

# SOIL BIOTECHNOLOGY LITERATURE

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## Summary

### PHILOSOPHY OF THE INNOVATION

Water is central to life. Water connects the living and the nonliving of the eternal cycle. So does soil and air. That life evolved in water and moved on to land shows perhaps that the primordial processes that gave birth to life are probably still at work and our search to communion with such forces must begin with water.

This planet came into being perhaps 5 billion years ago and Life evolved perhaps 2 billion years ago in water and then moved on largely to land impelled by the thermodynamic logic of minimizing energy needs for supporting dependent population. It comes as a surprise that aerobic life takes 500 kJ /g living carbon per yr in water compared to just 1.8 kJ/g living carbon per yr on land. In this light of energy demand for life we must rethink our designs for life processes, particularly sanitation. This is the inspiration for this work.

Life on this planet, as we understand, is governed by three fundamental processes, viz., photosynthesis, respiration and mineral weathering. Photosynthesis produces food; respiration engages this food for life activities, mineral weathering by producing soil, clay and sand regulates pH of the environment. The chemistry of these reactions reveals beautiful synergy and complementarities. The products of these reactions sustain life and produce materials for the progress of civilization.

The rates of these fundamental processes vary much. Human civilizations of the past 5000 plus years have by and large lived within these natural rates. As we have acquired insights into the structure and properties of matter, space and Time, consumptions have changed resulting in huge increase in thermal and material load on our lifelines affecting detrimentally the rates of these fundamental processes and hence the quality of our lifelines of soil, water and air.

The carbon cycle reveals the course of evolution. Water supports just 4 billion tons of living carbon, 4000 billion tons of mostly dissolved inorganic carbon. In contrast, soil holds 1500 billion tons of dead carbon, 100 billion tons of living carbon and also supports 650 billion tons of living carbon of land .The fluxes of

carbon between the carbon pools (atmosphere, hydrosphere, biosphere and lithosphere) are governed by life needs of the pools of carbon. The great differences in the living carbon of the pools arise from available oxygen & energy supply. The relatively very large holdups of live and dead carbon on land (soil included) amidst the abundant oxygen supply is the gift of evolution that led to the development of intelligent beings on this planet.

Billions of tons of soil are lost year after year due floods & other types of erosion impacting food security. While there are factories for synthetic fertilizers; there are no factories for production of soil. It may seem a strange irony that 65 billion ton C/yr (equivalent to 10 times the global consumption of fossil energy) is lost in litter respiration of soil while the chemistry and technology of engaging this energy for soil production so critical to food security is not yet the passion of Science.

Similarly wastewaters and sewage kill fish life; yet we know of no economic methods of preventing loss of these aquatic life forms. Much of the present day waste treatment technologies aerate waste water intensely to oxidize the organics and recover the organics as pathogenic sludge for disposal. This procedure of supplying oxygen into water needs much energy and equipment; and the whole process is prone to frequent failures since at the very high shear rates of the process environment only a very narrow band of organisms work. Consequently effluent water quality is suspect and due to such waste water discharges we continue to lose water reservoirs of land and subsoil and densely populated regions of the globe struggle to cope with water needs in quality and quantity.

Agriculture of yesteryears chose plants with care and replenished mineral matter to soil as tank and river silt and flood waters as source of minerals. The rivers have been the unceasing treasure of soil regeneration. It is not an accident that great civilizations took birth and continued to flourish in the river valleys of the Nile, Tigris and Euphrates, Indus, Ganga and yellow river etc. Much of these procedures have fallen into disuse and have long been substituted by synthetic sources. And with them our connection to soil has been severed and with it our vital links that sustain life on this planet have been significantly shaken.

The carbon cycle reveals that land supports a large living population of plants and animals (650 billion tons live Carbon) and soil holds 1600 billion tons dead carbon. The natural design is that land animals feed on living carbon while soil bacteria and fungi feed on dead carbon. The message of carbon cycle is that soil is the ultimate answer to sanitation and so the urgent need to restore our links with soil.

But there is a more profound meaning-- that living and dead organics feed different consumers and that in nature there is no competition between organisms belonging to different food niche. The art of Design is to stay in the niche you belong as determined by Evolution. As per this principle of natural selection human and pest food are not the same and pest infestation of human food only indicates the quality of food entering human food chain. This is the way nature works to move food to the natural consumers. That different organisms come with a natural design of food needs must embody the way we feed ourselves, the way we care for and rear our animals, and also the way we care for life forms around us.

That life evolved from lowly forms to intelligent beings is well known-- that Evolution maintained huge redundancies is well known -- that life converts solar energy into order is well known -- that life forms lead to huge reduction in entropy production is well known. What is not well known is that migration of life from water to land marked a quantum jump in creation of order. Such is the power of soil.

Summing up soil emerges as the ultimate answer to sanitation. Engineered Processes that respect the connectivities of Nature give very little entropy productions and lead to highly efficient, wholly sustainable solutions, be it for air and water or soil and sanitation. And SBT presents one such wholesome pathway that promises immediate evergreen results.

## DESCRIPTION OF THE INNOVATION

The SBT processes contain four elements viz. i) media which houses the micro& macro organisms of soil ecology which supports aerobic/ including nitrogen fixation and active oxygen production ii) culture which also includes geophagus worms serves as the top carnivore to regulate soil population iii) additives- a natural mineral mix which regulates pH, iv) green plants to serve as bioindicator of the health of process. In view of the ecology of soil & engineered natural oxygen supply highly aerobic environment exists in the bioreactor. Accordingly in the said process three fundamental reactions of this planet viz. i) respiration brings about removal of organics by oxidation of the organic molecules, ii) mineral weathering brings about pH regulation iii) while photo synthesis serves to regulate the process at work.

Reaction rates achievable in SBT decreases with increase in electrical conductivity of water/ waste water; so SBT process is not effective if process environment is saline.

In the case of processes for all types of water treatment the dissolved oxidisable solids are removed by natural oxidation via bed ecology, suspended solids are removed on top of bioreactor by filtration. In the case of air purification air to be purified is scrubbed with GBT treated waste water; the residual waste water is returned to GBT process.

In the case of solid waste the ecology of the processing environment brings about bioconversion to various grades of product viz culture grade, fertilizer grade and soil grade products. In the case of hospital waste the evergreen ecology of the processing environment brings about destruction of the waste which is allowed to accumulate at site. Periodically the pathogen count is tested against control soil and when it is nearly the same the process is considered complete and the soil is incinerated by burning with a fuel.

All the processes listed above utilize the same four elements/ pillars to bring about the bioconversion. SBT process trainer is a teaching/ learning instrument to comprehend the fundamentals of the process.

## UNIQUENESS OF INNOVATION

Vision Earthcare presents an innovation inspired by the central message of carbon cycle; that water does not hold dead organic carbon and on this planet only soil supports dead organic carbon. It follows that disposing dead organic carbon into water is contrary to the design of carbon cycle.

Conventional Water purification technologies use intense aeration to remove dissolved oxidizable impurities; followed subsequently by filtration to remove sludge. Such technologies use much energy; engage a truncated food chain consisting of a small band width of aquatic microbiology capable of tolerating very high prevailing shear rates to operate to bring about the bioconversion. Consequently high energy consumption does not support green plants in the processing environment, excess biomass as sludge. The ecology of our innovation presents a quantum jump over all these issues since it produces active oxygen.

The global Carbon Cycle tells us that energy needed for organisms to work in aquatic environment is around 500 kJ/gram live carbon per year compared to 3 kJ/g live carbon per yr on land. As per this logic the same bioconversion carried in soil environment would consume much less energy. The beauty & uniqueness of the innovation is that it demonstrates how this energy advantage in soil can be realized for human society.

We have factories that make synthetic fertilizers. There are no reactors that can make synthetic nitrogen at the farm at rates required for the farm. The beauty & uniqueness of the innovation is that it demonstrates how this advantage of onsite very tiny scale production can be purposefully realized by human society to revolutionize global agriculture.

We have no factories that make soil. But we lose soil billions of tons year after year due to natural calamities. The beauty and uniqueness of the innovation is that it demonstrates how soil can be made; by bringing mineral weathering and respiration of wasted organics together in a process providing altogether new road to build sustainable pathways ahead.

Water disinfection uses chlorine; in some ozone. Whatever the case the technologies only destroy the pathogens leaving behind residues that are known to be more harmful. The beauty & uniqueness of the innovation is that it demonstrates how natural systems such as SBT can be harnessed for such a service of human society.

Overall SBT presents a powerful means of addressing the challenges to our global environment including climate change, greenhouse emissions etc.

#### DEVELOPMENT OF INNOVATION: CONCEPT TO PRODUCT

In 1976 I saw a paper from Purdue University on energy in agriculture by Lockeritz et al. This paper stated candidly what I knew as true; that energy wastage in animal foods is very large since these animals return as meat a very small fraction of food energy consumed. The paper also showed some data on agriculture in Tanga wherein efficiencies of potato production to be 20 times that in USA. These initial data of natural systems charged me with a passion to explore energetics embedded in the Global Carbon Cycle.

Early 80s this search led me to the early work of Charles Darwin (1898). The Origin of vegetable mold through the action of worms; this work revealed to me that the top carnivores of soil are the geophagus worms (known as earthworms in common parlance) that regulate soil microbial population. Around this time, I met an eminent historian of Indian Science Shri Dharampal; he pointed out that yield of wheat in England 1725 was about quarter of the then yield in India. In a subsequent search known as Barnard survey of some regions of Southern India of period 1760s yield of paddy was quoted as 8.4 ton/ha while the best known yield of today 21st century is 6 ton/ha. During this period I also met many field workers through PPST Foundation Chennai to learn that large yields continue to be realized organically in many parts of India even today without recourse to chemical agriculture.

All this indicated that soil is a unique chemical reactor to be explored for the well being of human race and as well for other life forms. And chemical reaction engineering is core to chemical engineering and I have trained in this area during my PhD program.

Further studies on the Global Carbon cycle revealed that three fundamental reactions keep this planet going, viz., photosynthesis, respiration and mineral weathering. And available technologies in water & sanitation do not recognize the beautiful synergies that drive the Carbon cycle.

Around this time 1984 the problems of sanitation in the third world began to engage my attention. I noticed that all the technologies engage some form of mechanical aeration to treat the water; filter off the sludge to get disposable water. But energetics of global carbon cycled reveals that energy needed to live in water is 500 kJ/g live carbon per yr as against on land 3 kJ/g live carbon per yr. It occurred to me then that sanitary engineering of last 100 yrs has missed this central message of Carbon Cycle. It began to make sense since diffusion coefficient of oxygen in water is very low  $10^{-9}$  sqm/s and solubility 8 mg/L. Indeed message was clear that thermodynamics has pushed life out of water on to land since it takes much less energy to live on land.

After many years of research it dawned upon me that the solution is a constructed soil environment, with good hydraulic conductivity, microbial density & diversity similar to soil. Thus SBT was born.

We measured the residence time distribution under different hydraulic flows; the oxygen transfer coefficient, liquid hold up, weathering indices, microbial density, diversity distribution, the enzymatic activities. We also measured the rate constants for removal of pollution load, viz, COD, ammonia nitrogen, nitrate nitrogen, phosphate, fecal and total coliform, besides many other features. Over time 1988-2008, it became clear that constructed soil is a valuable material; and it also facilitates supporting an evergreen environment so that the process space now looks like a beautiful garden with no moving parts. And our readiness to demonstrate the technology began to gather more & more conviction; we commenced in 1994 offering processes for water & air soil & sanitation to customers. US patent granted in 2005 and Indian patents in 2006

As we have gone around espousing soil as the winner for waste processing we discovered that under suitable conditions considerable amount of nitrogen fixation can be achieved; for instance, 25 kL SBT reactor can by using agri-residues and animal excrements, produce all the nitrogen 200 kg N/yr for a one hectare farm. Accordingly a novel SBT process for onsite farm fertilizer production is now available. And to enable the customers to see results prior to purchase a down to earth SBT trainer hardware and simulator is also in the market.

## COMMERCIALISATION & MARKETING RESULTS

We serve a niche of customers; a very large and growing number of enlightened environment conscious citizens of the globe. Our products are around for many years; they are known to be immortal as some say since the fundamental processes engaged are carved from Nature. Overall markets are large & growing and we are at it now.

### 1. INTRODUCTION

Water is a scarce resource. A technology which provides total water purification solution is the need of the hour. Water treatment provides usable water for domestic agricultural & industrial purposes; helps to conserve & enhance water in quality & quantity; in addition prevents degeneration of our water sources of surface & ground. Green technologies today provide impressive water quality at competitive costs without contributing to global warming. This technical specification presents a green biological purification engine using a natural novel high efficiency oxidation process variably known as CSF (constructed Soil Filter) or SBT (Soil Biotechnology) developed at IIT Bombay by Prof H.S.Shankar & his students which provides a total water purification solution.

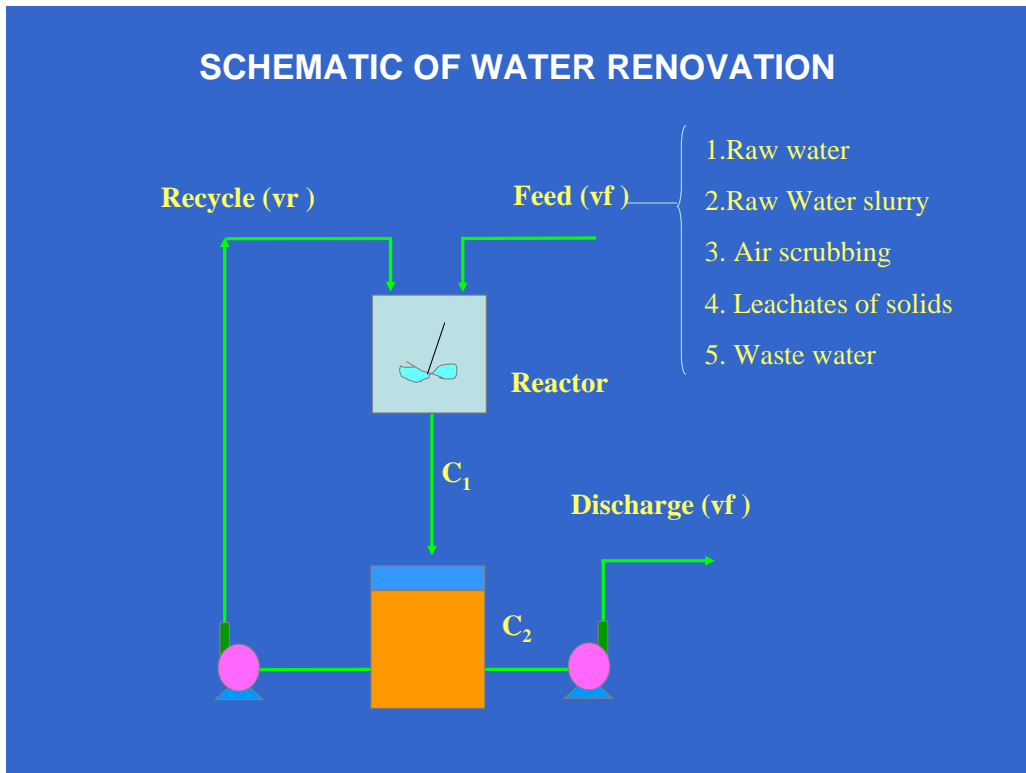
Soil Biotechnology (or SBT) is covered by one US patent (Patent no 6890438 B2) and 2 Indian patents (Patent no 203744 & 203425) all assigned to IIT Bombay.

### 2. PROCESS

The technology is based on a bio-conversion process where fundamental reactions of nature, namely respiration, photosynthesis & mineral weathering take place in a media housing micro & macro organisms which bring about the desired purification. SBT is an oxygen supplying biological engine and so the process can treat all types of water – domestic municipal & industrial. SBT is suitable for treating water with salinity <2500 mg/L. *When salinity levels exceed, reaction rates in the SBT system are lower and hence the system design is adjusted suitably to achieve the purification desired. If salinity is very high an additional facility using RO technology can also be included.*

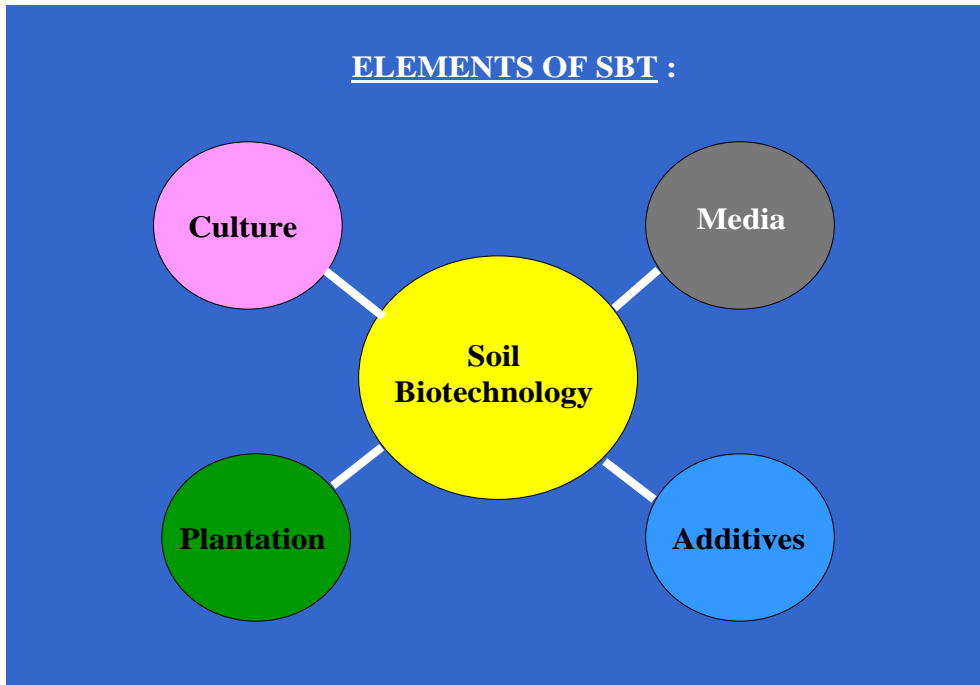
The process requires mesophyllic temperatures; so where the ambient temperatures are low/ very low a greenhouse infrastructure appropriate for the local conditions houses the SBT plant. However the process can work at high ambient temperatures.

The facilities of a treatment process for water & waste water consists of a raw water tank, bioreactor containment , treated water tank and where appropriate a greenhouse and associated piping ,pumps & electricals. Schematic of the process is shown in Fig 2.1.



**Fig 2.1: Schematic of Water Renovation**

Bioreactor containment houses i) the media , ii) the culture, III) the additives and iv) the plantation required for the bioconversion; Fig 2.2 shows the four pillars of the process.



**Fig 2.2: Elements of SBT**

Water or waste water is pumped over the bioreactor; the suspended solids are removed by the top media which is scrapped and discarded into municipal solid waste. The water trickles into the bed and treated water collects in the filtrate tank. Recirculation pumps are provided to obtain desired hydraulic retention times; in general purification to desired quality is achieved in one pass and so these recirculation pumps are not used.

The scheme for drinking quality raw water, swimming pool water, rain water & storm water & waste water treatment are identical to description above. Fig 2.3 shows schematic of multi level designs; here SBT bioreactor is developed at each level and arrangements for pumping & piping to the different levels are provided.

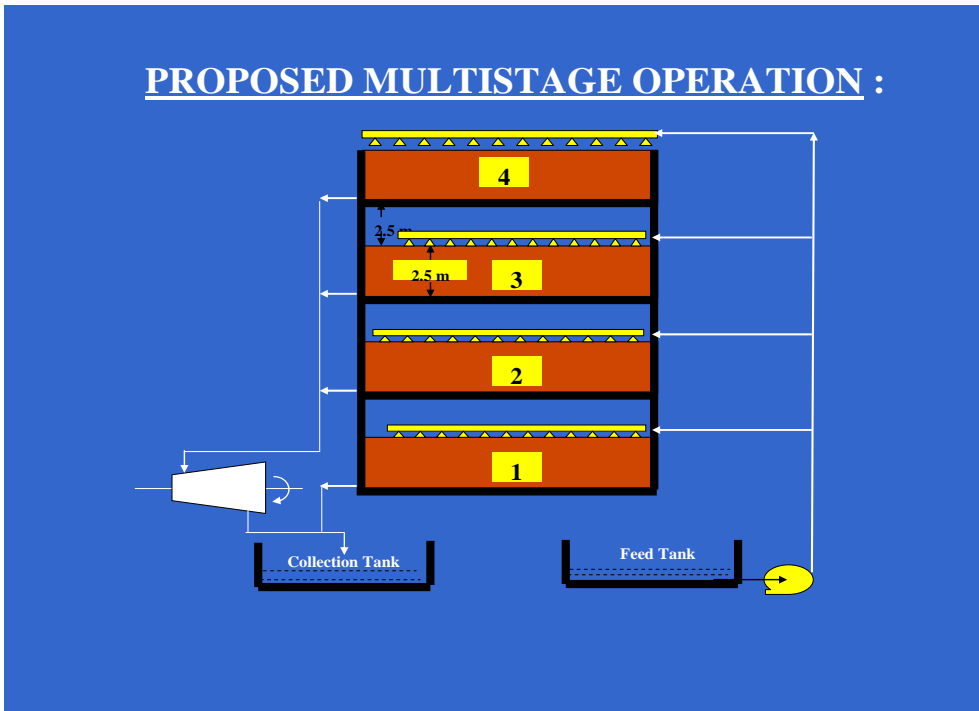


Fig 2.3: *Proposed Multistage Operation*

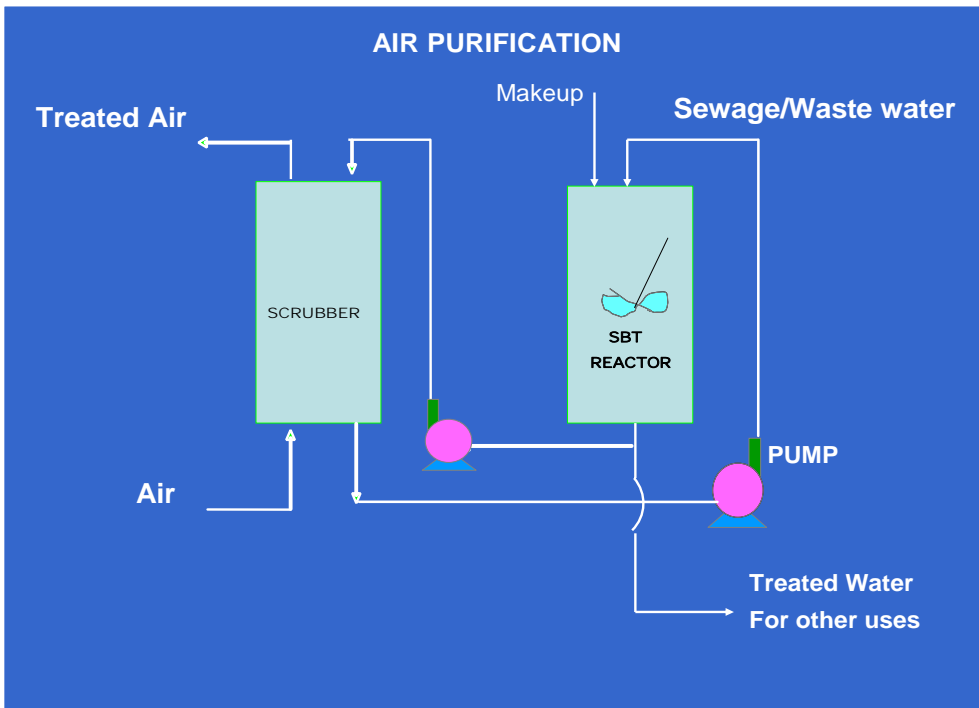


Fig 2.4: *Schematic of Air Purification*

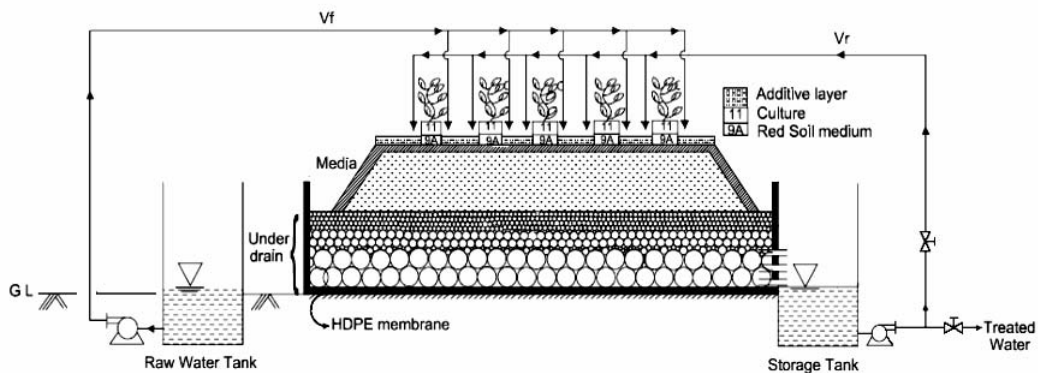
In the case of air purification the air to be purified is scrubbed with SBT treated water. Then the waste water so generated from scrubber is processed through

SBT system and treated water is recycled to scrubber. Fig 2.4 shows the schematic for air purification

The layout of media on the bioreactor is shown in Fig 2.5 & 2.6. The specific layout engaged depends on site conditions.

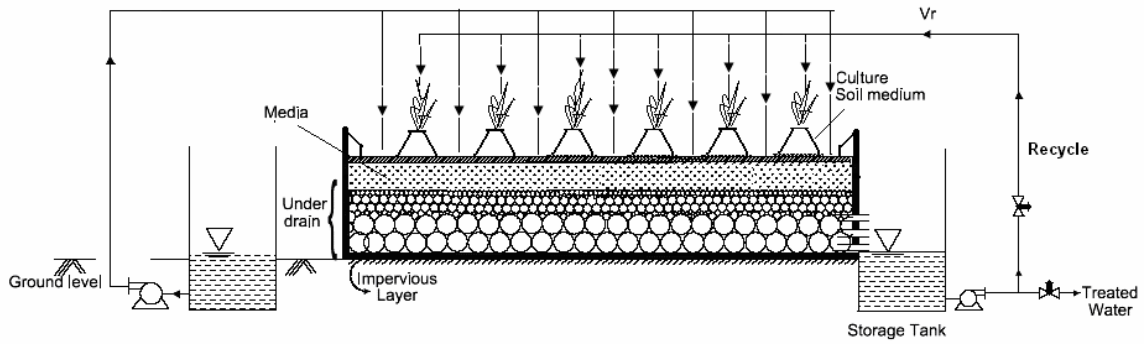
The green scheme for solid waste/ hospital waste is similar to water purification. here bioreactor is constructed and plantation developed as shown in Fig 2.7. Solid waste is unloaded on to bioreactor shown; here the waste undergoes bioconversion which takes 12-16 weeks during this period the environment pH & moisture are regulated by additives and moisture sprinkling. The processed material is harvested periodically and used as fertilizer.

Hospital waste also uses a similar scheme as shown in Fig 2.7. In the case of hospital waste the bioreactor floor is lined with waterproof membrane and media is then laid. The hospital waste is then charged into the bioreactor bed. The process is run along the same lines as municipal solid waste. After a process time of 28 weeks the material is turned mechanically with leaf litter & kerosene & incinerated. The incinerated material is returned to plants as fertilizer. The entire site is protected by fencing to prevent unauthorized entry & animal grazing.

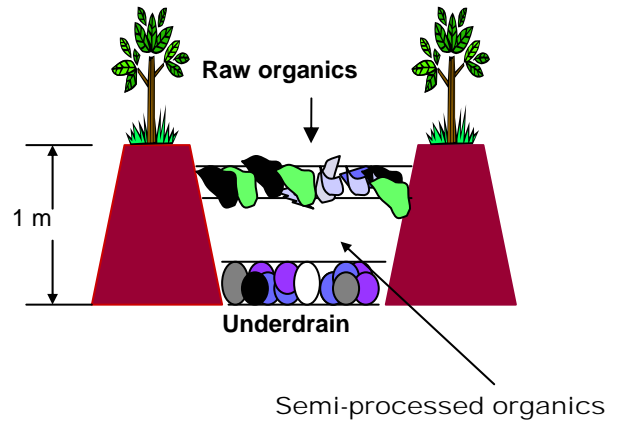
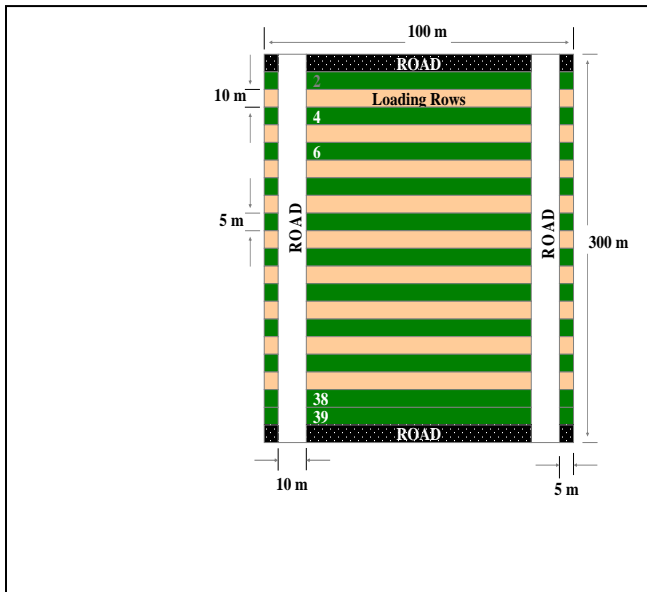


**Fig 2.5: Layout of SBT Media**

The components of SBT for plantation products such as fruits & vegetables is the same as shown in Fig 2.2.



**Fig 2.6: Layout of SBT Media**



**Fig 2.7**

### 3. Building & equipment

SBT plant is essentially a civil structure. However the civil structure can be all steel, if required; for small capacities this may be ideal. It comprises of tankages, bioreactor containment & a pump room and piping & pumping arrangements.

**3.1 Water treatment:** Raw water tank, treated water tank & bioreactor containment, pump cum store room constitute the civil structure of the SBT plant. Fig 2.5 & 2.6 show the types of layout of media; several other alternative layouts are also available but not shown here. The choice of media layout depends on

process requirements. The civil structure of the SBT plant is typically of stone rubble or RCC, steel and sometimes soil embankment.

In addition a green house infrastructure for very cold climes also forms a part of the SBT plant; the green house infrastructure is typically a bought out item

The piping system for the SBT plant is typically of 8 kg/sqcm HDPE pipes; but PVC & GI or other materials as per site conditions. All valves compatible with high pressure corrosion free service is fine for SBT plant.

Pumps are typically self priming & submersible type as per site conditions. All electricals cables switches alarms monitors & displays are as per design & safety requirements of the process on hand.

The details above also apply for primary purification of raw water from surface sources for drinking purposes; also for rain water, storm water, swimming pool water treatments. For these applications the SBT treated water is subjected to disinfection as per norms prior to delivery to end user.

3.2 Rain water Harvesting: The harvesting structure is the same as described above under water treatment. Here rain water is piped to the facility wherein it is purified and the stored underground.

3.3 Storm water Treatment: The harvesting structure is the same as described above under water treatment. Here storm water is channeled to the SBT facility wherein it is purified and the stored underground.

3.4 Swimming Pool water treatment: The structure is the same as described above under water treatment. Here swimming pool water is pumped to the SBT facility wherein it is purified, disinfected and returned to the pool.

3.5 Waste water Treatment: All the civil, mechanical, electrical and bioreactor required are identical to water treatment described above. The only difference is the pollution load & possible end uses of the treated water; and hence the differences in the design & construction of these plants.

In some cases particularly near airports, if birds are to be kept away; the plant environment is covered by wirenet and where required creepers are grown over it.

3.6 Multilevel waste water treatment: The civil structure tankages included is typically of steel or RCC. All pumps & piping as in water treatment. The multi level design of waste water treatment plants typically use steel structures protected electrochemically against corrosion.

3.7 Air Purification: The system consists of raw water & treated water tanks, air scrubber & bioreactor, circulation pumps & associated electricals. All equipment details are as described for water treatment.

3.8 Hospital Waste: The system consists of fenced wirenet environment, water supply & distribution, power supply & distribution, storage sheds & tractor & earth moving equipment, mixing equipment, implements & trolleys, bioreactor with necessary water proof protection, internal roads for vehicular movement of materials & wastes, office space & facilities.

3.9 Municipal solid Waste: The system consists of fenced wirenet ( if required) environment, water supply & distribution, power supply & distribution, storage sheds & tractor & earth moving equipment, mixing equipment, implements & trolleys , bioreactor, internal roads for vehicular movement of materials & wastes, office space & facilities.

## 4. Construction of SBT Plant

4.1 Water purification Process Specification: The specifications for tankages & bioreactor required to treat water & waste water, solid & hospital waste are obtained from process models & laboratory investigations. Table 4.1 summarizes the data required for design.

Table 4.1 Specification of raw water quality

S No	Item	
1	Flow (kL/d)	
2	BOD (mg/L)	
3	COD (mg/L)	
4	Suspended solids (mg/L)	
5	Ammonia –N (mg/L)	
6	Nitrate –N (mg/L)	
7	Total –N mg/L	
8	Electrical conductivity (milli Siemen/cm)	
9	Total inorganics (mg/L)	
10	Fecal coli forms (CFU/100 mL)	
11	End use of treated water (quote website address of standards desired)	

Table 4.2 Specification of raw solid waste

S No	Item	Amount
1	Quantity (ton/d)	
2	Moisture (kg/ton)	
3	Organics (kg/ton)	
4	Inorganics (kg/ton)	
5	Proteins (kg/ton)	
6	Carbohydrates (kg/ton)	
7	End use ( quote website address of standards desired)	

The construction of the SBT plant involves essentially civil works; design follows standard civil engineering procedures

## 5. Safety

The SBT process involves no moving parts excepting feed & discharge pumps. So safety needs are minimal. However gloves & gum boots are required while handling solids and during movements in the plant area so that accidental fall into tanks are avoided. Accordingly all tanks are provided closures and ladders.

## 6. Personnel Training

Personnel training required are i) routine pump operation & maintenance ii) routine O&M of plantations. These instructions are imparted during commissioning and trial run period by Vision Earthcare Pvt Ltd and their associates.

## 7. Reporting & Recording

Table 7.1: Summarizes the typical reporting & recording procedures to be adopted.

SN	Item	Description	Remarks
1	Pump1	Record start and end time, date etc .Record performance in a separate log sheet	
2	Pump 2	-do-	
3	Bioreactor 1	Record hours of use date, time etc	
4	Bioreactor 2	-do-	
5	Tank 1	Record maintenance work done	
6	Tank 2	-do-	

## 8. O&M of SBT plant

The water purification plant works on the principle of Soil Biotechnology which applies the biochemistry of nature in a concentrated manner. It aims at enriching soil & extracting excellent water for use in drinking, irrigation, fisheries, industries & construction & fire-fighting. The solid waste facility also uses the same principle to process waste for disposal or for conversion to fertilizer.

O&M of pumps & pipes: All pumps should be run daily to ascertain maintenance requirements. All monitors & alarms should be checked daily. All pipe ports should be maintained daily to ensure that water flows out of all the ports. All valves & fittings should be checked and where faulty should be restored.

Bioreactor: The top surface should be scrapped daily/weekly as necessary and the solids should be disposed. The top surface additives should be replenished periodically once say every 8 weeks.

Plantation: The plantation on the bioreactor and surroundings should be regularly watered pruned, replaced and provided with manure as required.

Tanks: All tanks should be thoroughly scrapped to remove adhering dirt and washed.

## **9. Conclusion**

SBT is a novel green technology for total purification of air & water & for processing of organic solids.