4.9
Nitrogen (%)	5.4	6.1	5.8	5.3
Sulphur (%)	0.61	0.78	1.20	1.79
$P\text{-}PO_4^{-3}$ (mg/kg)	399.0	219.2	96.5	ND
Zeta potential (mv)	-17.6	-39.0	-33.6	-

Table 2: Metallic elements in secondary sludges

Metal	SGU-SS1 (mg/kg)	JKPM-SS1 (mg/kg)	ITC-SS1 (mg/kg)	APPM-SS1 (mg/kg)
Sodium	2593	1891	1754	4267
Calcium	43680	14850	39770	78925
Magnesium	6330	10649	7086	5281
Potassium	2066	2653	2059	2137
Aluminum	2820	12871	5800	9026

Table 3: Heavy metals in secondary sludge samples

Metal	SGU-SS1 (mg/kg)	JKPM-SS1 (mg/kg)	ITC-SS1 (mg/kg)	APPM-SS1 (mg/kg)
Lead	24	26	13	131
Nickel	12.9	22.4	11.6	27.2
Iron	1468	2308	4241	4594
Chromium	33	63	27	49.5
Manganese	88	230	238	258
Zinc	72	140	135	115
Copper	29	255	29	35
Cobalt	2.7	2.6	12.7	7.0

Cadmium, Selenium and Mercury were non-detectable in the secondary sludge.

Table 4: Organochlorine contaminants in secondary sludge samples

Parameter	SGU-SS1	JKPM-SS1	ITC-SS1	APPM-SS1
AOX (mg/kg)	2251	3663	451	5140
EOX (mg/kg)	765	1464	168	728

Table 5: Characterisation of secondary sludge samples

Sample	Moisture (%)	Solid (%)	Organic (%)	Inorganic (%)	AOX (mg/kg)
ITC-SS2	95	5.0	75.8	24.2	490±33
APPM-SS2	94.5	5.5	66.1	33.9	940±7
Star-SS	94.1	5.9	72.0	28.0	1944±52
SGU-SS2	91.0	9.0	73.5	26.5	2231±137
JKPM-SS2*	12.1	87.9	60.9	39.1	2341±39

*Sun dried sample (hence low in AOX content)

Table 6: Twelve identified chlorophenolic compounds in secondary sludge samples

Compound (mg/kg)	SGU-SS2	Star-SS	JKPM-SS2	APPM-SS2	ITC-SS2
2, 4, 6- Trichlorophenol	0.311±0.023	0.264± 0.018	0.074 ± 0.001	<0.021	<0.021
2, 4, 5- Trichlorophenol	0.085±0.014	<0.062	<0.070	0.088 ± 0.005	ND
2, 3, 4, 5- Tetrachlorophenol	0.132±0.005	<0.023	<0.026	<0.026	ND
3, 4, 6- Trichloroguaiacol	<0.043	ND	0.056± 0.009	ND	ND
3, 4, 5- Trichloroguaiacol	0.089±0.038	0.061± 0.015	ND	ND	ND
4, 5, 6- Trichloroguaiacol	ND	<0.043	ND	ND	ND
3, 4, 6- Ttrichlorocatecol	0.240±0.025	ND	<0.085	ND	ND
Pentachlorophenol	0.259±0.032	ND	0.015± 0.0	ND	ND
3, 4, 5- Trichlorocatecol	0.319±0.032	ND	0.263± 0.136	ND	ND
Tetrachloroguaiacol	0.064±0.012	ND	0.328± 0.028	ND	<0.059
Trichlorosyringol	0.233±0.037	0.141± 0.044	0.599± 0.086	ND	ND
Tetrachlorocatecol	0.311±0.054	ND	0.125± 0.0	ND	ND

ND: Non-detectable

Table 7: Dioxins and dibenzofurans in secondary sludge samples

PCDD/PCDF (pg/g DM)	TEF	APPM-SS1	APPM-SS2	ITC-SS1	JKPM-SS2	SGU-SS1
2,3,7,8-TCDD	1	10	ND	< 0.83	31	16
1,2,3,7,8-Pe CDD	0.5	ND	ND	ND	4.1	<2.0
1,2,3,4,7,8-Hx CDD	0.1	ND	ND	<0.92	ND	ND
1,2,3,6,7,8- Hx CDD	0.1	0.75	ND	6.0	ND.	2.2
1,2,3,7,8,9-HxCDD	0.1	<0.68	ND	2.0	ND	<2.4
1,2,3,4,6,7,8-HpCDD	0.01	4.9	9.9	220	13	250
OCDD	0.001	68	41	1900	170	8300
2,3,7,8-TCDF	0.1	140	5.1	3.7	320	210
1,2,3,7,8-PeCDF	0.05	4.3	ND	<0.34	34	7.4
2,3,4,7,8-PeCDF	0.5	3.0	ND	<0.34	23	6.1
1,2,3,4,7,8-HxCDF	0.1	1.2	ND	0.62	5.3	<1.4
1,2,3,6,7,8- HxCDF	0.1	0.6	ND	0.65	ND	<1.4
1,2,3,7,8,9- Hx CDD	0.1	ND	ND	ND	ND	ND
2,3,4,6,7,8-HxCDF	0.1	2.4	ND	0.66	3.5	3.0
1,2,3,4,6,7,8- HpCDF	0.01	7.6	22	44	9.3	23
1,2,3,4,7,8,9-HpCDF	0.01	ND	ND	ND	ND	ND
OCDF	0.001	11	21	81	37	87
Lower bound I-TEQ from PCDD/Fs		26	0.89	6.0	80	52
Upper bound I-TEQ from PCDD/Fs		27	3.3	7.3	80	54

ND: Non-detectable

Table 8: Filamentous microorganisms in secondary sludge samples

SGU-SS1	JKPM-SS1	ITC-SS1	APPM- SS1
Nocardia	Nocardia	Nocardia	Nocardia
N.Limicola-1	N.Limicola-1	N.Limicola-1	N.Limicola-1
N.Limicola-2	N.Limicola-3	Cell type-1851	N.Limicola-2
M.Parvicella	M.Parvicella	-	M.Parvicella

Table 9: Comparative characterization of filamentous organisms

Sl.No	Parameter	SGU-SS1	JKPM-SS1	ITC-SS1	APPM-SS1
1	Branching	Absent	Absent	Absent	Absent
2	Filament shape	Irregular shaped-chain of cells	Straight, smoothly curved	Smoothly curved	Irregular shaped
3	Location	Partly within the floc and mostly free	Extending floc surface	Free floating	Partly within the floc and mostly free
4	Attached growth of epiphytic bacteria	Present	Present	Very few present	Present
5	Cell septa	Present	Present	Few present	Present
6	Filament diameter (µm)	1 - 1.40	1 -1.88	1 - 2	1 - 1.62
7	Cell shape	Square	Square	Rectangular	Rectangular
8	Size (average length) µm	180.6	113.5	61	68.73
9	Sulfur deposit	Absent	Absent	Absent	Absent
10	Gram stain	Mostly gram positive	Positive	Positive	Positive
11	Neisser stain	Positive	Positive	Positive	Mostly positive
12	Additional information	Excessive filamentous organisms as compared to bacilli and cocci	Filament-ous organisms abundant	Least filamentous organisms; bacilli and cocci present	Excess of filamentous organisms present

Table 10: Filament count in secondary sludge samples

Parameter	SGU-SS1	JKPM-SS1	ITC-SS1	APPM-SS1
Min (µm)	7.6	7.8	11.2	9.0
Max (µm)	502.4	576.8	279.0	771.7
Avg (µm)	111.9	113.5	61.1	68.7
Count	412	282	283	168
Dilution	1000	1000	1000	100
Sample (ml)	0.01	0.02	0.02	0.02
MLSS (g/l)	5.3	3.2	8.0	4.1
MLVSS (g/l)	3.6	2.0	5.7	3.2
No. of filament/ml	4.13×10^7	1.41×10^7	1.42×10^7	8.40×10^5
Extended filament length (µm/ml)	4.62×10^9	1.60×10^9	8.64×10^8	5.77×10^7
Extended filament length (µm/g MLSS)	8.71×10^8	5.00×10^8	1.08×10^8	1.41×10^7

Table 11: Pathogenic organisms in secondary sludge samples

Sample	E.Coli count (TVC/g)	Total Salmonella count (TVC/g)	Salmonella Typhi (TVC/g)	Cryptosporidium Parvum (TVC/g)
SGU-SS1	86×10^6	2.58×10^8	Non-detectable	Non-detectable
JKPM-SS1	347×10^6	6.74×10^8	Non-detectable	Non-detectable
ITC-SS1	115×10^6	9.5×10^8	Non-detectable	Non-detectable
APPM-SS1	268×10^6	0.28×10^8	Non-detectable	Non-detectable

Table 12: Coagulants and flocculants for the dewatering of secondary sludge

Chemical	Nature	Charge (meq/g)
PAC	Cationic coagulant	1.24
$FeCl_3$	Cationic coagulant	0.82
OP 5810	Cationic coagulant	2.72
OP 5925	Cationic coagulant	2.46
SF1118	Anionic flocculant	1.46
OP 5540	Anionic flocculant	4.37
Suyog 2131	Anionic flocculant	3.21
DK SET CA 60	Cationic flocculant	1.25
DK SET C 715 HN	Cationic flocculant	0.25
Suyog K 30	Cationic flocculant	2.25
Zetag 7653	Cationic flocculant	1.88
Nalco 9914	Cationic flocculant	0.88

Table 13: Design parameters of decanter centrifuge

Item	Specification
Sludge feed pump flow (m^3/h)	2-3 @ sludge consistency 2-3%
Flocculant dosing pump flow (lph)	0-250
Flocculant preparation tank (l)	500
Power consumption (kW/h)	4.0 @7 amp
Centrifuge power consumption (kW/h)	2.9 @ 5 amp

Table 14: Optimization of flocculant dose (Suyog K-30)

Flocculant dosage (kg/t)	Solid consistency (%)	Solid (centrate) (mg/l)	Solid captured in cake (%)	Solid in centrate (%)
0.0	13.7	5980	78.6	21.4
2.42	14.9	1052	96.0	4.0
3.07	15.4	282	98.9	1.1
3.72	17.1	170	99.3	0.7
5.01	17.9	84	99.7	0.3

Feed consistency: 2.79 %, feed flow: 2.11 m^3/h, pH: 6.5, organic: 63.35 %, SVI: 309 ml/g

Table 15: Optimization of flocculant dose (Nalco –9914)

Flocculant dosage (kg/t)	Solid consistency (%)	Solid (centrate) (mg/l)	Solid captured in cake (%)	Solid in centrate (%)
0.0	13.7	5980	78.6	21.4
1.78	14.9	3420	87.1	12.9
2.42	16.4	208	99.2	0.8
3.07	17.0	124	99.5	0.5
3.72	17.4	86	99.7	0.3

Feed consistency: 2.79 %, feed flow: 2.11 m^3/h, pH: 6.5, organic: 63.35 %, SVI: 309 ml/g

Table 16: Conditions maintained for vermicomposting

Set no.	Material	Ratio	Moisture maintained in compost tank (%)
Batch 1			
Set-1 (without flocculant)	Sec. sludge	29.8	77
	Worm culture	5.8	
	Saw dust	8.0	
	Soil	56.4	
Set-2 (with Suyog)	Sec. sludge	25.7	72
	Worm culture	17.0	
	Saw dust	8.7	
	Soil	48.7	
Set-3 (with Nalco)	Sec. sludge	24.2	74
	Worm culture	21.7	
	Saw dust	8.2	
	Soil	45.9	
Batch 2			
VC-1	Sec. sludge	95.4	79
	Worm culture	5.0	
	Saw dust	0	
VC-2	Sec. sludge	77.3	77
	Worm culture	12.6	
	Saw dust	10.0	
VC-3	Sec. sludge	50.0	72
	Worm culture	12.3	
	Saw dust	37.3	
VC-4	Sec. sludge	24.6	74
	Worm culture	12.0	
	Saw dust	63.3	
Batch 3			
Set-1	Sec. sludge	86.0	83
	Worm culture	14.0	
Set-2	Sec. sludge	68.3	80
	Worm culture	13.9	
	Saw dust	17.8	
Set-3	Sec. sludge	45.5	74
	Worm culture	14.1	
	Saw dust	40.4	
Set-4	Sec. sludge	22.7	62
	Worm culture	13.8	
	Saw dust	63.5	

Table 17: Characteristics of constituents of vermicomposting

Parameter	Secondary sludge	Worm culture	Saw dust
Batch-2			
Carbon (%)	25.9	26.9	45.7
Kjeldhal nitrogen %	3.3	1.7	0.5
AOX (mg/kg)	2232	5	7
Batch-3			
Carbon (%)	20.1	25.7	44.3
Kjeldhal nitrogen %	5.8	2.4	0.9
Phosphorous as PO_4^{-3} (%)	0.7	0.5	0.2
AOX (mg/kg)	2155	79	2

Table 18: Compaction of compost pile and penetration of worms (Batch-3)

Vermicompost set	Height of pile (cm)			Worms penetration (cm)	
	0^{th} day	30^{th} day	60^{th} day	30^{th} day	60^{th} day
Set-1	22	15	13	4-5	Upto bottom
Set-2	19	13	12	9-10	Upto bottom
Set-3	14	12	11.5	9-10	Upto bottom
Set-4	16	15	14	9-10	Upto bottom

Table 19: Organic content in the compost with variation in composting time

Sample	0^{th} day	30^{th} day	60^{th} day	90^{th} day
VC-1	46.6	42.8	38.5	35.9
VC-2	49.4	46.8	40.9	39.4
VC-3	57.4	53.0	49.6	49.0
VC-4	67.4	62.7	59.5	58.0

Organic content in Secondary sludge as such, Saw dust and Culture material: 46.5, 91.5 and 51.3 % respectively on 0^{th} day

Table 20: C, N and C/N ratio in the compost with variation of composting time

Sl no.	Material/compost	0^{th} day			90^{th} day		
		Carbon (%)	Nitrogen (%)	C/N ratio	Carbon (%)	Nitrogen (%)	C/N ratio
1	Secondary sludge as such	25.9	3.3	7.7			
2	Saw dust	45.7	0.5	87.9			
3	Culture material	26.9	1.7	15.8			
4	VC-1	25.6	3.1	8.4	19.9	2.1	9.4
5	VC-2	27.8	2.6	10.8	22.5	1.6	13.9
6	VC-3	31.3	2.0	15.5	27.0	1.5	18.5
7	VC-4	31.6	1.7	18.1	28.6	1.5	19.0

Table 21: Characterization of compost material

Parameter	Day	Set-1	Set-2	Set-3	Set-4
Moisture (%)	0^{th} day	89.4	80.2	74.0	73.1
	30^{th} day	76.4	74.1	69.5	71.9
	60^{th} day	72.6	64.2	68.1	72.5
Organic (%)	0^{th} day	45.8	58.2	69.2	79.8
	30^{th} day	41.9	48.5	60.2	74.6
	60^{th} day	41.5	47.6	57.3	64.3
	90^{th} day	38.1	47.4	57.1	64.2
Carbon (%)	0^{th} day	19.8	24.9	26.6	33.6
	90^{th} day	17.3	20.6	22.5	26.9
Kjeldhal nitrogen (%)	0^{th} day	4.50	4.22	3.69	1.90
	30^{th} day	1.62	1.02	0.93	0.87
	60^{th} day	1.09	0.89	0.97	0.75
	90^{th} day	1.20	0.94	0.91	0.34
Phosphorous as PO_4^{-3} (mg/kg)	0^{th} day	594	438	306	139
	90^{th} day	122	70	52	58
Weight loss (%)	90^{th} day	14.0	18.1	20.9	24.2

Table 22: Pathogenic organisms in constituents and composted material before and after composting (Batch-3)

Sample	E coli (TVC/g)
SGU-SS2	46×10^6
Cow dung	57×10^3
Set-1	92×10^4
Set-2	124×10^4
Set-3	30×10^4
Set-4	87×10^4

Table 23: AOX content in the compost with variation in composting time

Vermicompost set	AOX compounds (mg/kg)				AOX reduction (%)
	0^{th} day	30^{th} day	60^{th} day	90^{th} day	
Batch-2					
VC-1	1838	1670	1632	1832	22.6
VC-2	1629	1652	1658	1720	15.3
VC-3	1114	1055	1171	1179	15.3
VC-4	621	587	654	562	26.7
Batch-3					
Set-1	1855	1738	1757	1737	19.5
Set-2	1441	1359	1417	1340	23.9
Set-3	923	900	968	889	23.9
Set-4	491	463	530	520	19.8

Table 24: Concentration of chlorophenolic compounds in constituents

Compound (mg/kg)	SGU-SS2	Worm culture	Saw dust
2, 4, 6- Trichlorophenol	0.311±0.023	<0.021	<0.021
2, 4, 5- Trichlorophenol	0.085±0.014	ND	ND
2, 3, 4, 5- Tetrachlorophenol	0.132±0.005	<0.026	ND
3, 4, 6- Trichloroguaiacol	<0.0434	ND	ND
3, 4, 5- Trichloroguaiacol	0.089±0.038	ND	ND
4, 5, 6- Trichloroguaiacol	ND	ND	ND
3, 4, 6- Ttrichlorocatecol	0.240±0.025	ND	ND
Pentachlorophenol	0.259±0.032	ND	ND
3, 4, 5- Trichlorocatecol	0.319±0.032	ND	ND
Tetrachloroguaiacol	0.064±0.012	<0.059	ND
Trichlorosyringol	0.233±0.037	<0.055	ND
Tetrachlorocatecol	0.311±0.054	0.032	0.044

ND: Non-detectable

Table 25: Concentration of chlorophenolic compounds before and after composting (Batch-3)

Compound (mg/kg)	Set-1		Set-2		Set-3		Set-4	
	0^{th} day	90^{th} day	0^{th} day	90^{th} day	0^{th} day	90^{th} day	0^{th} day	90^{th} day
2, 4, 6- Trichlorophenol	0.269	0.033	0.200	<0.021	0.149	<0.021	0.061	<0.021
2, 4, 5- Trichlorophenol	< 0.071	<0.069	< 0.071	<0.071	<0.071	<0.071	<0.071	<0.071
2, 3, 4, 5- Tetrachlorophenol	0.100	<0.025	0.087	0.034	0.058	ND	0.030	ND
3, 4, 6- Trichloroguaiacol	0.005	ND	<0.044	ND	<0.044	ND	<0.044	ND
3, 4, 5- Trichloroguaiacol	0.067	ND	0.060	ND	<0.047	ND	<0.047	ND
4, 5, 6- Trichloroguaiacol	ND	ND	ND	ND	ND	ND	ND	ND
3, 4, 6- Ttrichlorocatecol	0.198	ND	0.161	ND	0.111	ND	<0.085	ND
Pentachlorophenol	0.220	ND	0.165	ND	0.121	ND	0.059	ND
3, 4, 5- Trichlorocatecol	0.271	0.056	0.209	ND	0.148	ND	0.072	ND
Tetrachloroguaiacol	< 0.059	ND	< 0.059	ND	<0.059	ND	<0.059	ND
Trichlorosyringol	0.209	ND	0.151	ND	0.110	0.099	0.060	<0.055
Tetrachlorocatecol	0.253	0.161	0.201	0.146	0.144	ND	0.067	ND

ND: Non-detectable

Table 26: Concentration of PCDD and PCDF before and after vermicomposting (Batch-3)

PCDD/PCDF (pg/g Dm)	SGU-SS2	Set-1	Set-2	Set-3	Set-4
2,3,7,8-TCDD	16	5.7	4.2	3.6	2.1
1,2,3,7,8-Pe CDD	<2.0	ND	ND	ND	ND
1,2,3,4,7,8-Hx CDD	ND	ND	ND	ND	ND
1,2,3,6,7,8- Hx CDD	2.2	<2.5	<2.7	<1.7	ND
1,2,3,7,8,9-HxCDD	<2.4	<2.5	ND	ND	ND
1,2,3,4,6,7,8-HpCDD	250	45	34	21	19
OCDD	8300	390	390	170	150
2,3,7,8-TCDF	210	49	40	27	19
1,2,3,7,8-PeCDF	7.4	<1.4	<1.4	<0.99	<1.0
2,3,4,7,8-PeCDF	6.1	1.5	<1.4	<0.99	<1.0
1,2,3,4,7,8-HxCDF	<1.4	<2.1	<2.4	ND	<1.7
1,2,3,6,7,8- HxCDF	<1.4	ND	ND	ND	<1.7
1,2,3,7,8,9- Hx CDD	ND	ND	ND	ND	ND
2,3,4,6,7,8-HxCDF	3.0	<2.1	ND	ND	ND
1,2,3,4,6,7,8- HpCDF	23	8.2	8.4	8.2	8.0
1,2,3,4,7,8,9-HpCDF	ND	ND	ND	ND	ND
OCDF	87	23	14	9.1	9.3
Lower bound I-TEQ from PCDD/Fs	52	12	9.0	6.7	4.4
Upper bound I-TEQ from PCDD/Fs	54	14	11	8.2	6.1

ND: Non-detectable
Dm: Dry material

Table 27: Various metals in constituents of vermicompost (Batch-3)

Metal (mg/kg)	SGU-SS2	Worm compost	Saw dust
Na	1241	2110	451
Mg	3040	3555	927
Al	5560	943	123
K	1387	5033	1837
Ca	39254	4929	5768
Fe	2241	1791	247
Cr	11	2.8	1.3
Mn	124	127	45
Co	1.2	0.7	0.1
Ni	18	1.8	1.4
Cu	20	18	4.2
Zn	75	67	20
Cd	1.1	0.1	0.1
Pb	4.0	3.2	0.9

Hg, Se and As were non-detectable in the samples

Table 28: Various metals in the vermicompost (Batch-2)

Element	VC-1	VC-2	VC-3	VC-4	EC directive (86/278/ EEC Apppendix 1B)	USEPA
Na	2470	2630	2990	1979	-	-
Ca	91253	79628	57339	31867	-	-
Mg	3567	5326	4572	3179	-	-
K	4521	5296	7894	8755	-	-
Al	5405	5647	3895	2916	-	-
Fe	3127	4348	4771	2681	-	-
Mn	115.3	121.2	102.3	81.2	-	-
Pb	11.4	9.2	8.6	5.1	720-1200	840
Ni	14.2	11.4	10.1	6.5	300-400	420
Zn	119.1	128.3	100.8	78.3	2500-4000	7500
Cu	29.7	26.5	26.8	20.5	1000-1750	4300
Co	1.5	1.6	1.2	1.0	-	-
Cr	16.1	12.2	11.4	7.6	1000-1500	-
Cd	1.0	1.0	0.6	0.3	20-40	85

Table 29: Concentration of common metals before and after composting (Batch-3)

Metal (mg/kg)	Na		Mg		Al		K		Ca		Fe	
	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day
Set-1	1346	1594	3046	3619	4894	5505	1850	2378	35461	45226	2025	2156
Set-2	1693	1898	2843	3575	4729	5739	2037	2469	28954	39363	1902	2015
Set-3	1214	1466	2422	3106	3055	3724	2102	2818	21054	26362	1412	1446
Set-4	855	891	1859	2703	1688	1899	2220	3215	12985	19188	977	1001

Table 30: Concentration of heavy metals before and after composting (Batch-3)

Metal (mg/kg)	Cr		Mn		Co		Ni		Cu		Zn		Cd		Pb	
	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day	0th day	90th day
Set-1	12.4	14.1	124	130	1.2	1.2	15.5	16.7	22.5	28.2	74.5	82.2	1.0	1.0	3.7	4.0
Set-2	11.5	12.3	112	124	1.2	1.3	13.3	13.9	19.9	18.5	65.8	67.0	0.7	0.6	3.4	2.8
Set-3	7.7	5.7	95	117	0.8	1.1	9.6	10.7	14.9	16.2	55.2	57.2	0.5	0.7	2.7	2.4
Set-4	5.0	5.4	74	103	0.7	0.7	4.7	5.3	11.2	11.8	45.5	46.5	0.3	0.4	2.2	2.4

Table 31: Conditions maintained during aerobic composting

Experiment	Material	Ratio (%)	Moisture maintained (%)
AC-1	Sec. sludge	100	80
	Saw dust	0	
AC-2	Sec. sludge	73	75
	Saw dust	27	
AC-3	Sec. sludge	59	76
	Saw dust	41	

Table 32: Organic content in the aerobic compost with variation in composting time

Sample	0^{th} day	30^{th} day	60^{th} day	90^{th} day
AC-1	45.2	38.3	37.5	35.2
AC-2	54.5	48.4	46.5	45.9
AC-3	62.5	55.8	52.0	49.0

Organic content in Secondary sludge as such , Saw Dust and Culture material : 46.5, 91.5 and 51.3 % respectively on 0^{th} Day

Table 33: C, N and C/N ratio in the aerobic compost with variation in composting time

Sl no.	Material/compost	0^{th} day			90^{th} day		
		Carbon (%)	Nitrogen (%)	C/N ratio	Carbon (%)	Nitrogen (%)	C/N ratio
1	Secondary sludge as such	25.9	3.3	7.7			
2	Saw dust	45.7	0.5	87.9			
3	Culture material	26.9	1.7	15.8			
4	AC-1	25.4	3.3	7.7	19.6	2.4	8.2
5	AC-2	28.3	2.8	10.1	25.4	2.0	12.7
6	AC-3	27.7	2.3	10.2	23.9	1.9	12.5

Table 34: AOX content in the aerobic compost with variation of composting time

Material /Set	0^{th} day	30^{th} day	60^{th} day	90^{th} day	Reduction (%)
Secondary sludge as such	2232	-	-	-	
Saw dust	7	-	-	-	
Culture material	5	-	-	-	
AC-1	2174	1872	2158	1785	39.5
AC-2	1502	1254	1591	1488	27.2
AC-3	1177	1398	1331	1338	20.9

Table 35: Various metals in the aerobic compost

Element	AC 1	AC 2	AC 3	EC Directive (86/278/ EEC Apppendix 1B)	USEPA
Na	2272	2501	2177		-
Ca	93455	77582	64192		-
Mg	5845	4857	4257		-
K	2235	3958	4899		-
Al	6199	4920	4254		-
Fe	2228	3508	2568		-
Mn	126.9	96.3	86.4		-
Pb	11.0	9.0	8.4	720-1200	840
Ni	14.6	12.6	9.9	300-400	420
Zn	158.3	121.7	89.4	2500-4000	7500
Cu	29.5	26.8	21.3	1000-1750	4300
Co	1.3	1.4	0.9	-	-
Cr	16.1	13.4	11.7	1000-1500	-
Cd	1.3	1.0	0.8	20-40	85

Table 36: Height (cm) pattern of wheat and onion (Batch-3)

Day	A: Wheat	B: Wheat	C: Wheat	A: Onion	B: Onion	C: Onion
0	-	-	-	21.1±1.1	22.0±1.5	21.5±0.3
30	16.1±2.2	17.3±2.3	15.7±1.4	22.0±1.1	21.1±1.2	20. 2±1.0
45	23.5±2.6	24.8±3.4	23.3±1.2	23.6±1.5	27.5±0.3	25. 4±1.6
60	47.5±3.5	49.5±3.0	38.2±2.9	43.3±4.1	54.7±1.1	36. 3±0.1
90	52.3±1.6	52.2±2.9	43.6±0.9	43.8±2.2	53.8±2.3	31. 8±1.0

A: Set-2, B: Set-3, C: Natural compost

Table 37: Weight (g) pattern of wheat and onion

Day	A: Wheat	B: Wheat	C: Wheat	A: Onion	B: Onion	C: Onion
0	-	-	-	1.4	1.4	1.4
60	9.1	10.1	7.0	18.1	23.1	12.6

A: Set-2, B: Set-3, C: Natural compost

Table 38: Height (cm) & weight (g) pattern of wheat spike (per spike)

Weight (Avg. of 6)	AW-spike	BW- spike	CW- spike
	2.8	2.9	1.3
Height	14.1±0.8	14.0±0.4	10.3±0.6

AW: wheat cultivated with set-2
BW: wheat cultivated with set-3
CW: wheat cultivated with natural compost

Table 39: Transformation of PCDD and PCDF in crop

PCDD/PCDF (pg/g Dm)	TEF	SGU-SS1	W-com	W-con
2,3,7,8-TCDD	1	16	ND	ND
1,2,3,7,8-Pe CDD	0.5	<2.0	0.24	ND
1,2,3,4,7,8-Hx CDD	0.1	ND	0.19	ND
1,2,3,6,7,8- Hx CDD	0.1	2.2	0.35	0.19
1,2,3,7,8,9-HxCDD	0.1	<2.4	0.26	0.16
1,2,3,4,6,7,8-HpCDD	0.01	250	3.2	1.7
OCDD	0.001	8300	12	6.3
2,3,7,8-TCDF	0.1	210	0.69	0.72
1,2,3,7,8-PeCDF	0.05	7.4	0.42	0.28
2,3,4,7,8-PeCDF	0.5	6.1	0.68	0.39
1,2,3,4,7,8-HxCDF	0.1	<1.4	0.69	0.31
1,2,3,6,7,8- HxCDF	0.1	<1.4	0.69	0.39
1,2,3,7,8,9- Hx CDD	0.1	ND	ND	ND
2,3,4,6,7,8-HxCDF	0.1	3.0	0.68	0.42
1,2,3,4,6,7,8- HpCDF	0.01	23	2.0	2.0
1,2,3,4,7,8,9-HpCDF	0.01	ND	ND	ND
OCDF	0.001	87	ND	ND
Lower bound I-TEQ from PCDD/Fs		52	1.01	0.47
Upper bound I-TEQ from PCDD/Fs		54	1.05	0.56

ND: Non-detectable

Dm: Dry material

W-com: wheat spike cultivated with compost material from secondary sludge

W-con: wheat spike cultivated with compost material from natural compost

Table 40: Presence of PCDD and PCDF in different cereals and food

Food item	I-TEQ
Wheat (Germany) (pg/g dm)	0.23
Wheat (Germany) (pg/g dm)	0.17
Wheat (Germany) (pg/g dm)	0.18
Barley (Germany) (pg/g dm)	0.14
Barley (Germany) (pg/g dm)	0.18
Barley, cleaned (Germany) (pg/g dm)	0.002
Rye (Germany) (pg/g dm)	0.19
Rye (Germany) (pg/g dm)	0.25
Oat (Germany) (pg/g dm)	0.15
Triticale (Germany) (pg/g dm)	0.068
Cereals (pg/g dm) / mean value; n = 21	0.015
Fish meal (North Sea) (pg/g fat)	6.5
Fish meal (South America) (pg/g fat)	1.55

Source: University of Bayreuth (2000), Study on behalf of European Commission

Table 41: Effect of heating on AOX compounds

Temperature (ºC)	AOX (mg/kg)		
	ITC-SS2	APPM-SS2	SGU-SS2
Control	491 ± 47	941 ± 10	2231 ± 137
45 ^{0}C	446 ± 21	794 ± 51	1782 ± 14
Sunlight	370 ± 8	652 ± 16	1571 ± 36
100 ^{0}C	323 ± 16	578 ± 34	1138 ± 47

Table 42: Effect of incineration on chlorophenolic compounds

Compound (mg/kg)	SGU-SS2	800 ^{0}C	1100 ^{0}C
2, 4, 6- Trichlorophenol	0.311±0.023	0.023	0.005
2, 4, 5- Trichlorophenol	0.085±0.014	< 0.014	< 0.014
2, 3, 4, 5- Tetrachlorophenol	0.132±0.005	0.021	0.008
3, 4, 6- Trichloroguaiacol	<0.0434	< 0.009	< 0.009
3, 4, 5- Trichloroguaiacol	0.089±0.038	0.054	ND
4, 5, 6- Trichloroguaiacol	ND	ND	ND
3, 4, 6- Ttrichlorocatecol	0.240±0.025	ND	ND
Pentachlorophenol	0.259±0.032	0.006	ND
3, 4, 5- Trichlorocatecol	3.191±0.315	ND	ND
Tetrachloroguaiacol	0.064±0.012	<0.012	ND
Trichlorosyringol	0.233±0.037	0.017	<0.011
Tetrachlorocatecol	0.311±0.054	0.017	0.014

ND: Non-detectable

Table 43: MLSS & MLVSS content of seed, secondary and mixed sludge samples for anaerobic stabilization

Sludge	MLSS (g)	MLVSS (g)
Initial seed sludge	98.3	37.8
Secondary sludge	8.7	6.5
Mix sludge	112.6	46.8

Table 44: Comparative analysis of MLVSS removal in three reactors (duration 60 days)

RT (day)	MLVSS					
	Secondary sludge added (g) (A)	Total mix sludge (g) (B)	Removed sludge (g) (C)	Actual mix sludge (g) (D)	Removal (g) E=(B-(D+C))	Removal (%) (E*100/A)
10	48.14	85.93	16.86	51.21	17.86	37.10
15	33.41	71.19	10.52	46.51	14.16	42.39
20	25.36	63.15	7.29	45.86	10.00	39.43

Table 45: Comparative analysis of MLSS removal in three reactors (duration 60 days)

RT (day)	MLSS					
	Secondary sludge added (g) (A)	Total mix sludge (g) (B)	Removed sludge (g) (C)	Actual mix sludge (g) (D)	Removal (g) E=(B-(D+C))	Removal (%) (E*100/A)
10	65.61	163.92	38.58	109.06	16.28	24.81
15	45.73	144.04	23.33	105.43	15.29	33.43
20	34.58	132.89	17.55	106.06	9.28	26.84

Table 46: AOX reduction in three batch reactors after 60 days

RT (day)	AOX (mg)				AOX reduction (mg) (E=C-D)	AOX reduction (%) (E*100/C)
	Mixed sludge (A)	Removed sludge (B)	Mix sludge actual (C)	Mixed sludge final (D)		
10	213.6	4.02	209.6	93.6	116.0	55.3
15	158.5	1.26	157.2	75.9	81.3	51.7
20	127.6	0.58	127.0	61.6	65.4	51.5

Table 47: Concentration of PCDD and PCDF before and after anaerobic stabilisation

PCDD/PCDF (pg/g Dm)	TEF	SGU-SS1	Seed sludge	Treated sludge
2,3,7,8-TCDD	1	16	ND	ND
2,3,7,8-TCDF	0.1	210	2.8	10
Lower bound I-TEQ from PCDD/Fs		52	5.7	7.4
Upper bound I-TEQ from PCDD/Fs		54	10	8.6

ND: Non-detectable

Dm: Dry material

Table 48: Settling characteristics and dryness of sludge samples before and after anaerobic treatment

Sludge	DSVI (ml/g)	Zeta potential (mV)	Solid content (%)
Initial seed sludge	31	-	13.51
Secondary sludge	>400	-17.9	14.99
10 days RT	58	-	-
15 days RT	51	-13.6	23.69
20 days RT	52	-	22.16

Table 49: Impact of ozone pretreatment of sludge on reduction of MLSS, MLVSS and AOX content

Reactor	Ozone dosage (mg/g)	MLSS reduction (%)	MLVSS reduction (%)	AOX reduction (%)
A	20	21.9	30.0	43.0
B	40	44.7	55.5	51.5
C	0	14.0	21.6	37.8

Figure 1: SGU-SS1 Sulphar stain (1000x)

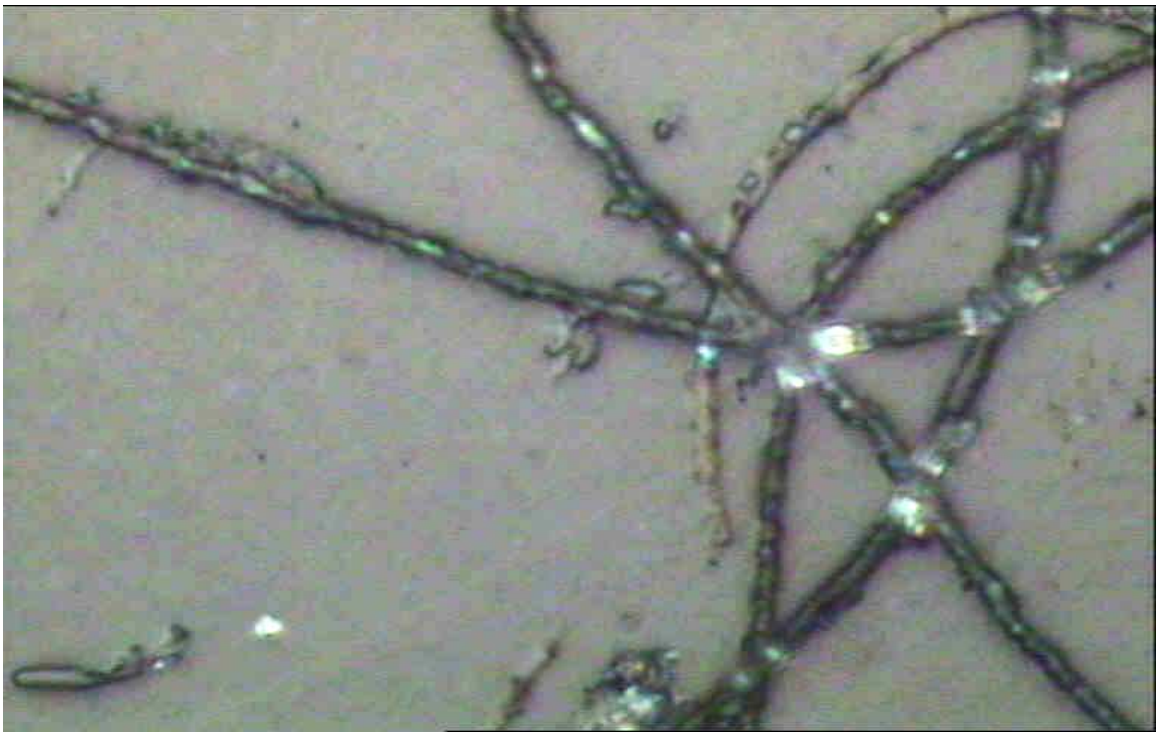


Figure 2: SGU-SS1 Gram stain (100x)

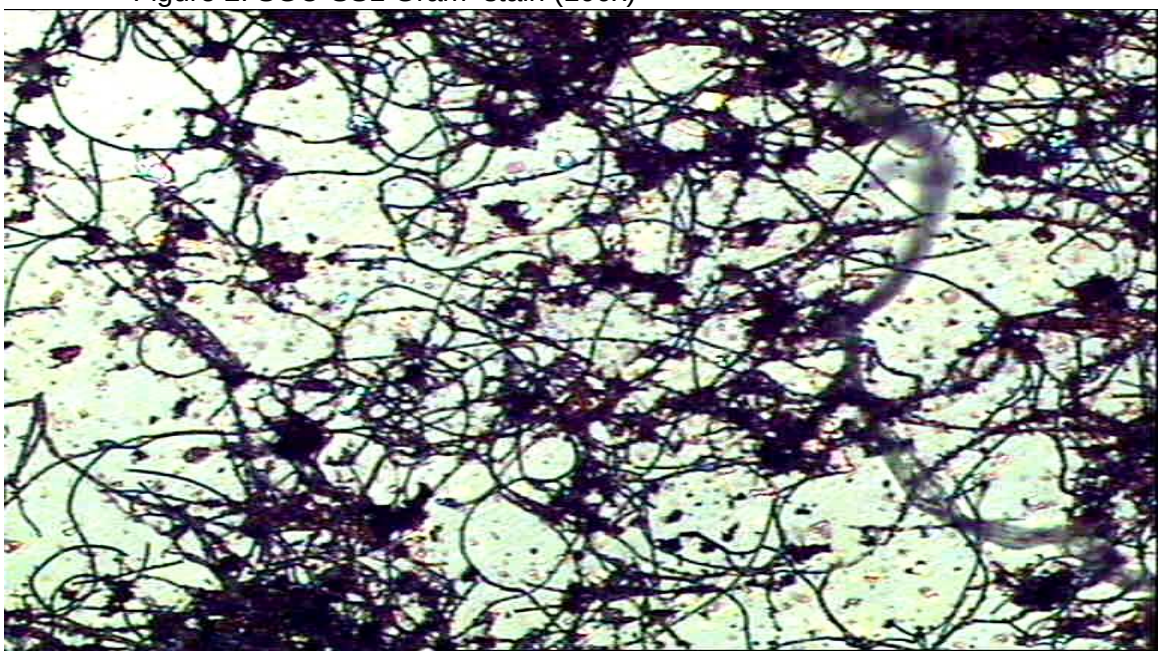


Figure 3: SGU-SS1 Neisser stain (1000x)

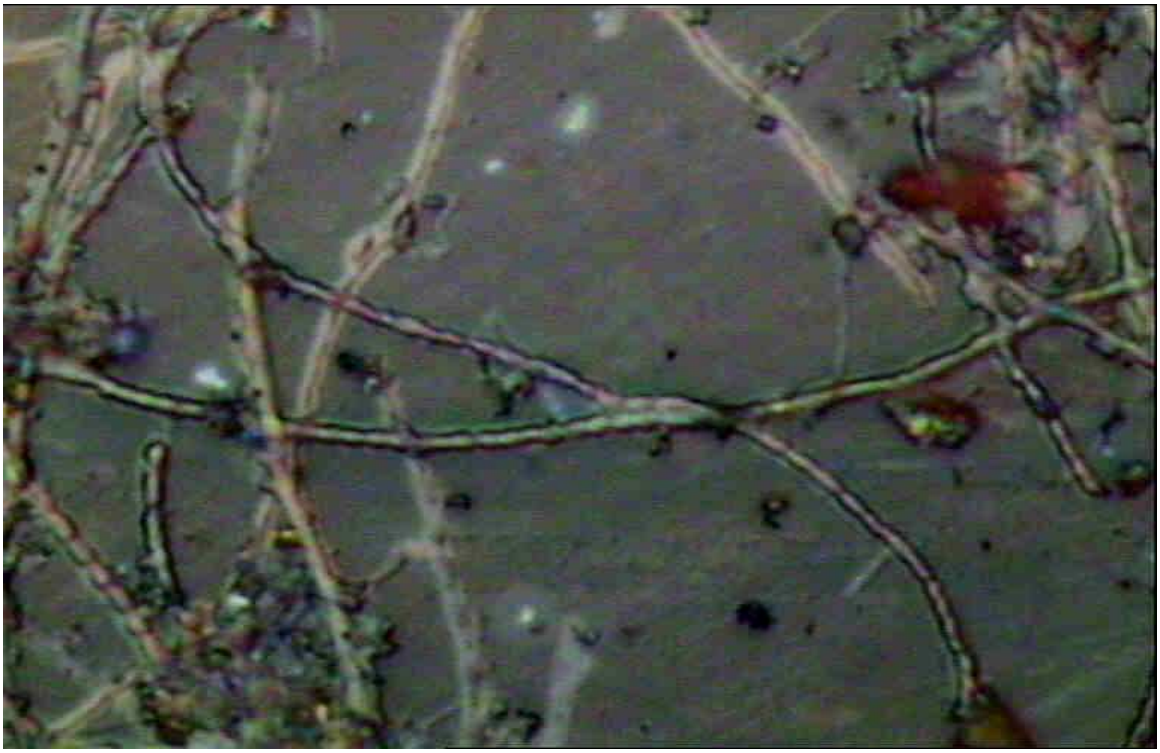


Figure 4: Length estimation in SGU-SS1 sample

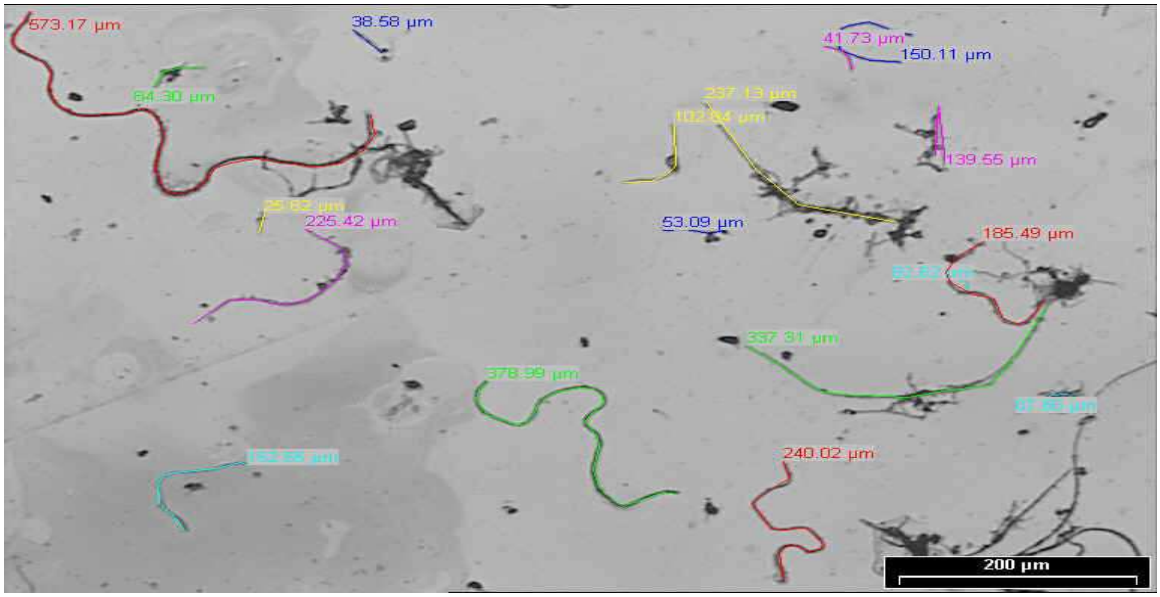


Figure 5: Diameter estimation in SGU-SS1 sample

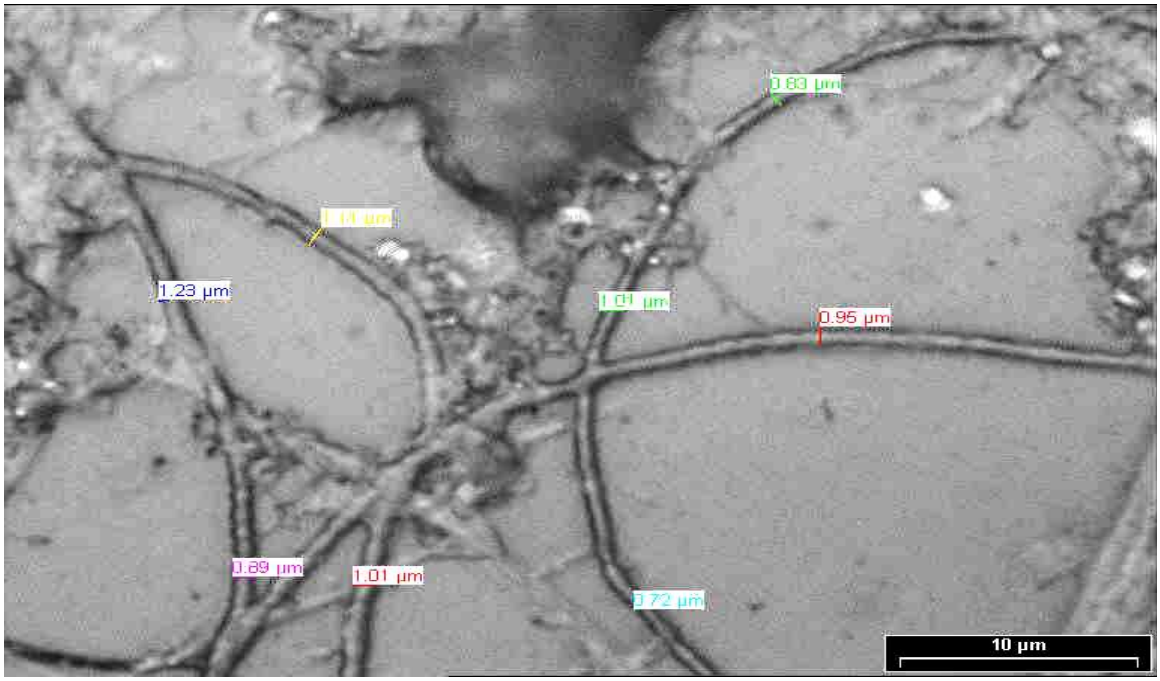


Figure 6: JKPM-SS1 Gram stain (400x)

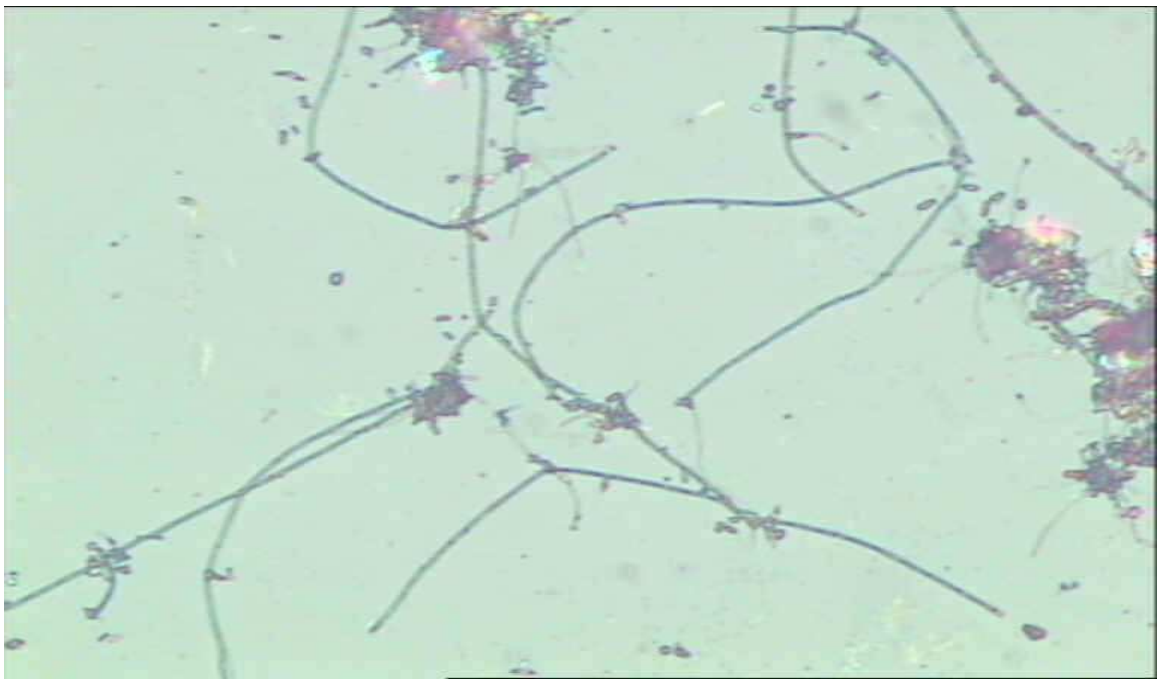


Figure 7: JKPM-SS1 Neisser stain (400x)

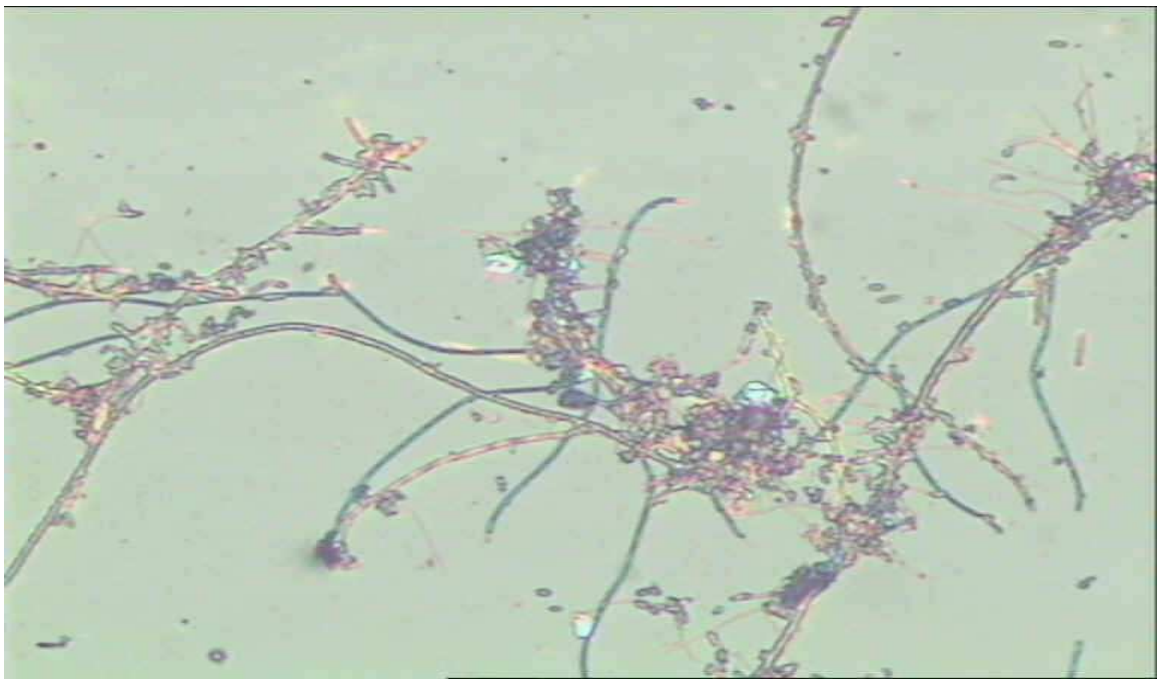


Figure 8: Length estimation in JKPM-SS1 sample

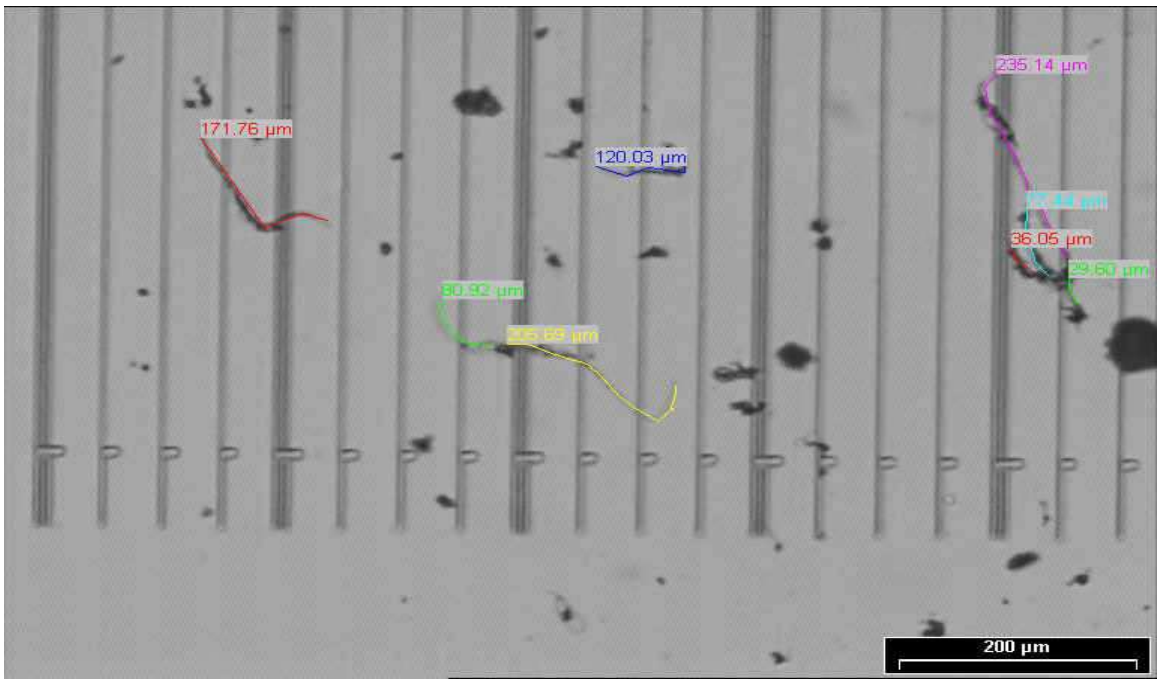


Figure 9: Diameter estimation in JKPM-SS1 sample

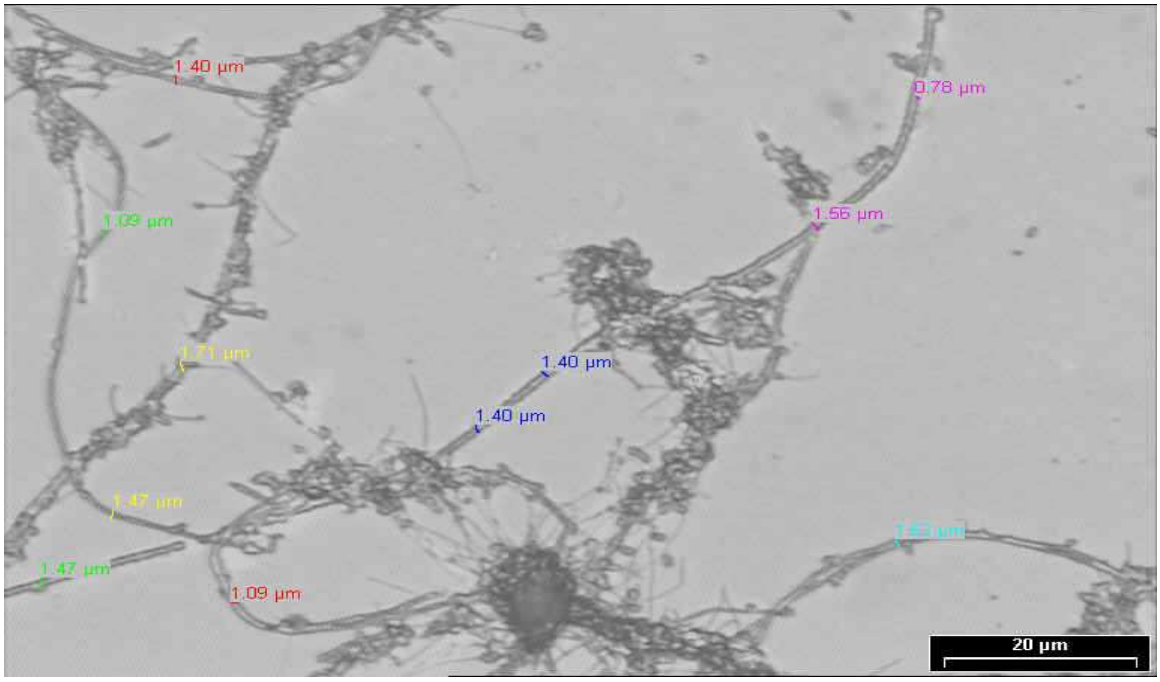


Figure 10: ITC-SS1 as such sample, 20x

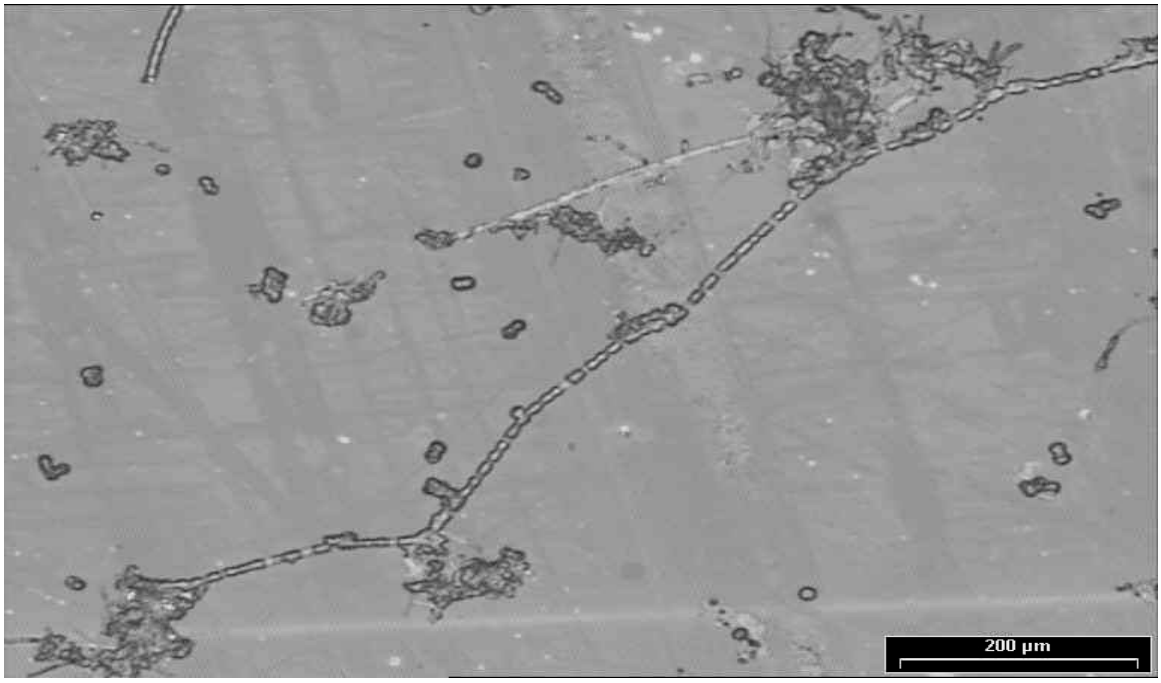


Figure 11: ITC-SS1 Sulfur stain, 20X

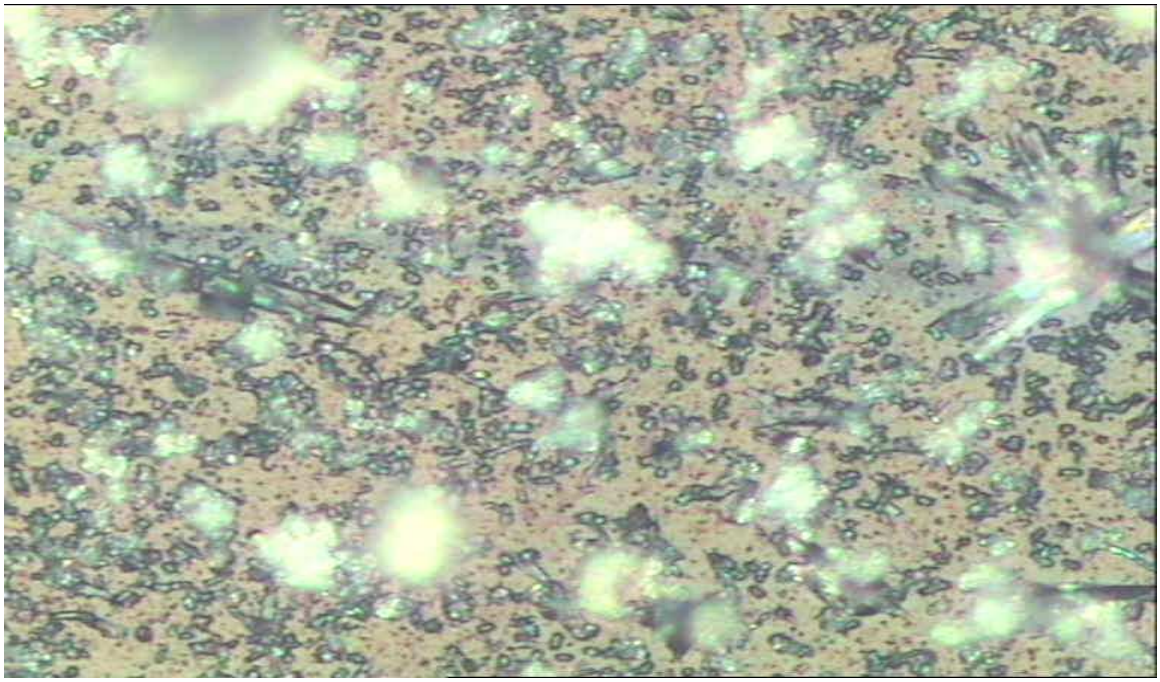


Figure 12: ITC-SS1 Gram stain, 10x

Figure 13: ITC-SS1 Neisser stain, 40x

Figure 14: APPM –SS1 as such sample, 40X

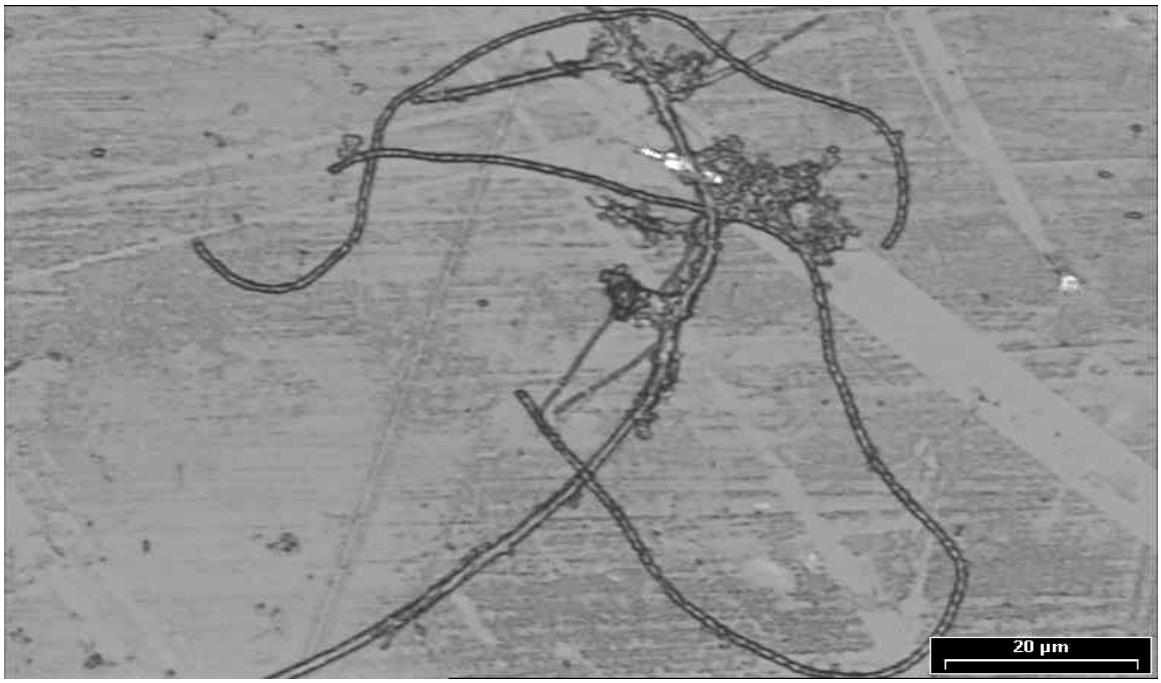


Figure 15: APPM –SS1 Sulfur stain, 40x

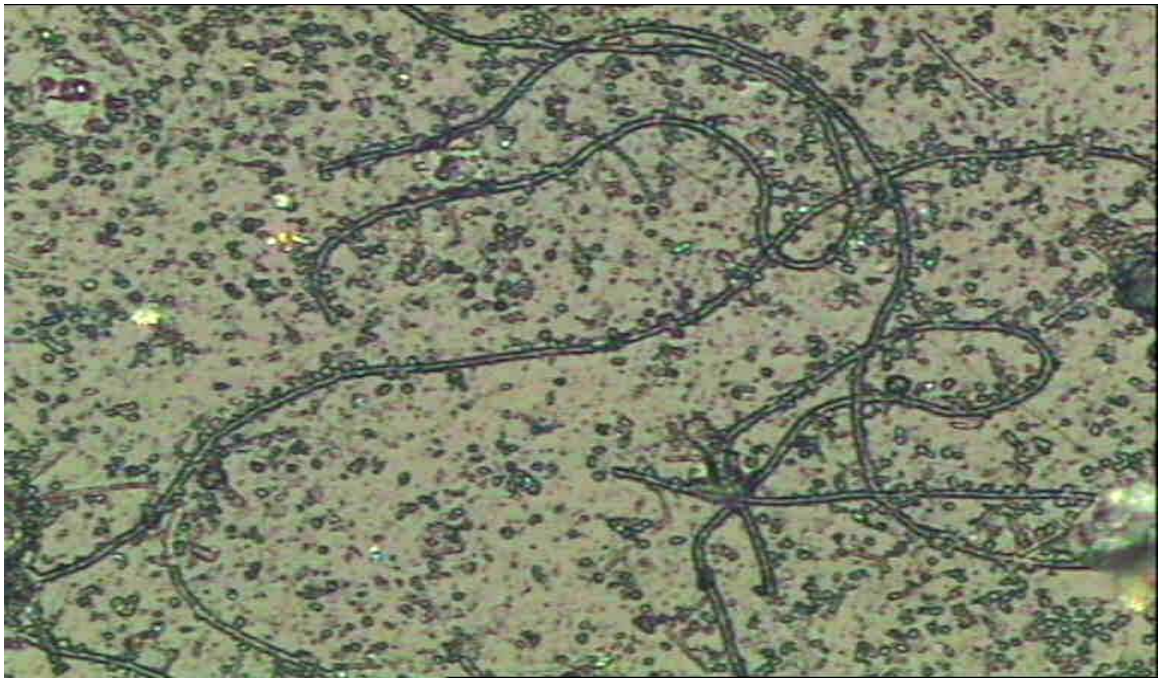


Figure 16: APPM –SS1 Gram stain, 5x

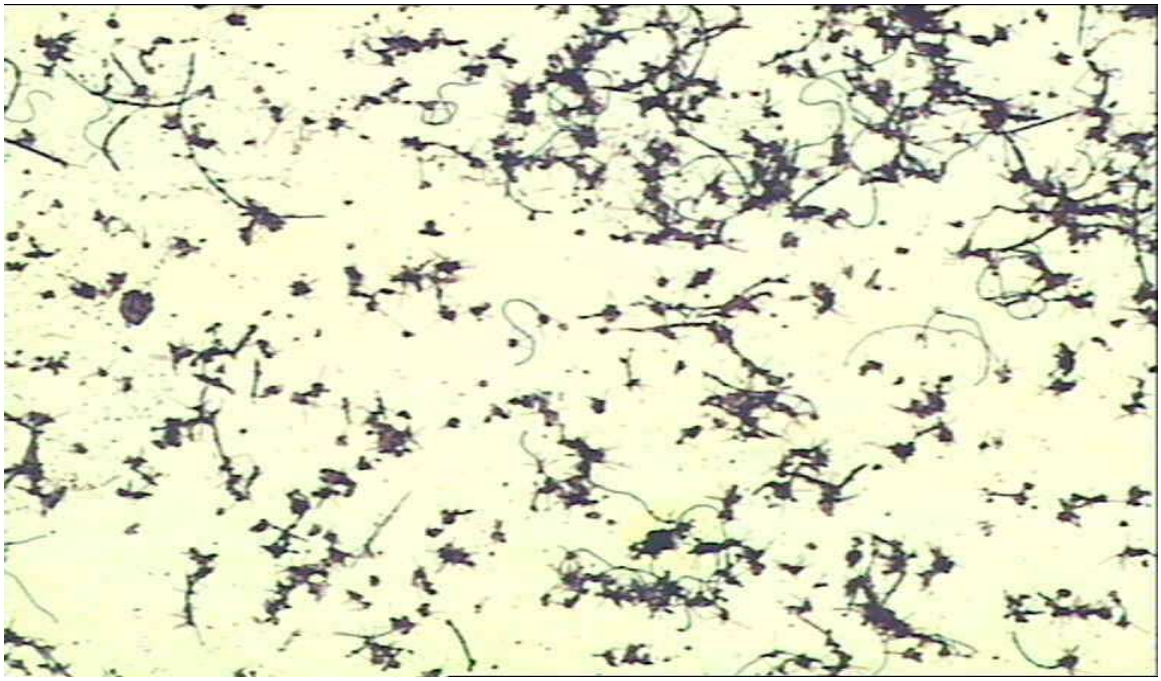


Figure 17: APPM –SS1 Neisser stain, 40x

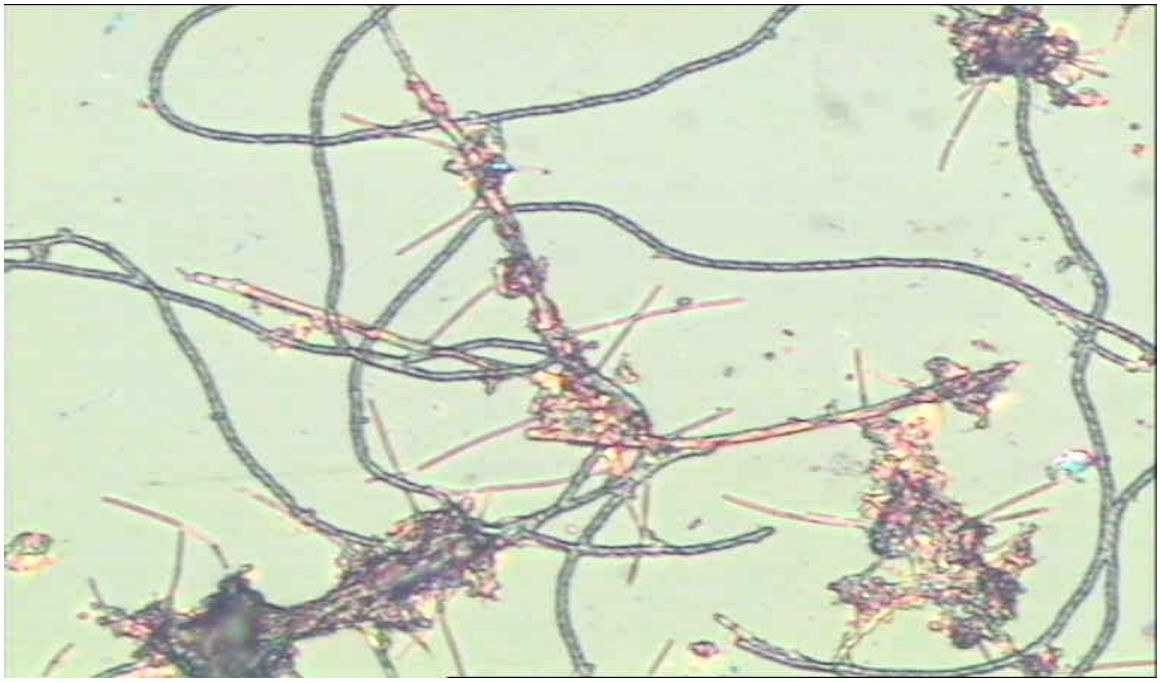


Figure 18: APPM –SS1 Cell diameter, 5X

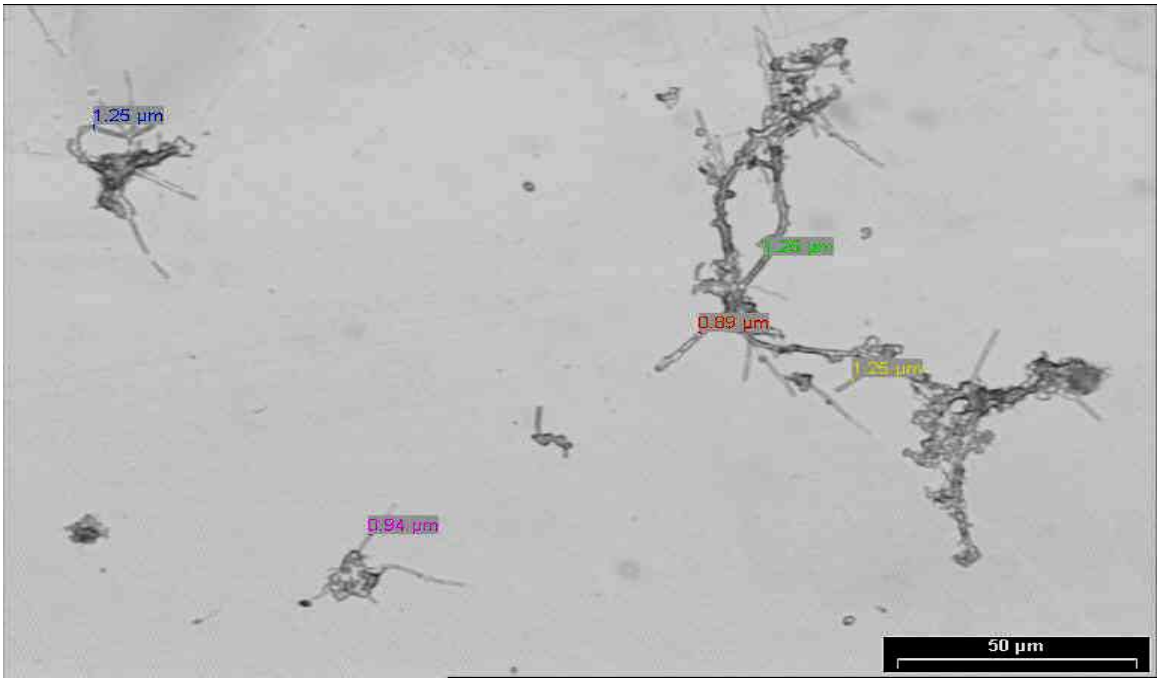


Figure 19: APPM –SS1 length and count, 10X

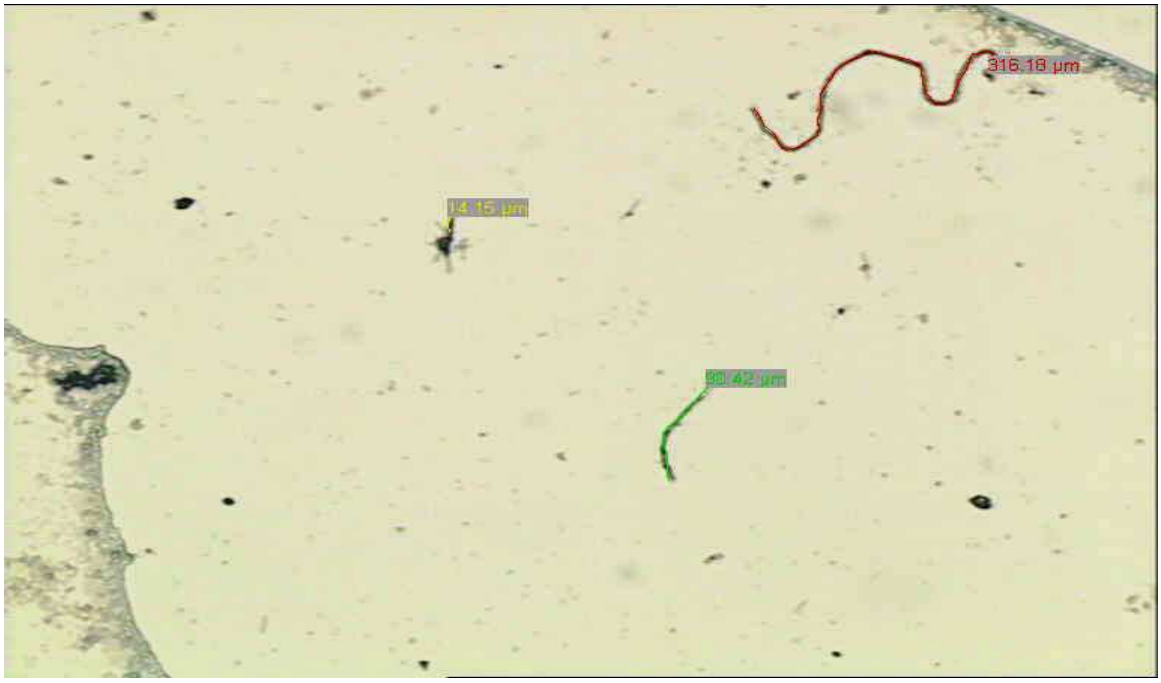
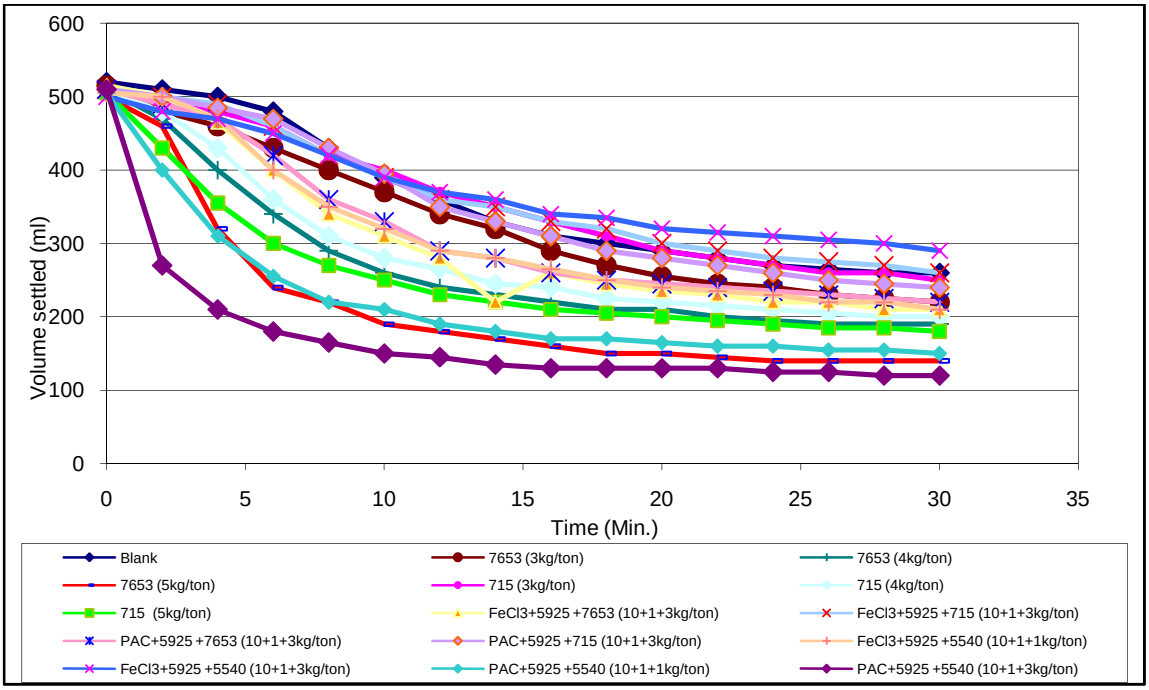


Figure 20: Settling characteristics of SGU-SS1 with organic flocculants and inorganic coagulants – organic flocculants



7653: Zetag-7653; 715: DK set C715 HN; 5925: Organopol 5925; 5540: Organopol 5540

Figure 21: Plant trial with decanter centrifuge at BILT-Unit Shree Gopal

Figure 22: Stack arrangement of vermicompost bins

Figure 23: Worms in composting material

Figure 24: Loss in organic content of compost material (Batch-2)

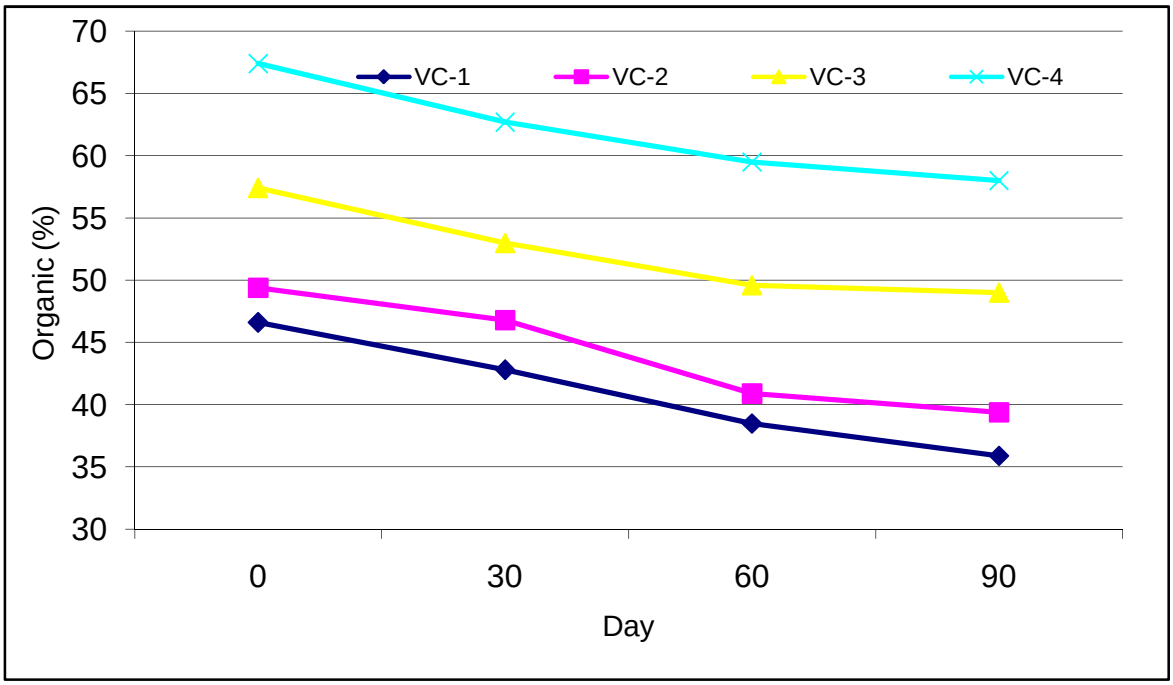


Figure 25: Loss in organic content of compost material (Batch-3)

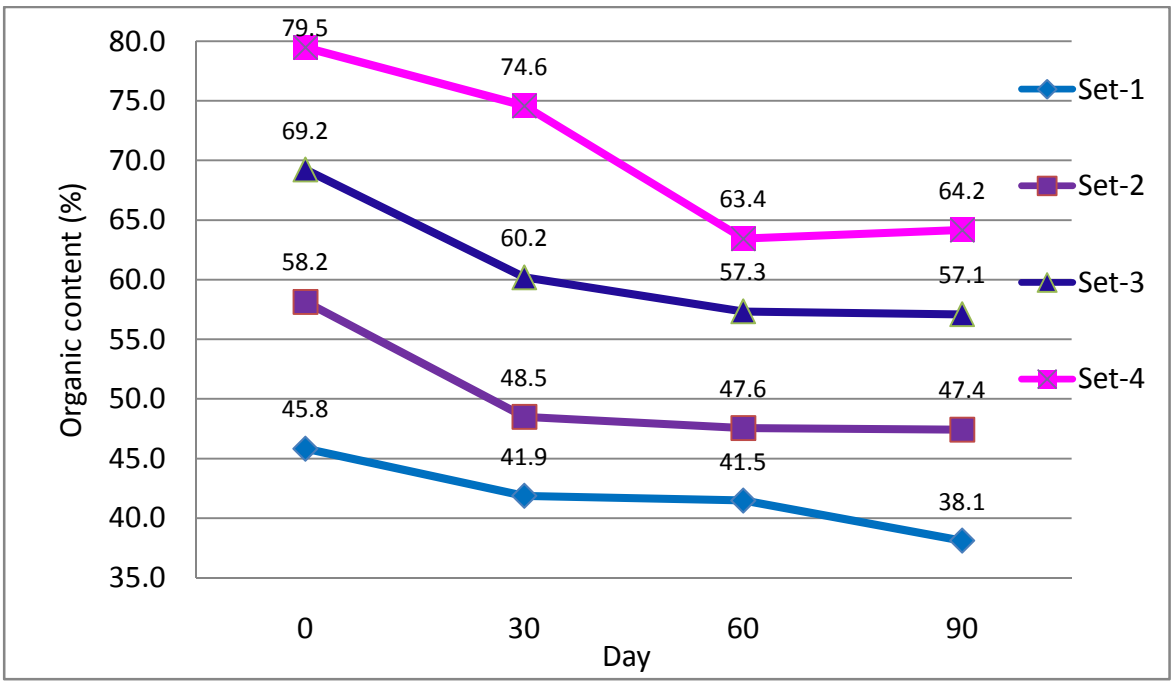


Figure 26: Arrangement in the aerobic composting

Figure 27: Crop pattern on 45th day

Figure 28: Growth of spawn in beaker containing composted material

1: Vermicompost
2: Aerobic compost
3: Compost from cow dung

Figure 29: Laboratory set –up for mushroom growth

Figure 30: Diagrammatic representation of incineration experiment

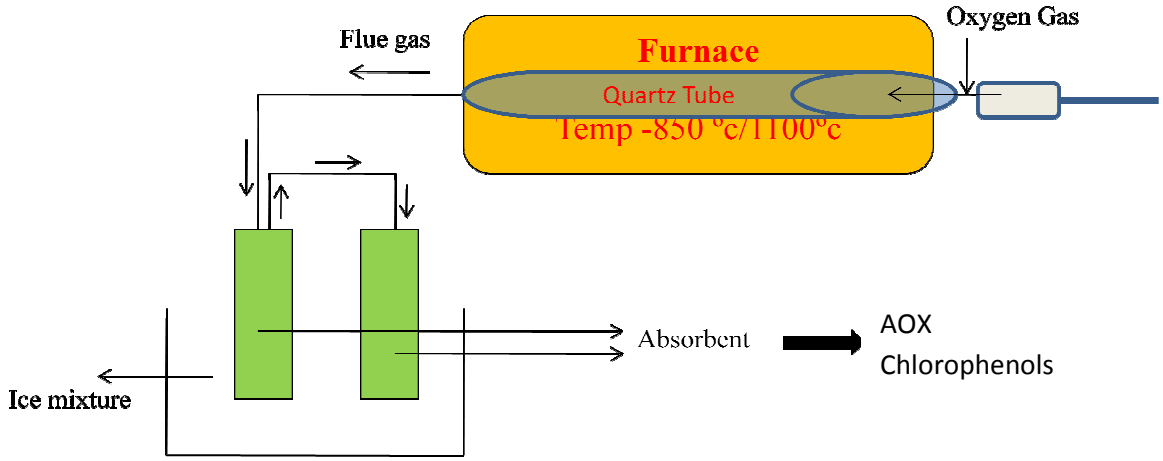
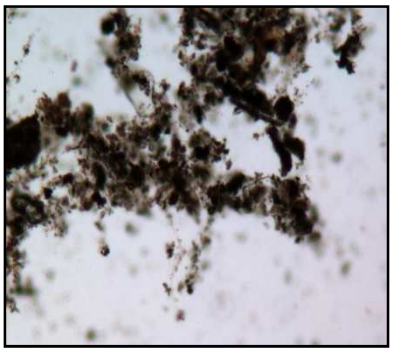


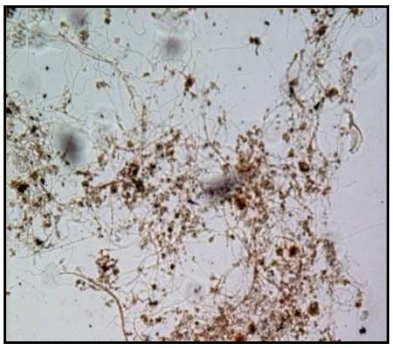
Figure 31: Reactor setup (Batch) for anaerobic stabilization of sludge

Figure 32: Reactor setup (continuous) for anaerobic stabilization of sludge

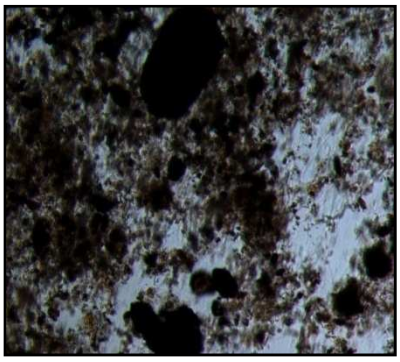
Figure 33: Morphology of sludge before and after anaerobic treatment



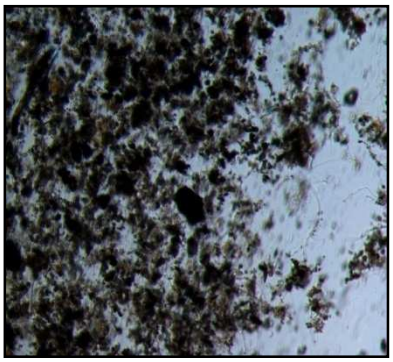
a)Seed sludge



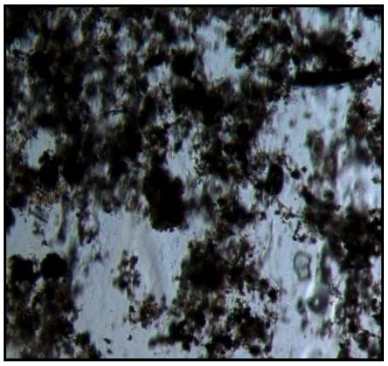
b) Secondary sludge



c) 10 days RT



d) 15 days RT



e) 20 days RT

Annexure 1: Publications

1. Gupta S., Purwar M., Chakrabarti S.K. and Singh S., (2011). Influence of drying of biosludge from pulp and paper industry on organochlorine compounds, 14th Punjab science congress on role of scientific innovations & knowledge in economic development, Longowal, Sangrur (Punjab), India, February 7-9, 2011, 135-136

2. Gupta. S., Sharma K.D., Chakrabarti S.K., Panwar S., Varadhan R., (2010). Handling and disposal of secondary sludge in the biological treatment process of pulp paper industry. Inpaper International, 12 (2), 24-28

3. Karn S.K., Chakrabarti S.K. and Reddy M.S., (2010). Pentarchlorophenol degradation by pseudomonas statzeri CL 7 in the secondary sludge of pulp and paper mill, J. Environm. Sci. 22(10), 1608-1612

4. Karn S.K., Chakrabarti S.K. and Reddy M.S., (2010). Degradation of pentachlorophenol by Kocuria sp. CL2 isolated from secondary sludge of pulp and paper mill. Biodegradation, 22(1), 63-69

5. Karn S.K., Chakrabarti S.K. and Reddy M.S., (2010). Characterization of pentachlorophenol degrading Bacillus strains from secondary sludge of pulp and paper industry. International biodeterioration and biodegradation. 64, 609-613

6. Gupta S., Sharma K.D., Chakrabarti S.K., Panwar S. and Vardhan R., (2009). Handling and disposal of secondary sludge in the biological treatment process of pulp and paper industry. 9th International Conference on Pulp, Paper and allied Industries, 4-6 December, 2009, New Delhi, India

7. Gupta S., Sharma K.D., Singh S. and Chakrabarti S.K., (2009). “Dewatering and Handling of Bio sludge in Pulp and Paper Industry.” National Symposium on Green Chemistry, Patiala, February 5-6 (2009)

Annexure 2: Training of students

S. No.	Name of student	College/ University	Topic
1	Santosh K. Karn Ph.D. student	Thapar University	Studies on the biodegradation of some chlorophenolics in secondary sludge of pulp and paper industry
2	Gurpreet Singh, M.Sc. Ist Year	Chandigarh Group of Colleges, Landran, Mohali, Punjab	Study on vermicomposting of sludge from pulp & paper industry
3	Pardeep Singh, M.Sc. Ist Year	M.M. Modi College, Patiala, Punjab	Study on filamentous organisms in activated sludge process