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Biodegradable Masks, A Path Towards Sustainability: A Review

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ABSTRACT: Face masks are used to prevent the transmission of aerosols, dust, pollen, and other pollutants. Biodegradable masks protect the wearer and the environment from the harmful effects of plastic pollution. Micro-plastics are used in normal grade masks, which take millions of years to disintegrate. Hence, biodegradable masks are an environmentally friendly option. The materials that were used to make biodegradable masks are cinnamon oil, starch, turmeric extracts, chitin, PBS non-woven fibre, bamboo fibre, lactic acid and natural polymers. These materials have a significant impact on the level of protection provided to the wearer and the environment. It also contributes to the fit's comfort. As a result, when producing fabric masks, the following attributes should be considered: comfort, breathability, thermal regulation, fit, durability, Permeability of air and water vapour entry and exit. These circumstances resulted in a significant drop-in global economic activity, but there were also indirect environmental advantages such as improved global air quality and reduced water contamination. Face masks are currently part of a comprehensive set of preventative and control methods. The extensive use of mask generates millions of tonnes of plastic garbage in the environment. The goal of this review is to look at the environmental impact of face mask waste and find a long-term way to reduce it.

KEYWORDS: Biodegradable mask, PBS (Poly-Butylene Succinate) non-woven fibre, Breathability, Permeability, Sustainability, Environment.

I. INTRODUCTION

Biodegradable masks are those masks which provide protection to the wearers as well as protect the environment from plastic pollution. Normal grade masks are made of micro-plastics which take millions of years to degrade. Hence, biodegradable masks make a sustainable choice. These biodegradable masks are made up of biodegradable materials like cinnamon oil, starch, turmeric extracts, chitin, and natural polymers, etc. These materials are used as an alternative to the plastic. Now, many biodegradable masks are innovated in a way that the masks which are discarded grow into a tree or sprout into beautiful flowers. The masks are designed out of 'rice paper' and are a perfect alternative to the surgical masks that are stockpiling in litters alongside streets and in waste disposal landfills adding to the global micro-plastic pollution levels.

Due to ongoing Covid-19 outbreak that spread to over 188 countries, most countries have adopted face mask wearing as a mandatory rule along with social distancing and the use of sanitizers and washing hands with disinfectants. Medical staff are advised to wear Personal Protection Kits. Corona virus is an RNA virus which was first reported in Wuhan, China on December 31st, 2019. The wearing of face mask is said to prevent the spread of aerosols which carry the infectious microbes. Measures are being taken to reduce the waste generation due to usage of face masks, gloves, etc by promoting re-usable face masks for the general public. Currently, the usage of cloth masks is being promoted along with procedures to wash and dry them. It is very critical to ensure the wearing of face masks by the public to fight the pandemic and eradicate COVID-19. [1]

The reasons why wearing a mask and regular hand washing with running water (or sanitization of hands) is necessary is to stop the transmission of infections via aerosols in former and contact in latter. These are the guidelines stated by WHO. There are 3 types of masks they are medical masks or Surgical masks (use and throw) used by medical staffs, Re-usable cloth masks that are used by general public, KN95 masks with respirators. Since, use and throw masks led to drastic increase in the waste generation and depletion of masks for the medical staff, it was advised that the public use re-usable masks. There have been initiatives made to produce bio-degradable masks to help the environment by reducing plastic production along with waste generation. These cloth masks can be re- used by treating them at a temperature greater than 50° Centigrade for 30 minutes and drying the masks with electrostatic appliances like hair dryers, electric fans, electronic ignites. It is important to regenerate the electrostatic charge as it is contributing to the mask's high-level filtration. Re-use of masks can be done after hot water decontamination and charge regeneration. Properties used to make

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the masks play a major role in the protection provided to the wearer and the person. It also plays a role in the comfort of fit. Therefore, the properties that should be kept in mind before making cloth masks are Comfort, Breathability, Thermal regulation, Goodness of fit, Air and water vapour entry and exit, Permeability, Thermal conductivity as breathing with masks creates micro-climate. Goodness of fit includes the materials that are used to make cloth masks. Filtration efficiency is the proportion of particles blocked by a filter (usually expressed as a percentage) and assessed using surrogate markers, not directly with transmissible pathogens. Some of the parameters considered for the filtration efficiency of cloth mask are Thread count, Number of layers, Type of fabric used, Water resistance. Some studies show that cotton masks have better filtration efficiency compared to gauze masks. Improper use of masks, that is improper washing of masks before re-using will sometimes result in virus collection, which enter through the capillaries. Evaluation of the micro-structure of the masks are done by using Scanning Electron Microscope, waterproof property is evaluated by using Hydrostatic pressure method, filterability is compared to the national and local standards, inner defects of the masks is inspected by Fluorescent Nanoparticle inspection. [1, 16]
Some face mask materials are capable of inactivating SARS-COV2. Non-woven masks face filter fabricated with a bio-functional coating Benzalkonium Chloride is capable of inactivating 99% of SARS-COV2 particles in 1 minute of contact. Materials coated on the mask have the capability of inactivating Bacteria like MRSA (*Methicillin resistant Staphylococcus aureus.)* [23]
Medical-grade masks are commonly made of polypropylene plastics; mask use is contributing to a secondary issue: a massive amount of plastic pollution, which is already one of our society's most critical environmental problems. Hundreds of millions of facemasks are produced each year using petrochemical-derived raw materials that are non-biodegradable after one usage, causing pollution and environmental damage. The most sustainable option forward is to design face masks that are comparable to or better than traditional ones, employing by-products from local industries as raw materials. They also discharge harmful micro-plastics into our waterways, which are consumed by unwary fish. [27]

II. ORIGIN AND HISTORY OF USAGE OF FACEMASKS

The earliest recorded face mask-like objects in history date to the 6th century BC. Some images of people wearing cloth over their mouths were found on the doors of Persian tombs. In the 14th century, when the Black Death spread to Europe, it greatly promoted the emergence of functional face mask-like objects. In the 16th century, French doctor Charles de Lorme invented the beak mask. In 1890 William Stewart Halsted pioneered the use of rubber gloves. The first country to practice the usage of facemask to prevent diseases in 1910-1911 in China. The Manchurian epidemic where doctors reported the mask as a ‘prophylactic apparatus’ that could be worn by all to protect themselves from the plague. In the same decade as the Manchurian epidemic, over 40 million people around the world lost their lives to the Spanish flu (1918). Stewert Halsted has led the way in the usage of surgical face masks during the Spanish flu. The practice of covering one’s face with and veils and scarves with the intention to protect themselves from the disease originated during this period and remained until it faded towards the end of 1919. During the early 20th century, various types of cloth masks which were made of cotton, gauze, and other fabrics were used in US hospitals. The respiratory rates of transmission of infections among healthcare workers who used masks made of 2–3 layers of gauze were seen to be reduced. [16,23]

III. INTERNATIONAL SCENARIO

Mask usage was already common in some East Asian countries before the start of the pandemic. These masks were word to protect themselves from pollution, and other flu related diseases. It Is said that masks were worn before to protect others as well as oneself from danger. [37]
The first case was reported on 30th December 2019 according to the WHO in Wuhan, China. Now, the virus has spread to over 188 countries. Total number of Covid-19 cases till April 20^{th,} 2021is recorded to be 143,622,127. Total number of deaths is 3,059,898 and recovered cases are 122,005,304. USA has the highest number of cases which is recorded to be 32.536,470. The first countries to set national mandates amid the corona virus crisis were Vietnam and the Czech Republic, in mid-March. The face mask market is projected to grow from USD 737 million in 2019 to USD 22,143 million in 2021 and then reduce to USD 3,021 million by 2025. [45]

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IV. INDIAN SCENARIO

In pre-pandemic India surgical masks were used by medical professionals, laboratory technicians, etc. General public used anti-pollution masks as pollution is still the main concern in Indian Metropolitan Cities like Delhi, Mumbai, Bangalore, etc. [38]
Dated April 20th, 2021, total Covid-19 cases in India is recorded to be 15,616,130 and the deaths in India is recorded to be 182,570. The government has made it mandatory to wear masks when in public places like workplace, place of worship, supermarkets, etc. [44]

V. TYPES OF MASKS

The idea behind these masks is to form a coverage around the nose and mouth that are used as physical barriers for the fluids and particulate materials in a certain efficiency.[9] They provide certain efficiency when used as physical barriers to fluid particles and effective protective against indoor aerosol transmission to prevent bacterial and viral transmission. [9,23]

TABLE 1: Characteristics analysis of types of masks used

Mask Type	Features	Efficiency	Re-usability	Breathability	Advantages	Limitations	References
I. Cloth face mask	Cover the user's nose and mouth. Physical barriers for the fluids and particulate materials.	Low	High	Moderate	Provides protection against large particles (Ex: Pollen, Dust) and can be reused.	Protection exposed to user; leakage occurs around the sides	[1],[10],[13], [15], [16], [35]
II. Surgical face mask	Creates barrier between n mouth and nose of the wearer and contaminants in the immediate environment.	Moderate	Low	Moderate	Provides protection against droplets from user as well as the patients. Limits the release of droplets larger than 5 µm.	It does not help in protection from spread of respiratory diseases. Leakage occurs around the edge of the mask when user inhales.	[13],[15], [35]
III. N-95 mask	Non-oil resistant, very close facial fit and a very efficient filtration of airborne particles.	High	Low (not washable)	Low	Provides protection against air borne particles and droplets. Filters out at least 95% of airborne particles. Captures particles from	Should be discarded after each patient encounter aerosol-generating procedures, contaminated with blood, respiratory or nasal secretions, or	[13],[15], [35]

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					wearer and the patient	other bodily fluids.	
IV. Biodegradable mask	Moisture-resistant, highly breathable, and high-performance fibrous mask.	High	High	Moderate	Reduce soil, air and water pollution,	Biodegradable masks are expensive. Not be easily available	[8], [28]

TABLE 2: **Comparison of materials and methodologies used in different types of masks:**

SL. No.	TYPE OF MASK	MATERIALS USED	METHODOLOGY	REFERENCES
I	**Cloth mask**	cotton Fleece pillowcase satin polyurethane medical gauze-absorbent cotton polyester nylon cellulose tissue	Face fit cut is made. Coffee layer is added to mask by embedding	[12,27,40]
II	**N95 MASK**	spun-bond polypropylene cellulose / polyester melt-blown filter material band of aluminium citric acid copper zinc	Spun-bond Melt-blown Reinforced with a hydrophilic plastic film Filled with metal ions	[4,27]
III	**Surgical mask**	Polypropylene polystyrene, polycarbonate, polyethylene, or polyester	Spun bond extruding the melted plastic melt blown technology cooling and binding.	[12,41]
IV	**BIODEGRADABLE MASKS:**			[19]

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	1) **Bamboo fibre filter mask(CHINA)** 2) **PLA (Poly lactic acid) biodegradable mask (CHINA)**	PBS non-woven fibre bamboo fiber filter layer Lactic acid non-woven fabrics soft PLA non-woven fabrics PLA melt blown filter non-woven fabrics	Inner layer: PBS non-woven fabric. Filter: bamboo layer Ear strap: PBS non-woven fabric. PLA melt blown filter. Electrostatic Treatment Seamless laminating	[20]

VI. MEDICAL WASTE: A MAJOR THREAT TO MARINE ENVIRONMENT

Needles, human remains, body fluids, industrial wastes, pharmaceutical waste and medical equipment are among the hazardous and non-hazardous medical waste produced in health facilities, primary care facilities, research facilities, morgues, post-mortem centres, blood banks, nursing homes, and other medical facilities. [27]
Pathogen contamination may linger if these materials are not processed or treated properly, making them potentially hazardous waste. Many governments throughout the world are still grappling with how to deal with the environmental threat posed by plastic garbage. Toxic medical waste, which is largely formed due to plastics used in medical waste, has recently emerged as a major threat to ecosystems.[9] When dealing with medical waste, segregation, storage, transportation, disinfection, and final disposal are all required steps to perform. [2]
These medical wastes are usually dumped into the oceans. Contamination in the oceans, has a detrimental effect on the aquatic ecosystem. These contaminants (mostly micro-plastics) cause severe damage to sea fauna and flora, as well as human as these micro-plastics enter the food web. The marine contaminants drastically alter the physical, chemical, and biological properties of coastal and ocean zones, endangering marine diversity. [27]

A. Reduction in waste recycling:

Recycling is an increasingly popular and effective method of reducing pollution, preserving energy, and conserving natural resources**.** [6]
Most countries have halted their recycling waste management activities because they pose a risk to personnel in recycling centres who may become infected because these domestic or medical wastes may include trace amounts of infectants. [4]Hence, biodegradable masks is a wise alternative to help tackle the issue of reduction in waste recycling.

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Table 3: IMPACTS OF BIODEGRADABLE MASKS

SL. No.	Type of impact	Impact	References
I	Environmental impact	•Reduction in waste generation •Reduction in micro-plastic pollution •Reduction in marine environment pollution •Reduced entry of micro-plastic into food web •Reduction in soil pollution •Reduced fossil fuels consumption	[32,11]
II	Health impact	•Helps contain aerosols from transmission, hence preventing diseases	[39]
III	Social impact	• Elimination of adverse impact on personnel in waste management plants.	[16,39]

VII. TESTING METHODS

American Society of Testing and Materials (ASTM) F2100 standard specifies the requirements to be met by materials used to make face masks [1].
Among many performance criteria, mainly masks are tested for particulate filtration efficiency, (PFE), bacterial filtration efficiency (BFE), fluid resistance, differential pressure, and flammability. [27]

A. Particle Filtration Efficiency:

A particle filtration efficiency (PFE) test determines the filtration efficiency of filter media and other filtration devices. Particle filtration efficiency is done for single-use face masks and for surgical masks. Unlike single-use masks, surgical masks have a requirement where PFE should not be less than 30% under specific conditions.
Observing Dan Wang *et al., (2020)* results, it was found that most of the regenerated surgical masks had a filtration efficiency of an average of 92.3% which is much greater than 30%. For KN95-grade masks, the PFE should not be less than 95% under specific conditions, according to the Chinese national standard GB 2626–2019. [30]

B. Bacterial Filtration Efficiency (BFE):

Bacterial Filtration Efficiency is done to evaluate the performance of the mask in terms of its ability to filter bacteria when exposed to an aerosol of Staphylococcus aureus at an average particle size of 3mm as recommended by the ASTM F2101 standard. [13, 29] This test method is used to measure the BFE of medical face mask materials, in the ratio of upstream bacterial challenge to downstream residual concentration to determine filtration efficacy of face mask materials. [13]
Like PFE, BFE is also required to meet a minimum of 95%. Lin *et al., (2017)* suggest that care must be taken that some manufacturers refer to Greene and Vesley method and not ASTM specifications. [24] The difference is that, this method measures the efficacy of the mask from preventing bacteria passing through when worn on a user's face. Viscusi *et al. (2007),* suggest that his method is not comparable with ASTM F2101 and is not recommended by ASTM for comparison. [24, 25]

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C. Viral Filtration Efficiency (VFE):

Amongst the many, Viral Filtration Efficiency (VFE) is another parameter used to evaluate the performance of the mask by manufacturers. [14] However, ASTM has not approved VFE as a standard test method yet and hence it is not mandatory for mask assessment. [22]

D. Flammability:

Most mask are composed of natural and synthetic fibres that are highly flammable. Usage of masks is commonly seen in hospitals and other healthcare centres where plenty of sources of ignition can be found. Collectively, these can pose as a potential risk and increase the speed of flame spreading. [17]
Hence, to assess and overcome this issue, flammability is evaluated with respect to the 16 CFR part 1610 standard. The test is performed on 5-10 samples. [22]

VIII. INNOVATION IN THE PRODUCTION OF BIODEGRADABLE MASKS

The increase in transmission of infectious diseases in the recent past has posed as a great threat to public health. Modes of transmission of the diseases may differ, but the respiratory droplet or airborne route has the greatest potential to disrupt social normalcy. Due to sudden spike in Covid -19 infections lately, there has been a large demand for face masks which has led to a gap between demand and supply of masks. Various types of masks give different levels of protection to the users. [3]
Research has been accelerated towards improving the quality and performance of face masks by introducing super hydrophobicity and antimicrobial properties. There are different types of face masks and respirators offering different levels of protection to users. Many innovative methods have been utilized by using different biodegradable materials.

A. AirX Coffee Mask with Dual Antimicrobial Technology

A Vietnamese made coffee mask is assembled from a coffee yarn that is easily able to fit on a face of a user using PowerKnit technology. FlexKnit makes it easier to fit the mask over the nose. The mask can be washed and reused. It is made up of a replaceable bio-filter which combines silver nanoparticles along with antibacterial and germs. It is certified by QUATEST3. [46]

B. Gluten based Bio-mask

Gluten is a biopolymer which can be electro spun into nanofiber membrane and carbonised at 700 °C which can form a network structure. Lanosol, which is anti-microbe is added to this thin film of gluten which is bonded together using a carbonised mat and moulded into the shape of a mask. [8]

IX. COMPANIES INVOLVED IN BIODEGRADABLE MASK PRODCUTION

The usage of masks has become obligatory due to the COVID-19 pandemic leading to generation of enormous quantities of micro-plastic waste accumulation. World Health Organisation (WHO) release guidelines to help countries reduce the spread of the virus by wearing masks, maintaining respiratory hygiene, social distancing. Primarily, face masks are made of petroleum-based non-renewable polymers that are non-biodegradable. Hence, a few national and international companies have taken the initiative to produce 000biodegradable masks. [38, 39]

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TABLE 5: National and international companies involved in the production of biodegradable masks:

National companies			International companies		References
SL. No.	**Name of the company**	**Materials used**	**Name of the company**	**Materials used**	[40, 41, 42, 43]
I	Paper Seed Co	Hemp	Christy Dawn	Organic cotton	
II	Kalpavriksha textiles	Bamboo Fibers	Helmstedt	Dead stock fibers	
III	Esprin Nanotech	Nanofibers	Baserange	Starch corn	
IV	Defence of Advanced Technology	Cotton, Azadirachta indicia(Neem), Curcuma longa (Turmeric), Ocimum tenuiflorum(Holy Basil)	Hack with Design House	Bamboo fibers	

TABLE 6: Patents for biodegradable masks

SL. No.	Title	Patent number	Inventor	Published	Reference
I	**Biodegradable environment-friendly mask**	CN104814542A	Zhen Zhichao, Ji Junhui, Sun Xiaoxiao, Wang Gexia, Yang Bing, Xu Ying, Wang Pingli, Xiaowei, Ren Zhonglai, Lu Bo, Shen Bo, Zhang Jiwen,	2018-08-05	[25]
II	**A kind of biodegradable mask body structure**	CN205695852U	Wang Zhumei	2016-11-23	[26]

X. CONCLUSION

People have utilized masks for a variety of purposes since the dawn of time. An effort must be made to prevent environmental contamination caused by microplastics found in masks that disintegrate during mask degradation and end up in the environment (soil or water). In the event of a pandemic, facemasks are now mandatory. As a result, the amount of microplastics in the oceans and soils has increased dramatically. In the maritime ecosystem, there are around 14 million tonnes of microplastic. Waste management, which includes reducing plastic usage, recycling, and reuse of plastic, has been highlighted as a major problem in many nations due to its contribution to environmental degradation. As a result, the focus has shifted to biodegradable reusable masks that can be both biologically decomposed and reused over time. The materials utilised to construct these biodegradable masks must be entirely degradable so that no microplastic pollution is created.

Biodegradable masks are clearly a more environmentally friendly choice, as evidenced by this paper. It's critical that these biodegradable masks perform as well as single-use masks (embedded with plastic). The materials that can be used to produce these biodegradable masks were chosen after a thorough examination of their qualities. The various materials utilised in the creation of various masks, as well as their mythology, are also examined. The environmental, physiological, and social consequences of microplastic contamination are discussed, giving biodegradable masks an advantage. The decontamination techniques are briefly covered in this study because reusability is one of the most essential properties for reducing waste output. Testing methods are utilised to see if the masks have the necessary characteristics to make the cut, as well as procedures for analysing the masks' performance. The review then moved on to analyse the new advancements in the development of materials with superior filtration and antimicrobial properties. To conclude, information stated in this paper direct towards the usage of biodegradable masks as a sustainable choice for the environment as well as the human endurance.

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