Challenges & Prospects of Environment Friendly Brushes

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Brushes within our scope i.e. paintbrushes, artist brushes, cosmetic brushes, shaving brushes & toothbrushes are nowadays made from either fully synthetic or synthetic/natural material combinations. Increased consumer demand and declining natural resources have made the brush industry synthetic reliant and this trend is not reversible. A growing number of consumers are concerned about the use of synthetic materials and their environmental impact because they believe that synthetic materials do not environmentally degrade, will last forever, and this can only cause increasing environmental distress.

It is true that plastics last a long time in the environment, nobody knows for sure but it's certainly hundreds of years, depending on various environmental conditions. Natural products can also last for a long time. A metal ferrule will easily last about 100 years or even more. Wooden handles also last long. The most reliable and recent laboratory results found 1.5% conversion for softwoods and 6% conversion for hardwoods at <20 mm size, after 1.5 years under ideal laboratory conditions. The only field study of long-term biological decomposition had one site show 20% biological degradation after 46 years, and the others show no detectable (<4%) degradation after 25 years. The average consumer however does not have the same concerns about the disposal of natural products like metal or wood as those with synthetics.

Recycling is the preferred method to contain the environmental impact of plastics. It's not easy to recycle plastics used in the subject brushes at the end of each product's service life. Various components of each brush are usually made from different types of raw materials and fixed permanently together. it's not easy to take apart these components for recycling. As an example, various types of synthetic and natural fibers could be mixed in a brush, it's not possible to disassemble that mixture and hence recycling is not possible. In most cases, brushes discarded after use are not clean and are coated with a vast spectrum of foreign matter. It's practically not possible to get rid of these residues to enable recycling.

As reclaim or recycling of plastics from subject brushes is impractical, one must look for other alternates, namely bioplastics or degradable plastics to offer environment-friendly products. The same reasons which make recycling practically impossible, together with the methods available for waste processing, also make degradation a difficult subject. This difficulty is compounded by the choice of available raw materials, shelf-life expectancy, product service life expectations, and the overwhelming regulatory environment which may differ regionally.

Bioplastics are plastics derived from renewable biomass sources, such as vegetable fats and oils, corn starch, straw, woodchips, food waste, etc. Companies with bio-based bioplastics can either indicate the 'biobased carbon content' or the 'biobased mass content' of their products. A well-established methodology to measure the biobased carbon content in materials or products is the 14C-method (EU standard: CEN/TS 16137, corresponding US-standard: ASTM 6866). The OK biobased label, offered by TÜV AUSTRIA and founded by Vinçotte, uses a star system to indicate a certified product's biobased content – the more stars, the higher the biobased content. This labeling program applies to basic/raw materials, intermediates, and finished products with at least 30% organic carbon fraction and 20% biobased carbon content. A material or product can also be specified as biobased by indicating its biobased mass content. This method is complementary to the 14C-method and takes chemical elements other than the biobased carbon into consideration, such as oxygen, nitrogen, and hydrogen. The French Association Chimie du Végétal (ACDV) has introduced a corresponding certification scheme and the European Committee for Standardization (CEN) is currently developing a standard for this method. TUV, NEN, DIN, etc. are acceptable labels.

Biodegradable plastics are plastics that can be decomposed by the action of living organisms, usually bacteria, fungi, etc. over some time in an actively managed landfill which acts as a "bioreactor" to intentionally promote microbial degradation of the waste, with collection and utilization of the by-product i.e. gas. There is no requirement for leaving "no toxic residue" and no requirement for the "time it needs to take to biodegrade". The ASTM D5511 test [ISO 15985] is a short-term test to indicate the biodegradability of plastic materials in a high solid anaerobic environment. This is a test to quickly determine if materials can biodegrade but does not provide realistic waste conditions and real-life scenarios. The ASTM D5526 is a long-term test to simulate a landfill environment and provides realistic results of what to expect in real-life situations. This is the primary test that biodegradation time frames should be based on.

Plastics suitable for industrial composting and anaerobic digestion requires at least 90% disintegration after twelve weeks and 90% biodegradation (CO2 evolvement) in six months whereby the remaining share is converted into water and biomass, which no longer contains any plastic. The European standard EN 14995 is the applicable test for plastics in general and includes tests on ecotoxicity and heavy metal content. It determines the standard for biodegradable plastics designed for treatment in industrial composting facilities and anaerobic digestion. The ASTM 6400 standard is the regulatory framework for the United States and sets a less stringent threshold of 60% biodegradation ((CO2 evolvement) within 180 days for non-homopolymers, and 90% biodegradation (CO2 evolvement) of homopolymers within industrial composting conditions (temperatures at or above 140F). Municipal compost facilities do not see above 130F.

Biodegradability in soil i.e. aerobic environment demands at least 90% biodegradation in two years at ambient temperatures. The standard EN 17033 “Biodegradable mulch films for use in agriculture and horticulture is the closest standard one can refer to for littering i.e. products which are just thrown in the ground in many parts of Asia.

A plastic therefore may be degradable but not biodegradable or it may be biodegradable but not compostable (that is, it breaks down too slowly to be called compostable or leaves a toxic residue).

Waste is processed in most developed countries as follows:

1. Landfill – It is the most common method to dispose waste. Landfills are anaerobic in nature and could be very diverse, based on soil conditions. It means the rate of biodegradability could substantially vary from place to place. The bacteria-rich environment in a landfill will consume biodegradable waste and release gases, mainly methane as a by-product. Gases from landfills are used as a fuel to generate heat, capturing up to 80% of the calorific value of methane. Landfill gas can be combusted to drive engines or turbines for electricity generation. Fuel conversion efficiencies typically range from 26% (for gas turbines) to 42% (for dual-fuel engines), which are comparable to conventional gas-fired power stations. Production capacity varies from a few kilowatts (kW) to several megawatts (MW). The electricity generated can then either be used directly or sold to the grid. In 2003, landfill gas generated about 3.27 TWh of electricity,105 equivalent to 24% of renewable electricity production in the UK and 1% of net UK generation. Landfill gas is by far the largest single source of new renewable electricity (i.e. excluding large hydro plants) – by contrast, all the wind farms in the UK generated just 1.3 TWh. Old and poorly designed landfills are not considered environmentally friendly because methane is released into the environment through fissures in the soil, contributing to greenhouse gases. No system has yet been developed which completely inhibits the release of landfill gas into the atmosphere. In a modern landfill with a comprehensive gas collection system, an average of 85% of the gas will be collected,25 whilst the remaining methane will migrate through the capping layer where 90% will be oxidized by methanotrophic bacteria en-route. So, at a minimum, methane emissions from new landfills will be just 2% of total generated methane. The EU has an active program to reduce landfill waste and other waste disposal methods include:

2. Anaerobic Digestion (AD): biodegradable waste degrades anaerobically in a controlled environment, with the resulting biogas captured and used as a low-carbon energy source. The 4 stages of anaerobic digestion are hydrolysis, acidogenesis, acetogenesis, methanogenesis. Anaerobic digestion could be designed as a batch or continuous process. Mesophilic digestion takes place optimally at 30 to 38-degree C where mesophiles are the primary microorganism present. Thermophilic digestion optimally takes place at 49 to 57 degrees C or at elevated temperatures up to 70 degrees C where thermophiles are the primary microorganisms present. Mesophilic species outnumber thermophiles, and they are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are therefore considered to be more stable than thermophilic digestion systems. In contrast, while thermophilic digestion systems are considered less stable, their energy input is higher, with more biogas being removed from the organic matter in an equal amount of time. A limit case has been reached in Bolivia, with anaerobic digestion in temperature working conditions of less than 10 °C. The anaerobic process is very slow, taking more than three times the normal mesophilic time process. Digestion systems can be configured with different levels of complexity. In a single-stage digestion system (one-stage), all of the biological reactions occur within a single, sealed reactor or holding tank. Using a single-stage reduces construction costs, but results in less control of the reactions occurring within the system. In a two-stage digestion system (multistage), different digestion vessels are optimized to bring maximum control over the bacterial communities living within the digesters. The residence time in a digester varies with the amount and type of feed material, and with the configuration of the digestion system. In a typical two-stage mesophilic digestion, residence time varies between 15 and 40 days, while for single-stage thermophilic digestion, residence times are normally faster and take around 14 days. The anaerobic digestion process can be inhibited by several compounds, affecting one or more of the bacterial groups responsible for the different organic matter degradation steps. The degree of the inhibition depends, among other factors, on the concentration of the inhibitor in the digester. Potential inhibitors are ammonia, sulfide, light metal ions (Na, K, Mg, Ca, Al), heavy metals, some organics (chlorophenols, halogenated aliphatics, N-substituted aromatics, long-chain fatty acids), etc. Anaerobic digestion is particularly suited to organic material and is commonly used for industrial effluent, wastewater, and sewage sludge treatment. It's a simple process that can greatly reduce the amount of organic matter which might otherwise be destined to be dumped at sea, dumped in landfills, or burnt in incinerators. The three principal products of anaerobic digestion are biogas, digestate, and water. Power generation from anaerobic digestors is tiny as compared to landfills. The power potential from sewage works is limited – in the UK, there is about 80 MW total of such generation, with the potential to increase to 150 MW, which is insignificant compared to the average power demand in the UK of about 35,000 MW. Biogas grid injection is the injection of biogas into the natural gas grid. The raw biogas must be previously upgraded to biomethane. In October 2010, Didcot Sewage Works became the first in the UK to produce biomethane gas supplied to the national grid, for use in up to 200 homes in Oxfordshire. The biogas (transformed into biomethane) can be used as vehicle fuel in adapted vehicles. This use is very extensive in Sweden, where over 38,600 gas vehicles exist, and 60% of the vehicle gas is biomethane generated in anaerobic digestion plants. By using a bio-digester, which produces the bacteria required for decomposing, cooking gas is generated. The organic garbage like fallen leaves, kitchen waste, food waste, etc. is fed into a crusher unit, where the mixture is conflated with a small amount of water. The mixture is then fed into the bio-

digester, where the bacteria decomposes it to produce cooking gas. This gas is piped to the kitchen stove. A 2 cubic meter bio-digester can produce 2 cubic meters of cooking gas. This is equivalent to 1 kg of LPG. Digestate is the solid remnants of the original input material to the digesters that the microbes cannot use. It also consists of the mineralized remains of the dead bacteria from within the digesters. Digestate can come in three forms: fibrous, liquor, or a sludge-based combination of the two fractions. Acidogenic digestate is a stable, organic material consisting largely of lignin and cellulose, but also of a variety of mineral components in a matrix of dead bacterial cells; some plastic may be present. The material resembles domestic compost and can be used as such or to make low-grade building products, such as fibreboard. The solid digestate can also be used as feedstock for ethanol production. Methanogenic digestate is rich in nutrients, which can be used as a fertilizer, depending on the quality of the material being digested. Digestate typically contains elements, such as lignin, that cannot be broken down by the anaerobic microorganisms. Also, the digestate may contain ammonia that is phytotoxic and may hamper the growth of plants if it is used as a soil-improving material. For these two reasons, a maturation or composting stage may be employed after digestion. The final output from anaerobic digestion systems is water, which originates both from the moisture content of the original waste that was treated, and water produced during the microbial reactions in the digestion systems. This water may be released from the dewatering of the digestate or may be implicitly separate from the digestate. The wastewater exiting the anaerobic digestion facility will typically have elevated levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). These measures of the reactivity of the effluent indicate an ability to pollute. Some of this material is termed 'hard COD', meaning it cannot be accessed by the anaerobic bacteria for conversion into biogas. If this effluent were put directly into watercourses, it would negatively affect them by causing eutrophication. As such, further treatment of the wastewater is often required. This treatment will typically be an oxidation stage wherein air is passed through the water in a sequencing batch reactor or reverse osmosis unit

3. Composting: biodegradable waste degrades aerobically to produce compost which can be applied to land, potentially displacing fertilizer. The process of biodegradation under aerobic conditions within a time frame of 6-12 weeks is called composting. Composting of industrial products usually takes place in industrial composting plants, where controlled conditions (e.g. temperature, humidity, aeration) are given. Microbes, like bacteria or fungi and their enzymes, can “digest” the chain structure of compostable polymers as a source of nutrition. The resulting end products are water, carbon dioxide CO_2 and a little biomass. The speed of biodegradation depends on the temperature (50-70°C are typical for an industrial composting process), humidity (water is required for the process), and the number and types of microbes. In industrial composting facilities, all those requirements are given, and certified compostable plastic products are converted into CO_2, water, and biomass within 6 to 12 weeks.

4. Mechanical Biological Treatment: breaking down waste by shredding, removing recyclable materials, and either composting or digesting the remaining waste to produce biogas. A mechanical biological treatment system is a type of waste processing facility and MBT plants are designed to process mixed household waste as well as commercial and industrial wastes. The "mechanical" element is usually an automated mechanical sorting stage. This either removes recyclable elements from a mixed waste stream (such as metals, plastics, glass, and paper) or processes them. It typically involves factory-style conveyors, industrial magnets, eddy current separators, trommels, shredders, and other tailor-made systems, or the sorting is done manually at handpicking stations. The mechanical element has several similarities to a materials recovery facility (MRF). Some systems integrate a wet MRF to separate by density and flotation and to recover and wash the recyclable elements of the waste in a form that can be sent for recycling. MBT can alternatively process the waste to produce a high calorific fuel termed refuse-derived fuel (RDF). RDF can be used in cement kilns or thermal combustion power plants and is generally made up of plastics and biodegradable organic waste. Systems that are configured to produce RDF include the Herhof and Ecodeco processes. It is a common misconception that all MBT processes produce RDF; this is not the case and depends strictly on system configuration and suitable local markets for MBT outputs. The "biological" element refers to either anaerobic digestion or composting or bio-drying.

5. Incineration with energy recovery: waste is fed directly into a furnace or boiler without prior separation or sorting. An incinerator is a furnace for burning waste. Modern incinerators include pollution mitigation equipment such as flue gas cleaning. There are various types of incinerator plant designs such as moving grate, fixed grate, rotary-kiln, and fluidized bed. According to the European Waste Incineration Directive, incineration plants must be designed to ensure that the flue gases reach a temperature of at least 850 °C (1,560 °F) for 2 seconds to ensure proper breakdown of toxic organic substances. To comply with this always, it is required to install backup auxiliary burners (often fuelled by oil), which are fired into the boiler in case the heating value of the waste becomes too low to reach this temperature alone.
The flue gases are then cooled in the superheaters, where the heat is transferred to steam, heating the steam to typically 400 °C (752 °F) at a pressure of 40 bars (580 psi) for the electricity generation in the turbine. At this point, the flue gas has a temperature of around 200 °C (392 °F) and is passed to the flue gas cleaning system. The heat produced by an incinerator can be used to generate steam which may then be used to drive a turbine to produce electricity. The typical amount of net energy that can be produced per tonne of municipal waste is about 2/3 MWh of electricity and 2 MWh of district heating. Thus, incinerating about 600 metric tons (660 short tons) per day of waste will produce about 400 MWh of electrical energy per day (17 MW of electrical power continuously for 24 hours) and 1200 MWh of district heating energy each day. Incineration has several outputs such as the ash and the emission to the atmosphere of flue gas. Before the flue gas cleaning system, if installed, the flue gases may contain particulate matter, heavy metals, dioxins, furans, sulfur

dioxide, and hydrochloric acid. If plants have inadequate flue gas cleaning, these outputs may add a significant pollution component to stack emissions. In a study from 1997, Delaware Solid Waste Authority found that, for the same amount of produced energy, incineration plants emitted fewer particles, hydrocarbons, and less SO2, HCl, CO, and NOx than coal-fired power plants, but more than natural gas-fired power plants. According to Germany's Ministry of the Environment, waste incinerators reduce the amount of some atmospheric pollutants by substituting power produced by coal-fired plants with power from waste-fired plants. The most publicized concerns from environmentalists about the incineration of municipal solid wastes (MSW) and plastics involve the fear that it produces significant amounts of dioxin and furan emissions. Dioxins and furans are considered by many to be serious health hazards. The EPA announced in 2012 that the safe limit for human oral consumption is 0.7 picograms Toxic Equivalence (TEQ) per kilogram body weight per day, which works out to 17 billionths of a gram for a 150 lb person per year. In 2005, The Ministry of the Environment of Germany, where there were 66 incinerators at that time, estimated that "...whereas in 1990 one third of all dioxin emissions in Germany came from incineration plants, for the year 2000 the figure was less than 1%. Chimneys and tiled stoves in private households alone discharge approximately 20 times more dioxin into the environment than incineration plants." According to the United States Environmental Protection Agency,[9] the combustion percentages of the total dioxin and furan inventory from all known and estimated sources in the U.S. (not only incineration) for each type of incineration are as follows: 35.1% backyard barrels; 26.6% medical waste; 6.3% municipal wastewater treatment sludge; 5.9% municipal waste combustion; 2.9% industrial wood combustion. Thus, the controlled combustion of waste accounted for 41.7% of the total dioxin inventory. Modern municipal incinerator designs include a high-temperature zone, where the flue gas is sustained at a temperature above 850 °C (1,560 °F) for at least 2 seconds before it is cooled down. They are always equipped with auxiliary heaters to ensure this. These are often fuelled by oil or natural gas and are normally only active for a very small fraction of the time. Further, most modern incinerators utilize fabric filters (often with Teflon membranes to enhance the collection of sub-micron particles) which can capture dioxins present in or on solid particles. For very small municipal incinerators, the required temperature for the thermal breakdown of dioxin may be reached using a high-temperature electrical heating element, plus a selective catalytic reduction stage. Other gaseous emissions in the flue gas from incinerator furnaces include nitrogen oxides, sulfur dioxide, hydrochloric acid, heavy metals, and fine particles. Of the heavy metals, mercury is a major concern due to its toxicity and high volatility, as essentially all mercury in the municipal waste stream may exit in emissions if not removed by emission controls. Incineration produces fly ash and bottom ash just as is the case when coal is combusted. The total amount of ash produced by municipal solid waste incineration ranges from 4 to 10% by volume and 15–20% by weight of the original quantity of waste, and the fly ash amounts to about 10–20% of the total ash. The fly ash, by far, constitutes more of a potential health hazard than does the bottom ash because the fly ash often contains high concentrations of heavy metals such as lead, cadmium, copper, and zinc as well as small amounts of dioxins and furans. The bottom ash seldom contains significant levels of heavy metals. Presently, although some historic samples tested by the incinerator operators' group would meet the being ecotoxic criteria at present the EA says "we have agreed" to regard incinerator bottom ash as "non-hazardous" until the testing program is complete. Fly ash is used as a filler in many products, mainly construction industry. Incineration is a key process in the treatment of hazardous wastes and clinical wastes. It is often imperative that medical waste be subjected to the high temperatures of incineration to destroy pathogens and toxic contamination it contains.

Various countries have diverse priorities but of the above, landfills continue to be the most widely used method and will continue to be so for many years or even decades. A sample waste policy for South Italy can be viewed at http://ec.europa.eu/environment/waste/framework/pdf/IT_SOUTH_factsheet_FINAL.pdf. It demonstrates the widespread use of landfills. It is likely that most brushes are presently ending up in landfills in various countries and in many parts of the world, especially the third world, they may not even end up in landfills & would just end up as litter.

After juxtaposing the standards, methods of waste disposal, available raw materials for composability, and accelerated anaerobic biodegradation & their service/shelf-life/cost issues, the preferred solution is to offer materials that qualify both ASTM D5511 and ASTM D5526 from accredited labs. The materials must also not leave any toxic residue, although this is not a legal requirement, it is nonetheless important and shuts the door on any future claims for ecotoxicity.

For ASTM D551, 70% biodegradation needs to be obtained within 30 days. For ASTM D5526, 70% biodegradation is required at the end of the test. While the tests laid down these conditions, there is no legal requirement for the time it takes for a product to biodegrade to claim biodegradability. The present alternate raw materials which meet the standards of composting and anaerobic digestion do not meet expectations of service life, shelf life and are 2-4 times the present cost of raw materials like polyester etc. & therefore, biodegradable brushes are not a viable option.

It is however possible to offer Bio-Based materials which meet the expectations of performance, service life, shelf life etc., and that is a sensible choice, given the limitations of technology.

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