ISBN: 978-81-974088-4-7

19. MOUNTING HUMAN WASTES (Both Solids & Wastewaters) in World Destroying the GLOBAL ENVIRONMENT: Promotion of VERMICULTURE Technologies (Vermicomposting & Verm filtration) to Convert the 'WASTES into WEALTH' (Valuable RESOURCES for the FARMERS for High FOOD Productivity) by the EARTHWORMS

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Abstract:

HUMAN WASTES (both Solid Wastes & Wastewaters) are mounting all over the World creating great 'Economic & Environmental' problems for the Govt. & Society. Earthworms act as an 'AERATOR', 'GRINDER', 'CRUSHER', 'CHEMICAL DEGRADER' & a 'BIOLOGICAL STIMULATOR' in the WASTES.

Being 'Bisexual Organism' Earthworms multiply very rapidly. They double their population every 60 - 70 days.

EARTHWORMS Biodegrade & Vermicompost all ORGANIC WASTES by 'ENZYMATIC ACTION' on the CARBOHYDRATES, LIPIDS & PROTEINS of the Waste components & by Proliferating the 'DECOMPOSER MICROBES' in the Waste Biomass in Billions & Trillions in a short time.

The process becomes faster with time. They enhance composting of waste from 60 to 80 % at room temperature (without heating).

Earthworm enhances the BIODEGRADATION of ORGANIC WASTES from 60 to 80 % at room temperature (without heating) and also 'DISINFECT' & 'DETOXIFY' the Vermicompost. VERMICOMPOST is highly NUTRITIVE rich in NPK, HUMIC ACIDS, MICRONUTRIENTS, BENEFICIAL SOIL MICROBES giving 30 to 40 % 'Higher FOOD

Productivity' than the 'CHEMICAL FERTILIZERS' & also 'Repelling PESTS & DISEASE Organisms'. It also contains 'Plant Growth Hormones' – AUXINS, GIBBERLINS & CYTOKININS secreted by the Earthworms. VERMIFILTRATION of Wastewaters by EARTHWORMS is a 'Novel Technology'. Earthworms 'Disinfect' & 'Detoxify' the Wastewaters into 'Clean Nutritive Water' (rich in NKP) reusable for 'Farm & Garden Irrigation' saving huge groundwater of Earth which are 'fast depleting' all over the World. It is also 'self-promoted'; 'self-regulated', 'self-enhanced', 'low-energy' & 'zero-waste' technology', easy to construct, operate & maintain. Emission of GHGs is also highly reduced by the Earthworms.

Earthworms body work as a 'BIOFILTER' and they remove the 5 days BOD (BOD5) by over 90 %, COD by 80-90 %, total dissolved solids (TDS) by 90-92 % and the total suspended solids (TSS) by 90-95 % from Wastewater. The Earthworms release 'COELOMIC FLUIDS' that have 'Anti-bacterial' properties and destroy all 'Pathogens' in the Wastewater.

They also devour the 'Protozoa', 'Bacteria' and 'Fungus' as food from the Wastewater making it completely 'DISINFECTED' & 'DETOXIFIED'. The resulting VERMIFILTERED WATER is CLEAN enough to be 'reused' in INDUSTRIES as Cooling Water. They are also highly NUTRITIVE (rich in NKP) to be reused for FARM IRRIGATION giving higher FOOD Productivity. It is also rich in 'Plant Growth Hormones' (AUXINS & GIBBERLINS).

Keywords:

VERMICOMPOSTING of Solid Organic Wastes & VERMIFILTRATION of Wastewaters is an Odor-Free & Chemical-free System; Earthworms DETOXIFY & DISINFECT the WASTES & WASTEWATERS by ENZYMATIC Actions; Earthworms BIO-ACCUMULATE, BIO-DEGRADE & BIO-TRANSFORM the TOXIC Materials in the Wastes & Wastewaters; Earthworms Remove Total 'Dissolved & Suspended' Solids (TDS & TSS) in the Wastewater; VERMICOMPOSTED Wastes are completely Disinfected, Detoxified & also NUTRITIVE (Rich in NKP) to be Used as ORGANIC FERTILIZER; VERMIFILTERED Wastewaters are also CLEAN (Disinfected & Detoxified) & NUTRITIVE to be Re-Used as WATER in Farm & Garden IRRIGATION;

19.1 Introduction:

Management of SOLID ORGANIC WASTES By EARTHWORMS By VERMICOMPOSTING Technology:

The most Voracious 'Waste Eaters' species of Earthworms are:

1). Tiger Worm (Eisenia fetida);

2). Indian Blue Worm (Perionyx excavatus) &

3). African Night Crawler (Eudrilus euginae) (See Photographs below).

Figure 19.1: The Red Worm *(Lumbricus rubellus)* and the Red Tiger Worm (*Eisenia andrei*) are also good 'Waste Eaters' & 'Degraders'.

Earthworms Biodegrade and Vermicompost all Organic Wastes by two ways:

1). Through 'ENZYMATIC ACTION' on the Carbohydrates, Lipids and Proteins of the Waste components.

2). Through 'Proliferating DECOMPOSER MICROBES' in the Waste Biomass in billions and trillions in a short time.

Vermicomposting by Earthworms involves about 100-1000 times higher 'Value addition' in the end-product. The process becomes faster with time. Each EARTHWORM 'EAT the COMPOSTED MATERIAL' at least 8 TIMES leaving the end product naturally rich in key 'MINERALS & MICROBES' essential for 'Plant Growth'.

Given the optimum conditions of 'Temperature and Moisture', about $^{1}/_{2}$ kg of adult Earthworms (approx. 1000) can Vermicompost 10 kg of Organic Wastes or 5 kg of Earthworms (approx.10,000) can Vermicompost 1 ton of Organic Wastes in just 30 days. Earthworms are very sensitive to 'touch', 'light' and 'dryness'.

They tend to migrate away from 'light'. Their activity is significantly **slowed down in COLD condition, but HEAT can 'Kill' them. Adequate** MOISTURE is also a critical factor in VERMICOMPOSTING process as the Earthworm's body need plenty of WATER for growth. Moisture content of 60 - 70 % of total weight of Waste is considered to be ideal for Vermicomposting. Vermicomposting is an 'Aerobic Process' and adequate flow of 'AIR' in the Waste Biomass is essential for Worm function. Earthworms' breath through their skin and need plenty of 'Oxygen' in the surrounding areas.

Some Additives in WASTES for Rapid Worm Action in Vermicomposting:

1) CALCIUM appears to be an important mineral in the body of Earthworms (as their CALCARIOUS tissues) and in their 'Biodegradation' activities. Although most Organic Wastes contains Calcium, it is important to add some additional sources of Calcium for good Worm Actions & Vermicomposting.
2) Generally, 25 parts CARBON to 1 part of NITROGEN by weight (C/N=25:1) is considered ideal for rapid Vermicomposting. Hence proper blending of CARBON & NITROGEN containing WASTE MATERIALS is essential for rapid Worm Actions & Vermicomposting.
3) CATTLE DUNGS has been found to enhance the Vermicomposting activities of the Earthworms. It is also rich in ESSENTIAL NUTRIENTS and DECOMPOSER MICROBES and is also the most loving FEED materials **for the Earthworms.**

Some Attributes & Actions of Earthworms in Vermicomposting Process:

1) Earthworms act as an 'AERATOR', 'GRINDER', 'CRUSHER', 'CHEMICAL DEGRADER' & a 'BIOLOGICAL STIMULATOR';
2) A temperature range of 20 ° C to 30° C and a 'Moisture Content' of 60-75 % is optimum and ideal condition for good 'Worm Action';
3) They MULTIPLY very rapidly. Being 'Bisexual Organism', they double their population every 60 - 70 days. Given the optimal conditions of Moisture, Temperature and Feed Materials Earthworms can multiply by 2^8 i.e. 256 worms every 6 months from a single individual. Each of the 256 worms multiplies in the same proportion to produce a huge Biomass of Earthworms in a short time. Up to 3 Cocoons per worm per week are produced & from each Cocoon about 10-12 tiny Earthworms emerge.
4) Most Earthworms consume, at the best, half their body weight of the Organics Waste in a day. Tiger worm (*Eisenia fetida*) is reported to consume waste equal to their body weight every day.
5) Earthworms can also partially 'DETOXIFY' (by Bio-accumulating any Toxic Chemicals) and 'DISINFECT' the WASTE BIOMASS while degrading them into VERMICOMPOST which is an ODORLESS process. They release 'COELOMIC FLUIDS' that have 'Anti-Bacterial' properties & destroy all PATHOGENS in the Waste Biomass. Earthworms can distinguish between the 'Harmful & Useful' MICROBES and selectively devour on the harmful PROTOZOA, BACTERIA & FUNGUS as their Food.
6) Earthworm participation enhances 'Natural Biodegradation' and 'decomposition' of Organic Wastes from 60 to 80 %.
7) Earthworms biodegrade waste by 'Multiple Action'. First, they GRIND the Wastes by 'MUSCULAR ACTION' followed by 'Breaking' the Waste Organics by

'ENZYMATIC ACTION' and then by the action of 'DECOMPOSER MICROBES' which is proliferated by the Earthworms in the Composting system in Billions & Trillions. Earthworms GUT is a 'Microbial Factory'. In the intestine of Earthworms some Bacteria & Fungus (*Pencillium* and *Aspergillus*) have also been found. They produce 'Antibiotics' and kills the 'Pathogens' in all the WASTES.

8) The final process in Vermicomposting and Biodegradation of Organic WASTES is the 'HUMIFICATION' in which about 25 % of the Organic Matters are converted into 'HUMUS' which is essential for ROOT growth in plants. It takes several years to form Humus in the Conventional Composting Systems without the Earthworms, but the Worms do it rapidly.
9) Earthworms have to be protected from their 'Natural Enemies' during Vermicomposting. Many Birds, Moles, Snakes, Lizards, Toads and Rats are known to eat Earthworms. Earthworms are also eaten by certain Arthropods e.g. Japanese Beetles and Centipedes. Leeches and Soldier Flies also feed upon the Earthworms. Pets (Cats and Dogs) can also eat the Earthworms as they are rich in Proteins better than in the Meat products. To protect the Earthworms in the 'Vermicomposting Beds', some physical barriers such as 'Water Channels', 'Wire Nets' & 'Shields' may be used.
10) All Conventional COMPOSTING systems emit more Powerful Greenhouse Gases (GHGs) than the Carbon Dioxide. These are Methane & Nitrous Oxides which are 22 times & 312 times more Powerful GHGs. However, our studies showed that VERMICOMPOSTING System emitted significantly less Methane (CH_4) as the Worms kept the system AERATED by BURROWING ACTIONS and retained more NITROGEN (N) in VERMICOMPOST rather than allowing them to escape as Nitrous Oxides (N_2O).

19.2 Wastes Suitable for Large Scale Commercial Vermicomposting:

19.2.1 Municipal Organic Wastes:

1) FOOD WASTES from Homes and Restaurants: All raw and cooked kitchen wastes- Fruits and Vegetables, Grains & Beans, Coffee grounds, used Tea Leaves & Bags, Crushed Egg Shells.
2) GARDEN WASTES (DRY LEAVES & DRY GRASS CLIPPINGS) from Homes and Parks: They constitute an excellent feed stock for Vermicomposting. Grass Clippings (high CARBON Waste) require proper blending with NITROGENOUS Wastes.
3) SEWAGE SLUDGE: Generated from the Municipal Wastewater also provide a good feedstock for the Earthworms. Millions of tons of Sludge from various Conventional Wastewater Treatment Plants (Municipal & Industrial) are being generated every day in World. The Earthworms digest the Sludge and convert a good part of it into 'Nutritive', 'Chemical-free' & 'Pathogen-free' Vermicompost. In the intestine of Earthworms some Bacteria & Fungus (*Pencillium* and *Aspergillus*) have also been found. They produce 'antibiotics' which kills the Pathogenic Organisms in the Sewage Sludge
4) PAUNCH WASTE Materials: The Gut contents of the Slaughtered Ruminants from Abattoir also make good feedstock for the Earthworms.

19.2.2 Agriculture & Animal Husbandry Wastes:

1) FARM WASTES such as CROP RESIDUES, DRY LEAVES & GRASSES.
2) LIVESTOCK REARING WASTES such as CATTLE DUNG, PIG & CHICKEN EXCRETA make an EXCELLENT FEEDSTOCK for EARTHWORMS. Animal excreta containing excessive NITROGEN component may require mixing of CARBON rich bulking agents (Straw, Saw Dust, Dried Leaves & Grasses, Shredded Paper Waste etc.) to maintain proper C/N ratio**.**

Some INDUSTRIAL WASTES Suitable for VEMICOMPOSTING:

Vermicomposting Solid wastes & also the 'WASTEWATER SLUDGE' from PAPER PULP & CARDBOARD industry, FOOD PROCESSING industry, BREWERY & DISTILLERY, VEGETABLE OIL factory, POTATO & CORN CHIPS manufacturing Industry, SUGARCANE Industry, AROMATIC OIL extraction Industry. SERICULTURE Industry, LOGGING & CARPENTRY Industry also offers excellent feed material for Vermicomposting by Earthworms. Scientists in India have successfully VERMICOMPOSTED the 'FLYASH' from the COAL-POWER PLANTS which is considered to be a 'Hazardous Waste'. As they are rich in 'Nitrogen' (N) Earthworms love to feed upon them too.

19.2.3 Pond Weeds:

WATER HYACINTHS considered to be a 'Noxious Weed' is a wonderful feed material for the Earthworms. The resulting Vermicompost is rich in PHOSPHORUS as the weed contain more Phosphorus. In fact, all WEEDS (aquatic & terrestrial) can be VERMICOMPOSTED by Earthworms**.**

Some Additives in Organic Wastes for Rapid Worm Action in Vermicomposting:

CATTLE DUNGS: They are most Loved FOOD for the Earthworms and its use with any ORGANIC WASTES (Municipal or Industrial) and in any Vermicomposting process is very efficient. Commercial Production of Vermicompost for the Farmers to Use as ORGANIC FERTILIZERS in their Farms Replacing the Toxic

19.2.4 Chemical Fertilizers:

To Vermicompost large amount of 'Organic Municipal & Farm Wastes' on Commercial scale, the most convenient & economical way is to

1) Construct WINDROWS - TRENCHES 10' (length) X 3' (width) X 2' (height) with Bricks Sidewalls, Cement Plastered Base & Inclined Base of Vermicomposting BED. They must be located in COOL & SHADED AREAS to prevent direct 'Sunlight' and 'Rain'. About ONE TON of Composting Materials (FARM & FOOD WASTES) can be VERMICOMPOSTED in this size of TRENCH (shown below) every 2 months.
2) Level of the TRENCH is kept 'Above Ground' and with 'Inclined Base' & an Opening to facilitate drainage & collection of LIQUID (Body fluid of Earthworms called VERMIWASH) in the Underground PIT at one end. VERMIWASH is highly

NUTRITIVE Liquid excreted by the Earthworms. It contains plenty of 'Nitrogen Fixing' & 'Phosphate Solubilising' Bacteria & 'Chitin & Cellulose' Degrader Microbes which repel 'Pests' & suppress the 'Diseases'. Hence it can be used as PESTICIDAL SPRAY on the CROPS to prevent the PESTS & DISEASES.

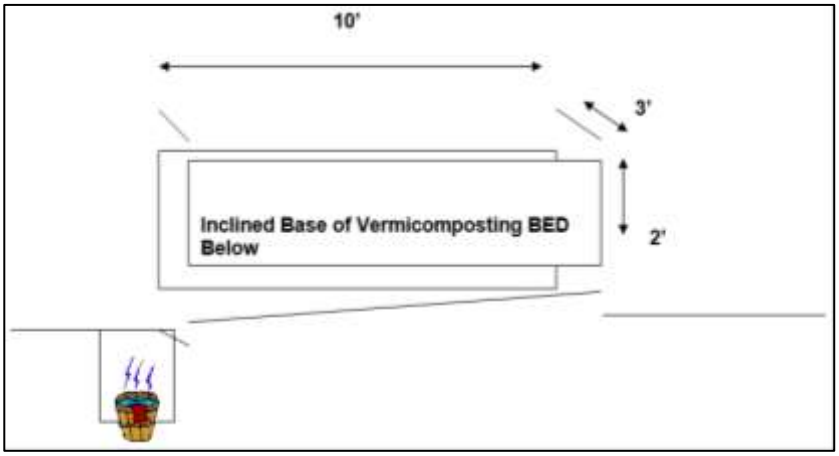

Figure 19.2: Underground Pit for Collection of VERMIWASH

3) VERMICOMPOSTING BED is prepared by placing about 3-4" thick layer of SOIL at the bottom followed by week old CATTLE DUNG above that.

Values of the Earthworms VERMICOMPOST for the Farmers & Society for High Productivity of Nutritious FOODS

1) VERMICOMPOST is highly Nutritive 'ORGANIC FERTILIZER' rich in NPK, HUMIC ACIDS, MICRONUTRIENTS, BENEFICIAL SOIL MICROBES and also contain all 'Plant Growth Hormones' – AUXINS, GIBBERLINS & CYTOKININS (secreted by the Earthworms) not to be found in other Composts.
2) It promotes GROWTH in crops 5-7 times HIGHER over other COMPOSTS & also the CHEMICAL FERTILIZERS.
3) It protects the SOIL, restore and improve its NATURAL FERTILITY.
4) It has great 'MOISTURE RETAINING' capacity significantly reducing the need of 'GOUNDWATER for Farm Irrigation' by 30-40 %.
5) More significantly, VERMICOMPOST also REPEL CROP PESTS & SUPPRESS the DISEASES.
6) Vermicompost can be used in Farms by the Farmers more easily as 'Foliar Spray' of 'Vermicompost Tea' produced by brewing it in water. It is very Effective 'PLANT GROWTH PROMOTER', also 'REPELLING PESTS' and 'SUPPRESSING DISEASES'.
7) The FOODS produced are also highly 'NUTRITIOUS' & HEALTHY, better in taste, much richer in PROTEINS, MINERALS, VITAMINS & ANTIOXIDANTS. As Vermicompost is rich in Earthworms Cocoons their application also increase the population of Earthworms in Soil which takes the command to 'RE-CONDITION & RESTORE' the 'SOIL FERTILITY' & enhance 'Food Productivity'.

a) WHEAT: Study at CSIRO Australia found that the Earthworms & its Vermicompost increased growth of Wheat crops by 39 %, grain yield by 35 %, lifted protein value of the grains by 12 % & also resisted diseases in Crops. We also studied it in Potted Wheat Crops in Australia (Photo Below);

b). RICE: Study in Philippines found that the yield of grain in Rice crops was 40 % higher. There was greater population of 'Nitrogen Fixers', 'Actinomycetes' and 'Mycorrhizal Fungi' in Paddy fields.

4) **CORN:** Study in Philippines found that there was 14 % increase in 'Ear Yield' of Corn crops. We also studied it in Potted Corn Crops in Australia (Photo Below);
5) GRAPE: Study in Australia found that it boosted YIELD by two-fold as compared to CHEMICAL FERTILIZERS. Even 'single application' of Vermicompost had good effects on yields of GRAPES for long 5 years. Farmers in India grew Grapes even on 'Eroded Wastelands' and applied Vermicompost @ 5 tons/ha. The GRAPE production was normal with improvement in quality of SOIL.
6) **CHERRIES:** Study in Australia found that Vermicompost increased its yield for three (3) years after 'Single Application'
7) **PECAN NUTS:** In USA Pecan Nut Farmers are using Vermicompost with dramatic results. 2 - 4 tons Per Acre of annual application showed 400 % increase in yield after 4 years. In the very first year there was 150 % increase over the Chemical Fertilizers**.**

Growth of CORN Crops:

A B C

Figure 19.1: Growth of CORN Crops

(A) Earthworms with Feed Materials → Av. Growth 57 cm

(B) Conventional Compost (400 gm) → Av. Growth 70 cm

(C). Vermicompost (400 gm) → Av. Growth 104 cm

Growth of WHEAT Crops:

A B C D

Figure 19.2: Growth of WHEAT Crops

(A) Composted Cow Manure (500 gm) → Av. Growth 32 cm

(B) Chemical Fertilizer → Av. Growth 43 cm

(C) Control (Only in Normal Soil)

(D) Vermicompost (500 gm) + Earthworms (25 Nos.) → Av. Growth 47 cm

19.3 Management of WASTEWATERS by EARTHWORMS By VERMIFILTRATION Technology:

19.3.1 Introduction:

WASTEWATERS (both Municipal & Industrial) are also mounting all over the World due to use of huge water every day by the global Human Society for Cooking, Washing, Bathing, Cleaning & in all Developmental Activities creating great Economic & Environmental Problems for Govt. to manage them properly. Wastewaters contains several 'Toxic Chemicals & Pathogens'. Most Nations in World operate the Wastewater Treatment Plants 'ACTIVATED SLUDGE PROCESS', 'TRICKLING FILTERS' & 'ROTATING BIOLOGICAL CONTACTORS' to treat their Urban (both Municipal & Industrial) Wastewaters. They use huge Electricity for transporting the Wastewaters to the Treatment Plants through Pipelines & for 'Churning & Aerating' the Wastewaters in the Treatment Plants. They also use TOXIC CHEMICALS to kill the PATHOGENS. They all generate huge 'HAZARDOUS SLUDGE' with Chemicals & Pathogens which have to be disposed

safely in the Waste Landfills. (Bajsa et.al., 2003). All Conventional Wastewater Treatment Plants also emit Huge & Powerful GREENHOUSE GASES Methane (CH_4 24 times) & Nitrous Oxides (N_2O 312 times) and **also Ammonia (NH_3 which creates foul odor) due to the Microbial Degradation of solids in the Wastewaters & the Slurry.**

Only the 'VERMIFILTRATION' Technology for Wastewater Treatment by Waste-eater EARTHWORMS give big hope to the World. It is a newly conceived NOVEL & INNOVATIVE TECHNOLOGY. Late Prof. Jose Toha & Prof. Maria Soto at University of Chile, Chile, were among the pioneer workers in 'Vermifiltration of Wastewater' (Sewage) since 1998. It was not known to the world as it was Patented by the University & not published. We also worked on it as a pioneer worker in Vermifiltration in Australia at Griffith University, Brisbane in 2005-06 and published his works in the U.K. Journal '*The Environmentalist*' in 2008. (Sinha et. al, 2008).

Earthworms completely 'Disinfect & Detoxify' the Wastewaters for their 'Reuse' in 'Farm & Garden Irrigation' which uses almost 75 % of the Groundwater thus SAVING Huge FRESHWATER of Earth which is 'Fast Depleting' all over the World.

The Voracious Waste-eater species of EARTHWORMS- Tiger Worms (*Eisenia fetida*), Indian Blue Worm (*Perionyx excavatus*), African Night Crawler (*Eudrillus euginae*) & Red Worms (*Lumbricus rubellus*) which manages the SOLID ORGANIC WASTES converting them into VERMICOMPOST for use to FERTILISE the FARMS also manages the WASTEWATERS converting them into CLEAN NUTRITIVE WATER for their reuse to IRRIGATE the FARMS. Tiger Worms are most 'Powerful & Healthy Organism' on Earth 'resistant' to even 'Toxic Chemicals' in the Wastewaters. These species of Earthworms can also 'BIO-ACCUMULATE, BIODEGRADE or BIO-TRANSFORM' any 'Toxic Chemicals' including 'Heavy Metals', 'Organochlorine Pesticide', 'Herbicides' and the Lipophilic Organic Micro-pollutants like 'Polycyclic Aromatic Hydrocarbons' (PAHs). This they do by 'Enzymatic Actions'. Hence, they can also be used to treat the 'TOXIC WASTEWATERS' of World.

19.3.2 BIOLOGICAL, CHEMICAL & PHYSICAL Characters of Municipal & Industrial: WASTEWATERS:

Municipal Wastewater (Sewage) is Cloudy fluid of human 'Fecal Matters' & 'Urine', high in Minerals & Organic substances. The Nitrogen (N) & Phosphorus (P) contents are very high and there are 'Heavy Metals' like Cadmium (Cd) & significant amounts of 'Coliform Bacteria'. Total Suspended Solids (TSS) is also very high. The average BOD (Biological Oxygen Demand) of the Raw Sewage ranged between 200 – 400 mg/L, COD (Chemical Oxygen Demand) ranged between 116 -285 mg/L, the TSS (Total Suspended Solids) ranged between 300 – 350 mg/L and the pH ranged between 6.9 – 7.3. The 'Normal Acceptable' values of BOD in treated Wastewater are 1-15 mg/L, COD is 60-70 mg/L, TSS 20-30 mg/L and pH around 7.0.

MATERIALS & METHODS Used for Formation of VERMIFILTER BED in the Experimental VERMIFILTER Kit & in the Commercial VERMIFILTER Plants:

Instruments & Materials to Be Used in The Formation of 'Commercial Vermifilter Plants':

1. PEBBLES of various sizes & SAND.
2. SAW DUST and/or DRY LEAVES: 50 kg each of dry leaves & saw dust.
3. VERMICOMPOST & Good Quality GARDEN SOIL.
4. WASTE-EATER EARTHWORMS: 30-40 kg or 5000 Worms per cum of Soil.
5. PUMP.
6. RAIN BIRD TYPE SPRINKLER: 2 Nos. (1 Standby)
7. PIPING: UPVC 25 mm Diameter PIPE (Length depends on actual location of Source of Sewage with respect to the VF Bed)
8. BALL VALVES: 25 mm size, 2 Nos.
9. SHED COVER (made of thick Green Plastic) all over the Vermifilter Bed of clear height 2 meter above the Brick Wall of the VF bed.

MATERIALS to be Used for Construction of VERMIFILTER BEDS in the Commercial Vermfilter Plants:

1) PEBBLES (Aggregates) of size 75 mm: 4.5 cum (bulk volume) at the bottom.
2) PEBBLES of size 35-40 mm: 2.5 cum (bulk volume) above them.
3) PEBBLES of size 10-12 mm mixed with Sand (50:50): 3 cum (bulk volume) above them.
4) VERMICOMPOST & GARDEN SOIL (50:50): 2.5 cum (bulk volume) at the top of the Bed.
5) Waste-eater EARTHWORMS Species are released in the SOIL.

Role of Earthworms & Mechanism of Worm Actions in WASTEWATER Treatment, Purification & Nutrification of the Clean WATER:

VERMIFILTRATION of Wastewater must be started with 'Higher Numbers' of Earthworms, at least over 15,000-20,000 Earthworms Per Cubic Meter of the Soil in the VERMIFILTER BED for good results.

19.4 BIOCHEMICAL ACTIONS of Earthworms:

Earthworms degrade the 'Organic Matters' in the WASTEWATERS (as in the SOLID WASTES) by 'Multiple Actions'.

1) First, they GRIND the matters in the Wastes by 'Muscular Action' followed by breaking the Organics in the waste by 'Enzymatic Action' and then by the action of 'Decomposer Microbes' which are proliferated by the Earthworms. The PEBBLES in the Vermifilter Bed provides wonderful site for the formation of 'Microbial Colony'.
2) Vermifilters provide a high Specific Area – up to 800 sq. m/g & VOIDAGE up to 60 %. SUSPENDED SOLIDS are trapped on top of the Vermifilter bed & fed to the SOIL MICROBES in the Vermifilter Bed.
3) Earthworms intensify the 'Organic Loadings' of Wastewater in the Vermifilter Bed. They granulate the 'CLAY PARTICLES' thus increasing the 'Hydraulic Conductivity'

of the system. They also grind the 'SILT & SAND' particles which enhances the ability to 'ADSORB' the 'Organic & Inorganic' substances from the Wastewater passing through it. The VERMICAST produced on the Vermifilter Bed also offers 'Excellent HYDRAULIC CONDUCTIVITY' like SAND & high Adsorption Power of CLAY.

4) Earthworms 'Disinfect' the Wastewater by their 'Ceolomic fluid' which is highly 'anti-pathogenic'. They also graze & devour on all the 'pathogens' (bacteria, fungus, protozoa & nematodes)
5) Earthworms 'Detoxify' the Wastewater by bio-accumulating any toxic chemicals including 'Heavy Metals'. The 'Chloragogen cells' in Earthworms bio-accumulate the heavy metals and immobilize them in small spheroidal 'Chloragosomes'. They also combine the heavy metals with special proteins called 'Metallotheanins' and render them biologically inactive or change their 'ionic states' to make them harmless.
6) The MICROBES *Pseudomonas, Mucor, Paenibacillus, Azoarcus, Burkholderia, Spiroplasm, Acaligenes,* and *Acidobacterium* associated with the intestine of the Earthworms also degrade several categories of Organics including the 'TOXIC ORGANICS' in the Wastewater. (Morgan & Burrows,1982; Xing et. al., 2005).
7) Earthworms also BIO-ACCUMULATE the 'Endocrine Disrupting Chemicals' (EDCs) from Sewage which cannot be removed by the Conventional Wastewater Treatment Systems (Markman et. al., 2007).

19.4.1 Some Critical Factors Affecting VERMIFILTRATION of Wastewater:

1) **Worm Population & Density (Biomass) in Soil of VERMIFILTER BED:** About 10,000 numbers of Earthworms per square meter of the Vermifilter Bed and in quantity (biomass) as 10 kg per cubic meter (cum) of Soil in the Vermifilter Bed is good for optimal function.
2) **Hydraulic Retention Time (HRT):** Hydraulic Retention Time is the time taken by the Wastewater to flow through the Vermifilter bed in which the Earthworms inhabits. It is very essential for the Wastewater to remain in the Vermifiltration System & be in contact with the Earthworms for certain period of time which must be at least 1-2 hours**.** The longer the Wastewater remains in the System in contact with Earthworms, the greater will be the efficiency of Vermifiltration & retention of 'Beneficial Nutrients'.

19.4.2 Some Studies on Vermifiltration of Municipal & Industrial Wastewaters:

1) We studied the Vermifiltration of 'Raw Sewage' at Griffith University, Brisbane, Australia as 40 CP Research Project for Master Students in 2005. Earthworms removed the 5 days BOD loads (BOD_5) of Sewage by over 98 % at HRT of 1-2 hours. The average COD was removed by over 50 %. They significantly removed the 'Total Suspended Solids' (TSS) by over 90 %. The Turbidity was removed by 98 %. (Sinha et.al. 2008).
2) We studied the Vermifiltration of 'Dairy Industry Wastewater' at Griffith University, Australia as 40 CP Research Project for his Master Student in 2006 & published in 2007. The BOD value was very high and ranged from 1,00,000 to 1,40,000 mg/L while the COD value was above 15,000 mg/L. The Total Suspended Solids (TSS) was also very high and ranged from 3,40,000 to 3,60,000 mg/L. The 'Turbidity' was high ranging between 3000 to 4000 NTU. The BOD was reduced by 99.2 %. The COD was reduced

to 314 mg/L from 15,000 mg/L. The TSS & Turbidity was reduced over 99 %. The pH value increased from Acidic (3.83) to almost Neutral (7.05) condition. There was absolutely no problem of any foul odor in the VERMIFILTER KIT (Sinha et.al. 2007).

3) We studied the Vermifiltration of 'Brewery Industry Wastewater' at Griffith University, Australia as 40 CP Research Project for Master Student in 2007. Earthworms reduced High BOD (6780 mg/L to 40.59 mg/L) 99 %; COD (1042 to 143 mg/L) 86 %; & High TSS (682 mg/L to 8 mg/L) 98 % at HRT of 3-4 hrs.
4) We studied the Vermifiltration of 'Petroleum Industry Wastewater' at Griffith University, Australia as 40 CP Research Project for Master Student in 2011 & published in 2012. The Wastewater contained mixture of 'Aliphatic' and 'Aromatic' volatile Petroleum Hydrocarbons (C 10 – C 36) and 'Organochlorines'. The Aliphatic fraction contained 'Cycloalkanes' as well as complex mixture of saturated TOXIC HYDROCARBONS. The Aromatic fraction mainly consisted of PAHs which is more Toxic and Persistent than the Aliphatic part.

The Chemicals of concern were the Total 'Petroleum Hydrocarbons' (TPH), 'Dichloromethane' (DCM), 'Dichloroethane' (DCE) and 't-Butyl Methyl Ether' (tBME). These compounds have raised global concern recently due to its high mobility and persistence in the Environment and their possible 'CARCINOGENICITY'.

About 1000 Earthworms of the species *Eisenia fetida* were released in the Soil of Vermifilter Bed. They not only tolerated and survived in the 'Toxic Petroleum' products around them, but also 'Bio-filtered' and 'Bio-remediated' the 'Dark Brown' 'Petroleum Wastewater' with 'Pungent smell' into 'Pale Yellow' and 'Odorless Water' indicating disappearance of all Toxic Hydrocarbons. The Hydrocarbons C 10 – C 14 was reduced by 99.9 %, the C 15 – C 28 by 99.8 % and the C 29 – C 36 by 99.7 % by the Earthworms. (Sinha et.al. 2012).

5) We studied the Vermifiltration of 'Fruit Juice Industry' Wastewater at Griffith University, Australia as 40 CP Research Project for Master Student in 2012 & published in 2013. Earthworms made a significant impact in the treatment of Fruit Juice Industry Wastewater. The Dark Brown color of the Wastewater became Light Yellow. BOD5 was reduced by 99.77 %, COD by 95.89 %, TSS by 91.57 %, TDS by 97.27 % & the Turbidity by 95.38 %. (Sinha et.al. 2013).
6) As the VERMIFILTERED SEWAGE is highly 'NUTRITIVE' rich in bio-available 'Nitrogen' (N), 'Phosphorus' (P) and 'Potassium' (K) good for 'Crop growth' we also studied its growth impacts on Rice Crops (*Oryza sativa*), in India at A.N. College, Patna as the Ph.D. Research Project of our Student Chandrajeet Kumar in 2015. It was found that during the entire plant growth cycle, the average SEED COUNT was 371 in single branch as compared to only 176 in Crops grown on Normal Water. The WEIGHT of single BRANCH SEED and the WIDTH of SHOOT GROWTH were almost 2 times and 4 times higher as compared to those grown on Normal Water. (Photographs Below).

Figure 19.2(a): Rice Crop Grown on Normal Water

Figure 19.2(b): Rice Crop Grown on Verm filtered Sewage

19.4.3 The Social, Economic & Environmental Benefits & Advantages of VERMIFILTRATION Technology for The Farmers & Society:

Vermifiltration is 'Low Energy System' & has several 'Social', 'Economic & Environmental' benefits & advantages over all the Conventional Wastewater Treatment Systems which are highly 'Energy Intensive', Costly to Install & Operate and do not generate any Resource as by-product.

Out of the total WATER available on Earth only less than 1 % is available for 'Human Use & Consumption'. 97.5 % is SALINE in the Oceans & 2 % is FROZEN in the Alps. VERMIFILTERED WASTEWATER can be reused for all 'non-potable' purposes in the Farm & Industries, Commercial Organizations, Public Lawns & Gardens.

GREEN GARDENS & WATER PONDS can also be created around the VERMIFILTER PLANTS to be used by Society**.**

1) The Capital and Operating costs of the Vermifilter Plants are much less than the Conventional Wastewater Treatment Plants.
2) It is Completely 'HYGIENIC & ODORLESS' System & there is 'No Formation' of 'HAZARDOUS SLUDGE'. Earthworms Degrade the Organics in Wastewater into Useful VERMICOMPOST.
3) There is no use of 'CHEMICALS' for 'Disinfecting' the Wastewater as Earthworms does the Job. They completely 'Disinfect' & also 'Detoxify' the Wastewater & also make them highly 'Nutritive' (rich in NKP).
4) There is also high value added 'By-products' & 'End-products' are generated as 'Huge EARTHWORMS BIOMASS', 'VERMICOMPOST' from Sewage Sludge & 'CLEAN NUTRITIVE WATER' which are very useful for the Farmers to promote 'Organic Farming' & achieve 'Higher Productivity' of 'Chemical-free' & 'Health Protective' Nutritive Organic Foods for Society & also saving WATER for Irrigation. The Earthworms Biomass can be used for Promoting Fish, Cattle & Poultry Industries & Pharmaceutical Industries for Production of Some Modern Medicines.
5) All the Wastewaters (Domestic & Industrial) can be treated at source of their generation in a 'Decentralized Manner', saving huge cost incurred on construction of 'Pipelines' for transmission of Wastewaters to long distances for their Treatment.
6) There is 'Less Use of Electricity' by 75 % as no 'Aeration' & 'Churning' of Wastewaters is needed in the Vermifiltration System & the Wastewaters are treated in a 'Decentralized' manner close to the sources of their generation avoiding long-distance transport of Wastewaters by Pipelines thus also highly reducing the emissions of 'Greenhouse Gases'. Nearly more than 15,000 Megawatt less Electricity per hour will be used in the operation of VERMIFILTER Plants as compared to the Conventional Wastewater Treatment Plants.
7) There will also be great savings in the use of 'Construction Materials' like Bricks, Sands, Cement, Steel & Rigid Plastics required for long distance transport of Wastewaters for Treatment in all the Conventional Plants.

19.5 Commercialization of Vermfilter Plants in India:

Our research done on VERMIFILTRATION of WASTEWATERS in Australia was Commercialised in India by the brilliant CEO Honourable Mr. Atul Shroff & the Technical Manager Dr. Mandar Prabhune at 'TRANSCHEM Agritech' in Gujarat.

They brought our 'Scientific Dreams' true. Thousands of VFT Plants are operating in Gujarat now. We wish all Govts. in States of India also understands their Social, Economic & Environmental Values & invite them to install VFT Plants**.**

Figure 19.5: Inner View of VERMIFILTER Plant in Gujarat, India with Verm filter Bed & Sprinklers Spraying Sewage over the Soil in Bed inhabited by Earthworms

Figure 19.5: Color of SEWAGE – Before & After Treatment by EARTHWORMS

19.6 Concluding Remarks:

(About the VERMICOMPOSTING & VERMIFILTRATION Technologies for the Benefits of Both Environment & Economy of Nations in World)

Both VERMICOMPOSTING & VERMIFILTRATION systems are 'Self-Promoted', 'Self-Regulated', 'Self-Improved' & 'Self-Enhanced', 'Low or No-energy' requiring 'Zero-Waste Technology', easy to Construct, Operate and Maintain.

Millions of tons of 'SOLID HUMAN WASTES', are being generated all over the World by the Human Society. They are mostly DUMPED above the Ground in the remote rural areas in the DEVELOPING NATIONS & DISPOSED in the 'WASTE LANDFILLS' in the DEVELOPED NATIONS every day, creating great ECONOMIC & ENVIRONMENTAL PROBLEMS for the Govt. & Society. FOOD & GREEN WASTES whether DUMPED on the Grounds or DISPOSED in the Waste Landfills emit more Powerful GREENHOUSE GASES (GHGs) – 'Methane' & 'Nitrous Oxides' (22 & 312 times more Powerful than 'Carbon Dioxide') inducing 'Global Warming & Climate Change'. Construction of 'Waste Landfills' also incurs 30-40 million Dollars, before the first load of Wastes are disposed.

Hence promotion of VERMICOMPOSTING Technologies to convert all 'Organic Wastes' into Valuable Resources (Organic Fertilizers) & diverting them from their 'Dumping' & 'Disposal' on the Grounds & in the Waste Landfills will greatly resolve both the ECONOMIC & ENVIRONMENTAL PROBLEMS of the Nations in World.

Large-scale production of 'VERMICOMPOST' & PROTEIN rich 'EARTHWORMS' can be a good 'Agri-business' opportunity today with awareness growing about use of these products in AGRICULTURE and other allied Industries. Vermicomposting plants are operating in almost all States of India. The Bhawalkar Earthworm Research Institute in Pune, Maharashtra is one of the largest VERMICOMPOSTING Organization in India. They have enhanced the lives of Poor in India and have also generated 'Self-employment' opportunities for the 'Unemployed' in India. It has become good source of livelihood for many. In India people are earning from Rupees 5 to 8 lakhs (Approx. AU $ 15-20 thousands) every year from sale of both Earthworms & their Vermicompost to the Farmers.

VERMICOMPOST contains more 'Stable forms of Carbon' as 'HUMATES'. Their use in Farms would also 'Sequester' huge amounts of CARBON and bury them back into the Soil, reducing 'Greenhouse Gases' & mitigating 'Global Warming'. Use of VERMICOMPOST in Farms would also significantly reduce the demand of WATER for Farm Irrigation which consumes about 70 % of the Groundwater of Earth which is a Fast-DEPLETING RESOURCES in Earth all over the World. They also help the CROPS to attain MATURITY & REPRODUCE faster, thus also shortening the 'Harvesting Time'. A farmer can take more than 'Two Crops' in a year from the same Farm by use of VERMICOMPOST. Use of VERMICOMPOST by Farmers replacing the TOXIC AGROCHEMICALS will provide both ECONOMIC & HEALTH BENEFITS to the Farmers. Thousands of Farmers in World are reported to be POISONED every year by the use of TOXIC PESTICIDES used to kill the PESTS & DISEASES in the Farms. Farmers in India, USA & Australia are very happy.

WASTEWATERS (both Domestic & Industrial) are also mounting all over the World creating great 'Economic & Environmental' problems for the Govt. & Society by Polluting the 'RIVERS & CANALS, PONDS & LAKES' as they are mostly drained into them in most Developing Nations. GROUNDWATER of Earth is also fast depleting all over the world leading to a severe 'Water Crisis' in future.

All Conventional Wastewater Treatment Plants (Activated Sludge, Trickling Filters & Rotating Biological Contactors) use huge 'ELECTRICITY' for transporting the Wastewaters to the Treatment Plants through Pipelines & for 'Churning & Aerating' the Wastewaters in the Treatment Plants. They also use TOXIC CHEMICALS to kill the PATHOGENS. They all generate huge 'HAZARDOUS SLUDGE' with 'Toxic Chemicals & Pathogens' which have to be disposed safely in the Waste Landfills. (Bajsa et.al., 2003). They also emit Huge & Powerful GREENHOUSE GASES Methane & Nitrous Oxides and also Ammonia which creates 'Foul Odor' due to the Microbial Degradation of Solids in the Wastewaters & the Slurry. Hence, only the promotion of VERMIFILTRATION Technologies by Earthworms for 'PURIFICATION of Wastewaters' can resolve the problems & save the Society benefiting both, the ECONOMY & ENVIRONMENT of Nations. The Earthworms completely 'Disinfect' & detoxify' the Wastewaters. The VERMIFILTERED WATER is CLEAN enough to be 'reused' in INDUSTRIES & for FARM IRRIGATION in World which uses about 70% of the Clean WATER of Earth.

Earthworms not only converts 'Human WASTE' into 'WEALTH', it also becomes a VALUABLE ASSET for the Society as the 'EARTHWORM BIOMASS'. Huge EARTHWORMS BIOMASS (in Tons) is produced every year in both the VERMICOMPOSTING & VERMIFILTRATION Systems. Under favorable conditions Earthworms can 'Double' their number at least every 60 – 70 days. They are rich in PROTEIN (65 %) with 70-80 % high quality essential 'Amino Acids' 'LYSINE' & 'METHIONINE'. It is a wonderful PRO-BIOTIC FEED for FISH, CATTLE & POULTRY INDUSTRY. Potentially large quantities of EARTHWORMS will also be available as 'PRO-BIOTIC' food for the CATTLE & FISH farming, after the very first year of operation of VERMICOMPOSTING & VERMIFILTRATION Systems. Farmers can start an 'Allied Industry / Agri-Business' of 'Poultry Farms' & 'Fishponds' from their byproducts.

Earthworms are also finding new uses as raw materials in production of 'DETERGENTS' & 'LUBRICANTS' & also as a source of 'MODERN MEDICINES' in the treatment of 'heart diseases' & several types of 'Cancers' and in the making of 'ANTIBIOTICS' from their Anti-pathogenic CEOLOMIC FLUID.

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19.8 Acknowledgement & Words of Gratitude:

We feel highly THANKFUL & GRATEFUL to Respected Mrs. Rajani Adam the Honorable CEO of K.D. Publishers in Pune, India & all the Brilliant Staff & Officers working at KDP for publishing our Papers as Chapters in her BOOK on *'Bridging Sustainability Solutions in Multidisciplinary Approach*'. They have highlighted the NAME of INDIA (my Nation of Birth) in the ACADEMIC WORLD. We PRAY to God for their GREAT SUCCESS in their JOB.

We have great appreciation for all the Women Vermiculture Scientist of World, Prof. Maria Angelica Soto of Chile & Prof. Radha D. Kale of India. Prof. Maria Soto pioneered in the research works in 'Vermifiltration of Wastewaters' with Late Prof. James Toha at Univ. of Chile in 1998. Dr. Shweta Singh (1st Author) is also following the footsteps of those brilliant 'Women Scientists' of World in her Academic & Scientific Life.

We also acknowledge all those eminent Vermiculture Scientists of world whose works on Earthworms greatly inspired in our Academic & Scientific Life. Sir Charles Darwin was one of them. He recognized the value of 'Earthworms' for Farmers in the 18th Century and called them as '*Unheralded Soldiers of Mankind & Friends of Farmers'.* Other was Sir Surpala of India who recognized the value of 'Earthworms' in 'Fruit Production' in the 10th Century A.D. Others were Prof. Anatoly Igonin of Russia who said that the 'Earthworms' perform the '*Disinfecting', 'Neutralizing', 'Protective' & 'Productive'* functions way back in the 19th Century. Prof. Ian Titov in Russia is another brilliant Vermiculture Scientist working today even after retirement. The great Indian Scientist Prof. Sultan Ismail gave the Earthworms the status of a 'Doctor' protecting the 'Health' of people on Earth. We are trying to revive their 'Scientific Memories', fulfill their 'Scientific Dreams' & 'Scientifically Validate' their great visions about Earthworms.