# Medical Textiles from Natural Resources

Edited by Md. Ibrahim H. Mondal

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# Medical Textiles from Natural Resources

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# Dedication

To Textile and Healthcare Professionals for their contribution to human well-being

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# Environmental impact, health hazards and waste management of medical textile products

**26**

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## Chapter outline



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## 26.1 Development of medical textile and its waste: industrial versus environmental viewpoints

Medical textile is generally a material of textile-based equipment used to protect the users from any body fluids (e.g., blood, saliva, urines and sweats). In medical facilities, body fluids can be a medium for transmitting infectious diseases through direct or indirect contact (Galante et al., 2020). Hazmat suits, coveralls, scrubs, scrub hats, face masks, face shields, medical gowns, gloves and foot covers are classified into one of the medical textile types called personal protective equipment (PPE) (Karim et al., 2020). Moreover, sutures, wound dressings and bandages, as well as beddings, mattress covers, towels, wash clothes and wipes in health facilities are also categorized as medical textiles (Morris and Murray, 2020). The importance of health to global communities causes the high demand for PPE and other health care necessities, particularly during the emergence of (unexpected) outbreaks such as the COVID-19 outbreak at the end of 2019, which is still ongoing in 2022. During the COVID-19 outbreak, the recommendation to wear a face mask on a daily basis, especially in public areas, has been issued by government officials such as the World Health Organization (WHO), Centers for Disease Control and Prevention (CDC) of the US, National Health Service (NHS) of the UK and Health and Safety Executive (HSE) of the UK. It was reported that single-use or disposable PPE has a broader market than reusable ones (Rowan and Laffey, 2021), with only 3% of the face mask global production intended for reuse, as the remaining 97% are disposable face masks (Ammendolia et al., 2021).

The medical textile demand has currently exceeded the global production capacity and its supply chain (Derraik et al., 2020). It is also predicted that the production of medical textile continues to be encouraged to meet its needs. The increasing demand for the production of medical textiles leads to an increase in their waste generation. Generally, most medical textile wastes come from medical facilities, such as hospitals and clinics, but they are also commonly found in household wastes, for example, discarded masks, gloves and wipes (Ammendolia et al., 2021). With the higher disposal rate of medical textiles compared to their reuse/recycle rate, this puts an excessive burden on waste management systems and infrastructures, and consequently, this causes a large amount of medical textile wastes improperly handled.

Due to the presence of pathogens, toxins and many other (potentially hazardous) chemicals, medical textile wastes are classified as an infectious and hazardous waste that can potentially infect humans and pollute the environment (NHS, 2020). Pathogens are harmful microorganisms that can cause various diseases through infection in the human body, while toxins are toxic substances commonly found in the form of small molecules or proteins. Toxins are classified as dangerous components due to their interacting abilities with enzymes or cellular receptors in the human body (Padmanabhan and Barik, 2019). Contact with the medical textile waste may lead to the entry of pathogens and toxins into the human body via ingestion, inhalation, eyes, dermal absorption and contact with mucous membranes (Karim et al., 2020; Padmanabhan and Barik, 2019). Bacteria or viral infections may cause the initial infection of various pandemics (e.g., COVID-19, HIV/AIDS and Ebola) through food or animals, but further transmission mostly occurs through the exposure to body fluids of the infected individuals. As medical textile wastes contain many types of body fluids, their waste management and processing become an important issue that requires special attention.

Most medical textiles, particularly disposable ones, are generally designed from nonwoven fabrics, engineered from synthetic polymers, and are very suitable for disposable PPE due to their durability, strength and ability to relieve disease transmission among people (De-la-Torre et al., 2021). This type of medical textile poses a big dilemma between the health care side and the environmental side. The disposable medical textiles provide more effective protection and reduce the rate of disease transmission. However, their high disposal rate provokes many adverse impacts on the environment and public health. The polymers constructing the textiles are the materials that are difficult to be decomposed; they only fragment themselves into microplastics. The disposal of these medical textile wastes promotes plastic pollution in the environments (Ammendolia et al., 2021), threatening the land and marine ecosystems, food chains, floras, faunas and human life (De-la-Torre et al., 2020).

During the current pandemic, medical textile wastes have significantly increased their presence in the environment. A study revealed that there were 1.56 billion face masks discarded into the ocean during 2020 (De-la-Torre et al., 2021). Moreover, it is estimated that there are 129 billion face masks and 65 billion gloves per month consumed by the world population during the pandemic, which may overload the infrastructures and further contaminate the entire global environment if the wastes are mismanaged (Prata et al., 2020). The careless disposal of medical textiles poses many direct or indirect risks to the environment, and certainly brings harmful impacts on human health (Padmanabhan and Barik, 2019). In landfills, the pathogens and toxins can be transferred from the leachate produced into the soil, further polluting the groundwaters. Meanwhile, the presence of these pollutants may endanger marine life.

The emergence of new diseases requires the development of medical textiles with enhanced protection capabilities and a lower amount of wastes. The resulted wastes must, as well, have lower health and environmental risks. Recent studies have developed more advanced materials for various medical textiles needed in health facilities. Many techniques are employed to modify medical textiles, such as surface coating, loading and implantation (Akpek, 2021; Bengalli et al., 2021; Fouda et al., 2018). Silver, copper, titanium and zinc, in the form of metal or metal oxide and also synthetic polymers, are commonly used to develop the properties of medical textiles, as shown in Table 26.1.

Several properties, that is, antimicrobial, antifouling, UV protection, body fluids repellent, water-resistant and washable/reusable, are desirable for medical textiles to offer more protection to the patients, health care workers and other individuals under health threats (Ye et al., 2020). Silver nanoparticles and graphene oxide are known to have antiviral properties (Kumar et al., 2020); therefore, these components can be used to upgrade the medical textile for various medical textiles. Moreover, it has been investigated that both silver and graphene oxide nanoparticles are able to destroy SARS-CoV-2, the main etiological agent of COVID-19. Quaternary ammonium salts are

**Table 26.1** The development of medical textiles.

| Innovation | Products | Abilities | References |
|---|---|---|---|
| Superhaemophobic and antivirofouling coated medical textile | Polytetrafluoroethylene nanoparticles coated medical textile | • blood, protein and virus repellent<br>• wash-stable medical textile | Galante et al. (2020) |
| Superhydrophobic and antibacterial coated medical textile | F/Q-MSNs[a] coated medical textile | • water-resistant<br>• acid- and alkaline-resistant<br>• bacterial shielding and killing function<br>• breathable and deformable textile | Ye et al. (2020) |
| Antibacterial and ultraviolet (UV) protective medical textile | ZnO loaded medical textile | • high antibacterial activities<br>• UV protection | Fouda et al. (2018) |
| Antimicrobial medical textile | CuO and ZnO coated medical textile | • excellent antibacterial, antiviral and antifungal activities<br>• bacterial and viral killing function | Bengalli et al. (2021) |
| Conductive and UV protective medical textile | Polyaniline-graphene oxide coated medical textile | • excellent antimicrobial activities<br>• high electrical conductivity for sensors<br>• UV protection<br>• washable and reusable | Tang et al. (2015) |
| Antimicrobial medical textile | Ag-graphene oxide coated medical textile | • excellent antimicrobial activities<br>• washable and reusable | Noor et al. (2019) |
| Antibacterial medical textile | Ag and $TiO_2$ implanted medical textile | • excellent antibacterial activities<br>• UV protection<br>• washable | Akpek (2021) |
| Release-killing medical textile | Polyelectrolyte multilayers coated medical textile | • excellent contact-killing properties<br>• excellent release-killing properties | Junthip et al. (2020) |

[a]F/Q-MSNs = fluorinated-/quaternary ammonium-functionalized mesoporous silica nanoparticles.

also reported to possess an excellent antibacterial property, which can be used to coat the medical textiles and protect the users from the bacteria transmission (Ye et al., 2020). These innovations are very beneficial for the development of medical textiles that possess excellent protection. The implementation of the innovations has to consider various aspects, namely production steps, costs and the environmental and health impact of the wastes.

From the industrial viewpoint, the addition of the loading or coating materials directly affects the production costs. Additional processes will be required to realize these modifications. The stakeholders in the medical textile industries will have to consider these issues carefully, as supplementary materials, especially with the utilization of metal or metal oxide nanoparticles, and extra processes lead to an increase in the selling price of the medical textile products. Although the medical textile demand during the current pandemic is exceptionally high, medical textiles with affordable price must be provided and maintained because it speaks of human health and humanity.

Meanwhile, from the environmental viewpoints, several modifications of medical textile, by loading or coating with additional components, may directly imply to the extra burden in the medical textile waste management. Many metals and metal oxides are easily detached from the medical textiles via the leaching process (Noor et al., 2019). This may occur when the waste of the washable textiles is in contact with the water or solvent in the environment. Another issue is the presence of antimicrobial agents, which can increase the resistance of medical textile from the external factors, leading to a condition where the existence of its waste in the environment is long and difficult to handle (Noor et al., 2019). The impact of medical textile waste on public health may also occur directly via dermal contact with the waste and indirectly via environmental pollution, which adversely affects human health. A study stated that the additional components used to modify the medical textiles could damage skin tissue through direct exposure (Bengalli et al., 2021). Therefore, the advancement of medical textiles has to consider several important aspects, ranging from industrial and environmental to human health aspects.

This chapter aims to discuss the medical textile waste management, the impacts of the management options and the regulatory frameworks. A wide discussion is emphasized from the environmental and human health viewpoints. This chapter is also intended to provide broad insight into the medical textile waste management and how the management practice will influence the development of medical textiles.

## 26.2 Current situation and emerging issues of medical textile waste management

The textile industries have expanded their products in several sectors, including medical and health care applications. Medical textiles, also known as health care textiles, are primarily used for first aid, clinical and hygienic purposes. Based on their fibre sources and applications, medical textiles are divided into five categories as follows

(Azam Ali and Shavandi, 2016): (1) implantable material, (2) nonimplantable material, (3) health care/hygiene, (4) extracorporeal devices and (5) intelligent medical and health care textiles.

Implantable material helps tissue healing and repair processes, such as wound closure, cardiovascular grafts, artificial tendons, ligament and cartilage. Meanwhile, nonimplantable material is mainly used for external applications to protect against infection, for example, protective dressing, bandage and adhesive tapes. Health care/hygiene products can be found in our daily life, like masks and surgical gowns. Extracorporeal devices are used for mechanical equipment for purification, filtration and circulation of blood. These devices are designed to assist human life, especially in artificial respiration. Artificial organs are mainly made from cellulose, polyester, polypropylene fibres or silicon membranes, which is also a part of medical textiles. Intelligent medical devices will be the future of the medical industries that can inspect human well-being using embedded chemical sensor-based textiles through simultaneous body fluid or odour interactions. Among the aforementioned categories, three of them (i.e., nonimplantable material, health care/hygiene products and intelligent medical devices) contribute to the medical waste (WHO, 2018); most of them are classified into hazardous waste, specifically infectious waste (e.g., contaminated bandages and health care products).

In this chapter, the discussion of health care waste will be limited only to medical textile waste. The health care waste generated from each country is different, depending on their economic condition. Developing and emerging countries usually have a lower rate of waste production than developed countries. However, there is a steady increase in health care waste production globally, even in middle and low-income countries, due to improved health care services and increased system usage (Minoglou et al., 2017). Among the health care products, the most general product found in our daily life is the mask, especially since the outbreak of COVID-19. The demand for the mask as a health care/hygiene product increases due to government instruction to wear masks in daily life to prevent the transmission of the virus via droplets. The COVID-19 pandemic has completely changed our routines; activities are limited and affected countries' economic growth globally. The amount of PPE produced increased significantly; 40% more disposable PPE was requested by WHO. Wuhan, as the centre of the COVID-19 outbreak, generated six times more medical waste (240 tonnes per day) at the peak of the pandemic than the average daily use of PPE (45 tonnes) (Adyel, 2020). Medical textile waste management needs to be taken seriously to minimize the effect on human life and sustain the environment.

### 26.2.1 Environmental and health risk of medical textile waste and its improper disposal

The ease of plastic usage in human life has led to massive wastes, especially in the medical textile industries. It is agreeable that disposable medical textiles are cheap and can reduce the risk of pathogens infections; however, the increasing quantity of their usage is problematic. The demand for synthetic polypropylene in industrial fibre is the second most significant demand in Europe in 2012 (Galloway, 2015). As one of the precautionary actions to lower the transmission rate of COVID-19, many types of medical textiles, including face masks, gloves, medical gowns and other PPEs are in a high-reaching demand (WHO, 2020). PPE mainly consists of synthetic textiles, which has various compounds such as polypropylene, polyesters, polyethylene and polyvinyl chloride. All of these materials will degrade in the waste stream as microplastics, a significant part of anthropogenic marine debris, with smaller particles size (less than 5 mm) (Galgani et al., 2015). Microplastics' impact causes aggravating environmental contamination of wildlife; 557 species among all wildlife groups have been affected by either entanglement or ingestion of plastic debris, especially marine fauna (Kühn et al., 2015). The persistence of plastics waste in the environment ends up creating a threat cycle in the ecosystem. The distribution coefficient of microplastic as persistence organic pollutants ranges between $10^{-4}$ and $10^{-6}$; this relates to low mass fractions of microplastics to transport a disproportionately high concentration of microplastic ingested to small organisms such as zooplankton, which eventually involves in the entire food chain (Andrady, 2015), as shown in Fig. 26.1. Notably, this also indirectly influences human health; in consequence of contaminated fish uptake in human causes, there are several damages due to the cumulative effect. Apart from that, microplastics can also enter the human body through inhalation and skin contact. Overall, microplastics lead to the nervous system's problematic condition, respiratory, skin, kidney, placental barrier, digestive and excretory organs (Campanale et al., 2020).

The standard practice of waste management performed in a hospital is either by dumping or incineration, but the implementation is different for each country. Only 58% of facilities from 24 countries have safe disposal for their health care wastes in

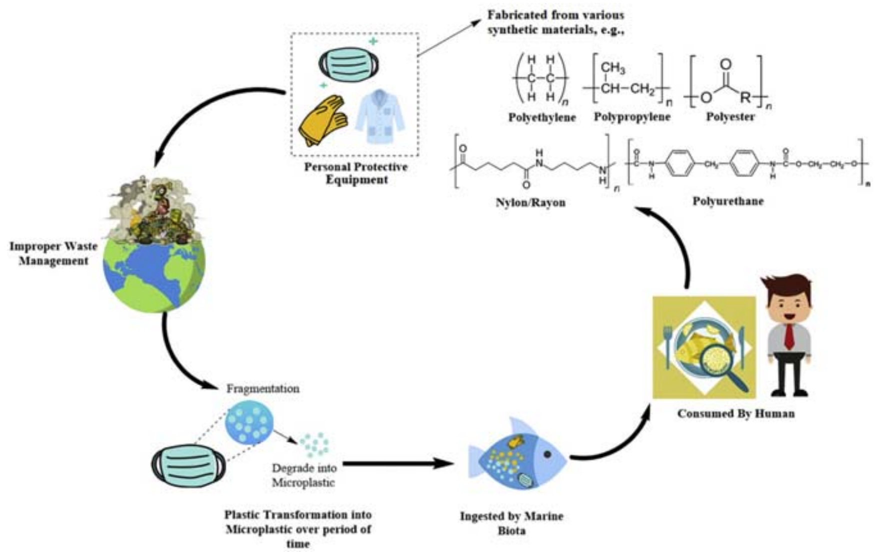


**Figure 26.1** Domino effect of medical textile waste mismanagement.

2015 (WHO, 2018). Most of the developing countries in Asia rely on open dumping, landfills and open burning systems. Open dumping and landfills are low-cost options for emerging countries, but they pose a high health risk due to uncontrolled and inadequate disposal. Dumping exhibits many disadvantages, particularly for infectious wastes, as it leads to water pollution, air pollution from anaerobic decomposition and emission of carcinogen or teratogen compounds (Chua et al., 2020; Ferronato and Torretta, 2019). Studies show that the area with exposure to landfill sites is more prone to a low congenital disability and reproductive disorders (Rushton, 2003).

Open burning is also considered as a way to reduce the amount of medical waste and its infectious effects; however, it causes detrimental outcomes in the atmosphere. The open burning results in a significant amount of contaminants such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) (Ferronato and Torretta, 2019). Not limited to those components, open burning contributes to greenhouse gases (GHG), which is a relentless issue worldwide. This method also produces small-size particulate matter (PM) in the category of $PM_1$ as the majority output, whose particle size is less than 1 μm. It is considered to be the most harmful PM since it can go into the most profound site of our lung, enter the bloodstream and spread to organs, thus make it contribute to several diseases such as heart attacks, lung cancer, dementia, emphysema, oedema and even premature death (Camfil, 2018). Incineration also produces toxic dioxin gas and mercury emissions from its disposal (Kaiser et al., 2001). Medical-waste incineration needs to have a specific furnace design, gas-temperature reduction program and air-pollution control device. These point toward user choice to adopt the best devices to create a suitable incinerator for handling medical waste (National Research Council (US) Committee on Health Effects of Waste Incineration, 2000).

### 26.2.2 Environmental actions to reduce medical textile

Wearing a face mask becomes a compulsory habit of protecting ourselves from COVID-19. However, the massive amount of medical textile waste generated during the pandemic demands the attention of the international and local government agencies. This waste should be considered infectious and disposed of properly during the pandemic, including many types of PPE (public face mask, gloves and others). The role of citizens in handling waste is necessary since every community is responsible for its waste. Taiwan, one of the best countries in handling pandemic, has a strict regulation to sustain their environment. Taiwan's Ministry of Health and Welfare and Environmental Protection Administration even educate the public to properly dispose of face mask via press conferences, official websites and social media platforms (Yeh, 2020). During the outbreak, many countries have insufficient quantities of surgical three-ply masks for the public. Reusable masks made of fabric or cloth become an alternative for citizens and progressed into a fashion and modern necessity in daily life during the pandemic (Shruti et al., 2020). As an international benchmark, the WHO set specific criteria for fabric masks, where they should have three-layer arranged of (1) innermost layer of hydrophilic material, (2) hydrophobic middle layer and (3) outermost layer made of hydrophobic material (WHO, 2020). Nonmedical masks are recommended for people who are not at risk of severe complications from COVID-19 while maintaining physical distancing. The utilization of reusable masks can help to suppress the amount of medical waste during the pandemic.

The practice of reducing, reuse and recycling must be complied with government regulations to work smoothly. For example, the government of Managua developed a project of sustainable waste management in the neighbourhood of Acahualinca in 2009. This project aimed to implement the technological improvement of municipal solid waste treatment and to improve the life quality of the local population. Spanish Agency handles this project on behalf of the Managua's municipal government and International Cooperation for Development (AECID), which also collaborates with a public Spanish engineering company called Tragsa (Hartmann, 2018). Nongovernment organizations (NGOs), private companies and international fund agencies also support sustainable waste management by promoting 4Rs (reduce, reuse, recycle and recover; Ferronato and Torretta, 2019). NGOs' role can also be widened to the health care waste management in inaccessible areas, certainly with the appropriate proposals (Khan et al., 2019).

Several possible methods to reuse PPE can be applied on a large scale, such as vapour infusion of hydrogen peroxide, ultraviolet or gamma-irradiation, ethylene oxide gasification and application spray-on disinfectant (Rowan and Laffey, 2021; Singh et al., 2020). In 2016, a project of decontamination of N95 filtering facepiece respirator (FFR) was conducted by Battelle Memorial Institute. This project is a part of extramural medical countermeasures funded by the United States Food and Drug Administrations (US FDA). Battelle shows satisfactory decontamination results of N95 FFR using hydrogen peroxide vapour up to 50 cycles; however, degradation occurred in the elastic straps after 30 cycles (Battelle, 2016). During the public health emergency in March 2020, the US FDA issued an Emergency Use Authorization (EUA) for Battelle to decontaminate compatible N95 FFR, to be reused by medical professionals on the front lines of COVID-19 (US FDA, 2020).

The urge to have better management of waste is related to the strict regulation of the government. The hospital and household waste management trajectory generally involves several sectors, but most importantly, formulating the waste management guidelines and scheming the process need to have a synchronous collaboration among the related aspects (Sangkham, 2020). Economic viewpoint shows that reusable medical textiles have better cost efficiency than disposable ones. Using reusable materials, the hospital can save $100,000 more than using disposable products (Sun, 2011). Reusable surgical gowns made of polyester or cotton-polyester can be used after laundering and disinfection with bleaching agents; it can withstand more than 50 cycles (Cao and Cloud, 2011; Sun, 2011). This practice has already been implemented by Ronald Reagan UCLA Medical Center and Carilion Clinic in Roanoke, Virginia. Reusable gowns demonstrated less energy and water consumption, also the production of GHG emissions and solid waste (Baker et al., 2020). The reusable medical textiles is currently more attractive in the European Union countries than other countries since their policies give more attention to environmental protection (Sun, 2011). Hence, it is critical for governments to implement policies to improve the life-cycle of plastics, develop alternative materials and educate the public about 4R (Zhang et al., 2021).

## 26.3 Impact assessment of medical textile waste management options

As medical textile waste is considered hazardous waste due to its serious health and environmental risks, safely managing the waste is crucial to successfully containing the pollutants. Mismanagement could provoke increasing environmental pollution, as this type of waste usually carries a large number of viruses, germs, chemical and radioactive materials. In recent years, with the viral crises happening around the globe, there has been an increase in public awareness and social responsibilities about the performance evaluation as well as the improvement of the medical textile waste management system. All countries should incorporate the disaster risk into the regulatory framework of their medical textile waste management to enhance their readiness and resilience, specifically against the current pandemic. Currently, the available options to administer medical textile waste include landfill, incineration, composting and reusing, where every technique offers both benefits and risks to the environment and human health. In this subchapter, the environmental and health issues associated with all four solid waste management options will be critically assessed.

### 26.3.1 *Medical textile waste landfills: health and environmental impact*

With the huge waste masses, landfill is considered one of the significant solutions for waste disposal within the waste management system (Gopikumar et al., 2021; Maghmoumi et al., 2020; Mishra et al., 2020; Torkayesh et al., 2021). A landfill is an engineered land construction to dispose the solid or hazardous waste in an environmentally secure and protective manner. Frequently, both domestic or municipal and health care wastes, including medical textiles, are buried in the same area without any clear segregation (Heidari et al., 2019; Mardani et al., 2019). However, the current pandemic brings a great challenge in the disposal of medical textiles from the infected patients, which requires the government to establish a separate, secure and sustainable landfill construction, as improper disposal of such materials causes serious health and environmental issues. The selection of landfill site itself is a challenging task as it involves several factors, including the land use, geological-hydrogeological, operational, economic and social aspects (Gorsevski et al., 2012; Sumathi et al., 2008). Many epidemiologic shreds of evidence for the potential health effects of landfill sites are reported, provoking the authorities to properly determine and design the landfill site and its remediation to respond to the public concern in a satisfactory way (Fazzo et al., 2017; Njoku et al., 2019; Vrijheid, 2000).

During the landfill process, the waste degradation via biological, chemical and physical routes results in the production of leachate and gases. Due to this reason, the construction design of landfills has to include several elements to control the emission according to the environmental regulations, for example, the liner, final cover, leachate and gas management facilities (Fig. 26.2). The liner system usually consists of multiple layers of clay and geomembrane, with a leak detection system placed

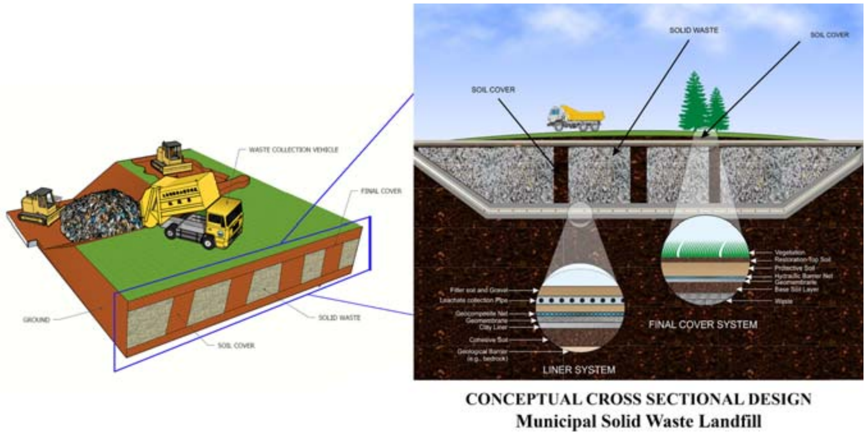


**Figure 26.2** Schematic diagram of a landfill design.

between every layer to observe any water leaks from the top liner. The leachate is continuously transferred through the drainage layer and perforated collection pipe to the on-site treatment facilities to reduce the contaminant present in the leachate before being discharged via deep well injection, or evaporation. Meanwhile, the final cap of a landfill, consisting of compacted soil, geomembrane, geocomposite drainage net, protective soil and vegetation, is placed to minimize rainwater infiltration and exfiltration gaseous contaminants. Similar with the leak detection in the liner system, the gas control system is placed in the final cap layer to monitor the resulting gas emissions from the landfills (Reinhart and McCreanor, 2000). Moreover, a series of extraction wells with a vacuum system have been installed to direct the collected gas to the gas treatment facilities.

However, regardless of how safe the landfill management is, its operation is still commonly associated with the contamination of water bodies by leachate, unpleasant odour, bioaerosol emissions and volatile organic compounds (VOCs) (De Feo et al., 2013; Garrod and Willis, 1998; Njoku et al., 2019). WHO reported how residing close to landfills negatively affects health (WHO, 2007). Moreover, many epidemiology studies revealed that residents living close to landfills site are closely associated with chronic health disorders, particularly on the respiratory and digestive systems and dermatological and neurological symptoms (Dongo et al., 2012; Fazzo et al., 2017). This is likely due to the resulting liquid and gas emissions caused by the complex chemical and microbiological reactions within the landfills, including dioxins, PAHs, heavy metals and other VOCs (Okeke and Armour, 2000; Palmiotto et al., 2014; Yu et al., 2010). A WHO report mentioned that exposure of individuals to a high level of dioxins, although in a short duration, results in skin disorders, for example, chloracne and dark spots, and an alteration in liver function. Additionally, a long exposure deteriorates the immune, endocrine and nervous systems, as well as the reproductive functions. Classified as a human carcinogen by the WHO International Agency for Research on Cancer (IARC), a risk of cancer may result from chronic exposure to dioxins. IARC, however, emphasizes that dioxins would not genetically affect human health and the cancer risk would be negligible when an exposure level is lower than the harmful degree (WHO, 2016).

Meanwhile, often observed in the leachate generated by sanitary landfills, PAHs are known as the most environmentally persistent and carcinogenic pollutants (Burchiel and Luster, 2001; US EPA, 2008). PAHs possess acute toxicity towards aquatic organisms via direct metabolism and photooxidation, and are more toxic in the presence of UV light. While PAHs are unlikely to pollute the soil and the living invertebrates, plants can absorb them through their roots and transfer these compounds to the other parts. Moreover, as PAHs can be bioaccumulated, their concentration in the living biota is predicted to be much higher than that found in the soil environment. Several studies reported that the uptake of PAHs by mammals and humans by inhalations, dermal contacts and ingestions causes adverse effects, for example, skin irritation, breathing problems, tumours, reproduction and growth abnormality, and immune system disorders (Beyer et al., 2010; Dong et al., 2012; Veltman et al., 2011).

Besides dioxins and PAHs, landfill leachate also consists of many forms of heavy metals, including chromium, lead, cadmium, mercury and several other metals. Exposure to heavy metals in the leachate increases the risk of the damaged nervous system, reduced lung function, ataxia, paralysis and cancer (Njoku et al., 2019). The United States Environmental Protection Agency (US EPA) stated that these metals belong to the priority metals that are of great public health significance, as they are all known as systemic toxicants and possess a high degree of toxicity, even at lower exposure levels. They have been found to interact with DNA and protein, causing damage and conformational alteration, leading to cell cycle modulation, carcinogenesis or apoptosis (Beyersmann and Hartwig, 2008; Cohen et al., 1996; Tchounwou et al., 2003; Wang and Shi, 2001). In addition, IARC classifies heavy metals as probable human and animal carcinogens due to their associated link between their exposure and cancer incidence in both humans and animals (IARC, 1990).

Meanwhile, continuous inhalation of VOCs causes nausea, vomiting and coordination loss due to neuro-disruption; and moreover, high concentration can be very lethal to human (Macklin et al., 2011; Njoku et al., 2019; Sharma et al., 2018; Shen et al., 2012). The gaseous VOCs, for example, nitrogen oxide, sulphur dioxide, hydrogen chloride and hydrogen fluoride, cause thoracic irritations and respiratory infections when inhaled continuously. It also increases human vulnerability to respiratory disorders. Moreover, these symptoms can trigger the asthma attack in the asthmatic patients (Kampa and Castanas, 2008; Macklin et al., 2011; WHO, 2003). From the environmental viewpoint, these acidic gases also react with the surrounding moisture to precipitate as acid rain, which is widely known for its adverse impact on the soils, water bodies, aquatic and land ecosystems, and corrosion of infrastructures (Magaino, 1997). In addition, sulphur dioxide is also reported to negatively affect the productivity and growth of the plants (Padhi et al., 2013).

In addition to the inorganic and organic materials, comprehensive studies have shown that pathogenic microorganisms can be associated with landfill leachates, especially when medical textiles are involved. These wastes are often described as biohazardous materials that have to be immediately disposed of and treated, due to the presence of infectious bacteria or viruses, and harmful substances that cause further health and environmental damages. Several studies reported that a number of pathogenic bacteria had been detected in the commercial general and medical landfills (Grisey et al., 2010; Mherzi et al., 2020; Yang et al., 2017). Bacteriological pollution such as faecal coliforms, *Streptococci* and also parasites of intestinal roundworms, for example, *Enterobius vermicularis*, *Ascaris lumbricoides*, *Trichuris* and *Hymenolepis nana* is found in the raw leachate, which pose a risk for the environmental safety and human health (Mherzi et al., 2020). However, a report mentioned that an increase in bacterial mortality had been observed along with the waste age and leaching time (Ware, 2004). A relatively high temperature during the aerobic stage of waste degradation also inhibits bacterial growth (Lu et al., 1985). Moreover, the low pH caused by the production of short carbon chain and $CO_2$ gas accelerates the bacterial inactivation (Engelbrecht et al., 1974). Therefore, many landfills operate at an elevated temperature to reduce the organic strength, the viral and bacterial activation rate, and reach the mature landfill faster (Reinhart and McCreanor, 2000).

With the aim to decrease the environmental and health risk in the landfill sites, the US EPA releases several design standards for the modern hazardous landfills, including (1) double liners and double final covers; (2) double leachate collection, removal systems and leak detection system; (3) drainage way; (4) ground water monitor system; (5) gas extraction wells and gas management facilities; (6) storm water run-on, run-off and wind dispersal controls; and (7) construction quality control programme to ensure the units are well selected and designed to minimize the release of hazardous waste into the surrounding environment (US EPA, 2020a). The modern landfills also require the leachate to be treated before discharge and the landfill gas to be connected to a central blower system and captured for power, steam or heat generation (Reinhart and McCreanor, 2000).

### 26.3.2 Incineration of medical textile waste and its risk assessment

As the annual generation amount of medical textile waste is projected to grow during the pandemic, incineration has become one of the most convenient methods to manage medical textile waste. The United States alone has almost 7000 existing medical-waste incinerators, with some are combined with autoclaving, microwaving, chemical disinfection via chlorination or hydrogen peroxide bleaching and other techniques. Medical textile waste is mainly considered as infectious (red) wastes due to its pathogenic nature. Studies stated that the infectious medical waste in the hospitals is commonly treated by on-site incineration, on-site steam sterilization and off-site treatment, with the distributional values of 60%, 20% and 20%, respectively (Hyland, 1993; Hyland et al., 1994). Currently, many medical-waste legislations from the developing and developed countries encourage the use of on-site incineration. According to the US EPA Office of Research and Development, the on-site incineration of medical waste has many advantages; it may (1) sterilize pathogenic waste, (2) reduce the mass and volume of the waste up to 95%, (3) provide heat recovery (which complies to the

Energy Policy Act of 1992, and the Resource Conservation and Recovery Act) and (4) be used simultaneously for hazardous chemical and radioactive waste disposal (US EPA, 1992).

While incineration of wastes, including medical textile waste, has been widely practiced, inadequate incineration results in the release of toxic air pollutants and excess ash residue. These toxic residues that are generally discharged to landfills have the potential to leach into groundwater. A report by US EPA has also identified medical waste, including its textile waste, as one of the biggest mercury emission contributors, counting for almost 10% of the total mercury released to the environment from human activities (US EPA, 1997). Therefore, incinerating mercury-containing waste will promote the direct entry of airborne mercury into the global distribution cycle in the environment, polluting the aquatic biota and wildlife in general. It is also widely known that mercury is strongly neurotoxic and harmful to the digestive and immune systems, lungs and kidneys. Exposure to high levels of mercury may cause a fatality, as it can cross the blood and brain barriers, as well as placenta (Gautam et al., 2010). The incineration of medical waste is also an important source of other heavy metals, such as cadmium and lead (Thornton et al., 1996).

Medical wastes incinerations are also the major source of dioxins in the environment (Gautam et al., 2010). The US EPA estimated that the total dioxin emission from the country's medical-waste incinerators reaches 5100 g (toxicity equivalent [TEQ] of polychlorinated dibenzo-p-dioxin/polychlorinated dibenzofuran [PCDD/PCDF] per year; US EPA, 1994). The incinerating process also releases additional quantities of dioxin in ash, slag and scrubber effluent (Thornton et al., 1996). Moreover, many medical-waste incineration units are operated in combination with further chlorination treatment, which is known to generate dioxins and furans. Both components are considered human carcinogens, and have been linked to many adverse health effects, for example, cancer, immune system disorders, diabetes, birth defects and disrupted sexual development (Emmanuel et al., 2001). The California Air Resources Board also reported that the PCDD/PCDF emissions from medical waste, including the medical textiles, incinerators increase the cancer risks from 1 to ~250 per million of persons in neighbouring communities (California Air Resources Board, 1990). With the air emission affecting the surrounding environment and local communities living hundreds or thousands of miles away, dioxins clearly raise the health and environmental issues and a challenge for the government institutions and professionals to manage the sources. An approach to avoid the dioxin production is by prohibiting the use of chlorinated plastic collection bags (Gautam et al., 2010; US EPA, 1994).

Additional hazards may also be posed by the release of PM and the incomplete combustion products, for example, carbon tetrachloride, vinyl chloride, polychlorinated biphenyls, chlorobenzenes, chloroform and chlorophenols that comes from the medical textile materials, including the retained chemical and biological waste on their surface. Both short and long PM exposures may lead to a variety of health effects. Short-term exposure to this pollutant causes acute bronchitis, aggravated asthma, lung function disorders and respiratory symptoms (i.e., irritation of the airways, coughing and breathing difficulty). Meanwhile, long exposures, for example, those communities living near the medical incinerator facilities, have been linked to chronic bronchitis, heart attacks and premature death of people with lung, heart or diabetic diseases. Some healthy individuals may also experience temporary symptoms, for example, mild eye, nose and throat irritations, phlegm and shortness of breath, due to the elevated levels of PM in the surrounding air (US EPA, 2020b). From the environmental viewpoint, PM can be carried by wind and settle on the ground or water surface. This may (1) increase the acidity and change the nutrient balance in the water bodies (lakes, streams, rivers and coastal waters), (2) decrease the soil nutrients, (3) destroy the agricultural crops, trees and sensitive forests, (4) leads to the diversity shift of the ecosystems and (5) contributes to the occurrence of the acid precipitation/rain (US EPA, 2020c). The chlorinated components as the incomplete combustion products may be the initial promotor for the formation of dioxins, which causes severe health and environmental issues.

Aside from the problems induced by chemical components in the medical textile waste, incineration of this type of waste, particularly ones with retained pathogenic microorganisms, can lead to other pathological problems. While incinerators are generally able to sterilize most microbial pathogens, some studies reported that this method is unable to inactivate the heat-resistant pathogenic bacteria; and those bacteria are released via the stack, bottom ash residue (Arciola et al., 2007; Blenkharn, 2005; Sawalem et al., 2009) and the quench (scrubbing) water. The US EPA mentioned that the survival pattern of pathogens in the solid, liquid and gas emissions from the incineration process indicates the inadequate design and operation of the incinerators (US EPA, 1971). The presence of these bacterial agents would certainly be harmful to the health and environment. Therefore, the medical textile waste classification, proper incinerator design and operation must be employed and strictly regulated by the government. The sterilization of all types of health care waste prior to its disposal is recommended to eliminate nosocomial infections and environmental pollution from clinical waste (Hossain et al., 2013). Another approach to minimize the formation and release of hazardous emissions from this process is installing the air-pollution control equipment (APCE), which can destroy the infectious and toxic components and effectively control the emissions to the atmosphere (Fig. 26.3). The most commonly

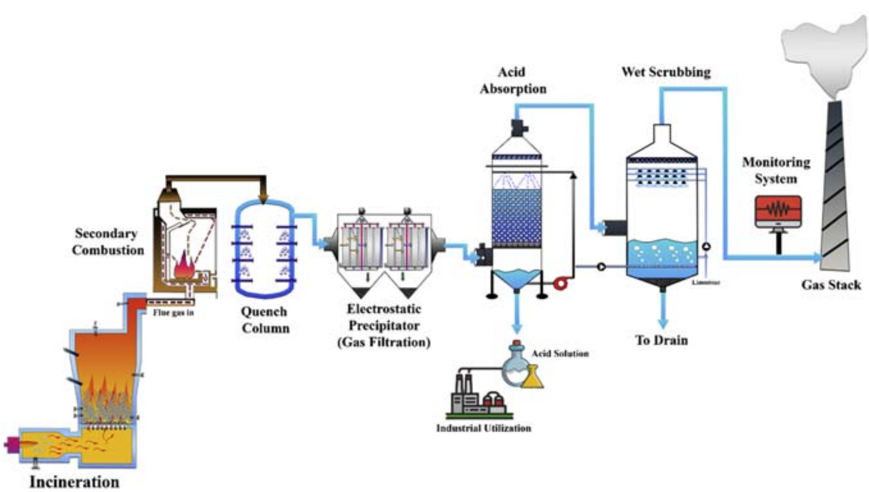


**Figure 26.3** The overview of an incineration system fully equipped with the APCE.

used APCE systems are fabric filters and wet scrubber systems. While fabric filters collect the PM, trace metals and organic solids, the wet scrubber system captures the gaseous pollutants and neutralizes acid and toxic gases produced during the combustion process (Lauber and Drum, 1990; US EPA, 1990). In several incinerator systems, a combination of dry-sorbent (e.g., carbon) injection (DSI) and spray dryer absorbers have been used to control the acidic gas emission, while electrostatic precipitators are installed to control the release of particulate matters. Studies show that the concentration of toxic components (e.g., dioxins and furans) emitted from the APCE-installed incinerator stack in the ground level have been found to be very low and pose an insignificant risk to human health and environment (Hasselriis et al., 1991; Hasselriis and Kasinathan, 1992; Konheim et al., 1993). The bottom ash residue is also generally tested below the harmful levels.

### 26.3.3 The composting process of medical textile waste and its emission

Composting is one of the safest methods for waste management, as both incineration and landfilling are considered more expensive and less eco-friendly because of their negative impact on the environment. A study also reviewed a significant reduction of microbial and chemical pollutants during the in-ground composting process; therefore, this composting process is able to protect the groundwater from becoming polluted (Ayilara et al., 2020). However, not all medical fabrics can be composted, particularly the ones manufactured from synthetic fibres. This method is also generally performed in the open air, resulting in several shortcomings, including pathogen detection, long duration of composting and odour production. Some other challenges from this composting technique are the release of carbon dioxide and hydrogen sulphide (caused by microbial activity via partial anaerobic route) into the atmosphere and the depletion of oxygen (Ayilara et al., 2020).

The detection of the pathogenic bacteria during the particular composting process of medical textile waste is majorly attributed to the nature of the medical textile itself. The life-cycle of a medical textile shows that its waste may be composed of pathogenic bacteria, viruses, hydrochloric acid, dioxins and furans, and toxic/heavy metals (Sun, 2011). Although studies show a declining trend of the numbers of pathogenic bacteria during composting (Dumontet et al., 2001; Jakobsen, 1995), both *Escherichia coli* (*E. coli*) and *Salmonella* spp. are observed to regrow in active compost during its mature thermophilic phase (at the elevated temperature of $>50°C$) (Bustamante et al., 2008; Elving et al., 2010; Grewal et al., 2007; Hess et al., 2004; Millner et al., 2014; Pourcher et al., 2005; Wichuk and McCartney, 2007). The reasoning for the survival of both bacteria is explained by the nonhomogenous heated areas of the compost piles (Elving et al., 2010) and also the incomplete inactivation associated with the process dryness (Soobhany et al., 2017). The presence of these pathogens poses potential health hazards, and their occurrence is of particular significance in the handling and storage of composts, as it will provide adverse effects to the surrounding communities and environment.

To ensure the pathogenic activity reduction, a modification of the composting technique can be realized by employing the vermicomposting using earthworms. Several studies reported that the vermicomposting process could effectively maintain the existence of pathogenic organisms under the safety levels (Hait and Tare, 2011a, 2011b; Soobhany et al., 2017; Yadav et al., 2011). Another study also elaborately described that the contact between the earthworms and the community of microbes decreases some bacterial pathogens indicators (Monroy et al., 2009). Moreover, a quicker and more complete pathogen removal has been achieved via vermicomposting using high densities of earthworms than thermophilic composting of the same materials (Eastman et al., 2001). This shows that vermicomposting can be considered a promising sanitation technique compared to the common composting processes. Moreover, a categorical separation of the infectious and noninfectious medical textile waste prior to the composting process should be performed to minimize the health and environmental risks due to the pathogenic microorganisms. As previously discussed in this chapter, the acidic gases, heavy metals and dioxins/furans retained on the medical textile surface may also bring a lot of harmful effects to human health and the environment. Although these components will be digested during the composting, but as this treatment requires an extended processing time, then there would be some components that will be released to the atmosphere (Jackson, 2020).

### *26.3.4 The health and environmental impacts of reusing the medical textile*

With the growing demand for medical textiles due to the current pandemic, many countries see an increasing trend of their waste amount and are currently looking for a sustainable practice to leave a smaller environmental footprint. As previously mentioned, the widely used waste management systems, for example, landfills and incinerations, generate adverse impacts on the health and environmental sectors. Therefore, many health care organizations recently encourage the use of reusable protective textiles (e.g., gowns, drapes, masks, underpads, dressings and others), which can be sterilized and laundered for reuse. The lifetime of reusable medical textiles is predicted to be more than 50 cycles, resulting in fewer resources (including raw material and energy), and at the same time, less waste generation (Cao and Cloud, 2011; Sun, 2011). Similar arguments were observed in many studies, where they highlighted the sustainability of reusable medical textile, noting that they are more cost-effective throughout their life-cycle, specifically in terms of cost, waste and carbon footprints (Baykasoğlu et al., 2009; Overcash, 2012; Vozzola et al., 2018). The emitted carbon dioxides are found to be 10 times lower with reusable textiles relative to the disposable products (Zimmer, 2009). The same study also found 20 times fewer carcinogenic compounds were released by the first as compared to the latter. With the biologically degradable final waste (if cotton and/or biodegradable polyester fibres, e.g., polylactic acid [PLA], is used as the major component), reusing the medical textiles will definitely produce fewer pollutants, compared to the other waste management systems (Sun, 2011).

However, the mentioned advantages do not fully cover the challenges faced by using these reusable textiles. While the surgical gowns, drapes and their accessories are known as the apparel intended to protect the patients and health care personnel, the used fabrics could be the ones that promote infection, as they contain retained pathological and infectious materials after use. Improper handling during the laundering and transfer of biological waste (i.e., fluids, tissue, blood) to the treatment system will induce bacterial spread and is potentially detrimental to public health and environmental safety. It was, moreover, reported that the laundering activity reduced the capability of the fabric to prevent the transmission of the bacteria (Leonas, 1998), indicating that the reusable medical textiles still require many improvements, particularly on their protective ability.

From the environmental viewpoint, reusable medical textiles in health care facilities also demand a large volume of water for laundering, and consequently, generates the same wastewater amount. Several chemicals, for example, sodium hypochlorite and hydrogen peroxide, are also used for disinfection and bleaching, adding toxic pollutants into the resulting wastewater. Although this wastewater can be fully treated and recycled to reduce the adverse effect on the environment, both laundry operation (which follows the CDC Guidelines; CDC, 2003) and its associated transport consume additional energy, which could negatively impact the environment as well.

### 26.3.5 Future perspectives of medical textile waste management

The future perspective for waste management of medical textiles will focus on waste minimization, material substitution, waste segregation and the improvement of current waste treatment technologies. Medical textile waste minimization can be achieved via source reduction and reusing practice. The measures to (1) change the clinical practices of the medical staffs to ones that use fewer materials and (2) shift the use of disposable protective textile to the reusable ones shall be promoted to the health care facilities and their staffs to implement a continuous act of waste minimization process. These actions are considered economically beneficial to the waste producers as both costs of purchased goods and waste treatment will be reduced. The environmental and health liabilities of the medical textile waste, which is usually regarded as the infectious and/or hazardous waste, are lower. However, along with the extensive use of reusable medical textiles, it is expected that the facilities require additional energy and chemicals for disinfection, sterilization and laundering purposes. As the use of chemical generally induce the formation and release of pollutants, the guidelines on best available techniques and provisional guidance on best environmental practices, known as the BAT/BEP guidelines, named several techniques, including steam sterilization, dry-heat sterilization and microwave treatment, as the alternative technologies to minimize the infection transmission to an acceptably low probability (UNEP, 2006).

Another approach to reduce the impact of the waste is by employing the environmentally preferable purchasing (EPP) policy. This policy describes the purchase of products and services that generate the least environmental impact and from suppliers implementing the environmental management system. A WHO report stated that the application of EPP helps the health care facilities to reduce their impact on the environment, decrease the expenditure of the waste disposal and its liabilities, and at the same time, contribute to create safer conditions for both patients and medical staffs (Chartier et al., 2014). This programme also encourages the replacement of high-risk products to the low-risk ones, for example, substituting the halogen-embedded medical textiles to the ones with the natural antibacterial or the other chemicals with low toxicity, which echoes with the material substitution scheme. A similar solution has been proposed via life-cycle thinking and green procurement, where the health care facilities are required to evaluate the health and environmental risks of a product or service during its life-cycle (including its waste management), and only purchase ones that can be safely recycled, reused and is low in toxicity (Kaiser et al., 2001).

As medical textiles are found in many forms, a proper segregation system is also mandatory for all health care facilities, and it shall be clearly set up in the waste management policy. Within the major categories, for example, nonhazardous, potentially infectious, highly infectious and hazardous, further segregation to reusables/recyclables, nonreusable/recyclables and biodegradable may be advantageous (Chartier et al., 2014). This practice is very important in the waste management system, specifically to determine a suitable process for each type of medical textile waste, predict the plausible risks that may occur, and plan the preemptive remedial action to a particular risk.

Besides the aforementioned plausible pathways, the improvement of the treatment technologies becomes one of the focuses for the prospects of waste management, specifically medical textile waste. The current technologies have been associated with emission of toxic pollutants that will incur health and environmental risks, as well as additional liability issues. To considerably reduce the pollution, the regulated incineration facilities, fully equipped with high efficiency APCE and appropriate ash disposal, can be one of the alternative options to replace the waste landfills and off-site nonincineration technologies. It is claimed that the newer waste incineration systems run in a cleanlier manner and result in fewer environmental problems (Tait et al., 2020); several upgraded features and proper maintenance to sustain the emission levels are required in these systems. A risk analysis correlating between the type of the waste, the incinerator design, siting location and the emission exposure pathways (ingestion, inhalation, dermal exposure) might also give valuable input to the management of waste. Based on the aforementioned discussions, these four acts (waste minimization, material substitution, waste segregation and the improvement of current treatment technologies) are expected to reduce the adverse impacts on public health and the environment, as well as to develop a better medical textile waste disposal.

## 26.4 Importance of the regulatory frameworks

The use of medical devices in health care practices inevitably leads to the generation of wastes that may be hazardous to health. Fig. 26.4 shows the proportion and type of wastes generated from the health care activities, wherein the hazardous wastes contributed to 15% of the total wastes (Hayleeyesus and Cherinete, 2016; WHO, 2018).

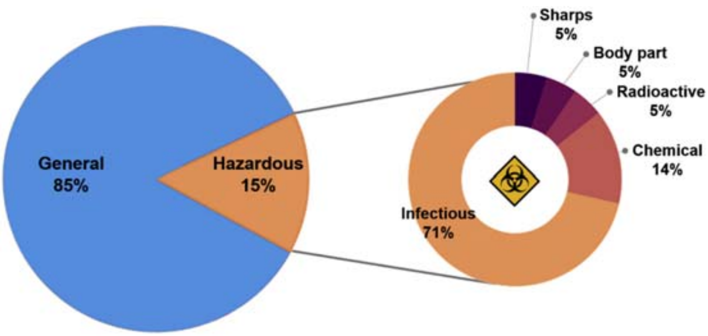


**Figure 26.4** The proportion of wastes generated from health care activities.

According to WHO, medical textile wastes are included in the category of hazardous waste. Furthermore, medical textile wastes are considered to be biohazards since they contain various infectious substances, such as contaminated fluids from laboratory work (e.g., waste from infected animals and autopsies), used-devices (e.g., swabs and bandages), pharmaceuticals and chemicals, and other bodily fluids (Chartier et al., 2014). Due to the high risk of biohazard, there must be adequate and appropriate handling methods for the medical textile wastes to reduce their impact on public health and the environment. Medical textile waste management guidelines and methods are not available explicitly for this waste alone but are covered by various regulations regarding hazardous and infectious wastes.

New knowledge and technology, as well as changes in people's lifestyles, have become a powerful impetus for research, manufacture, development and marketing of various types of medical textiles. While those are good at meeting people's needs, which are continually changing, they also drive a continuous-update to the national policy and legal frameworks (Rathinamoorthy and Rajendran, 2019; Yalcin-Enis et al., 2019). The high-dynamics in updating the regulatory frameworks can be a major issue for medical textile manufacturers and all related organizations. Unlike other regulations that apply to most health care practices, the medical-waste regulations are set at the state level rather than at the federal level. The waste regulations are often regulated by multiple agencies within a state, thus creating another layer of complexity to the regulation (Dumez, 2019). Despite the highly dynamics update of the policy and regulatory framework, the global and comprehensive guidance for the regulatory frameworks has been developed and available internationally. The guidance must be taken into consideration as the basis for developing national policy and legislation.

### 26.4.1 Available guidelines for developing regulatory frameworks

#### 26.4.1.1 International agreements and conventions

The handling of medical textile wastes requires multi-sectoral cooperation at all levels. This action is not only subjected to the medical textile wastes but also other medical-related wastes. The establishment of a national policy and legal framework is a must to ensure efficient waste management, create sustainable coordination between each sector, raise public awareness and finally achieve successful medical-waste management. Legislation and supporting bodies concerning waste management should be developed once the national policy has been prepared.

The regulated national policy might differ for each state by considering the regional differences and the region's socioeconomic conditions. Despite the contrast of each state's policy due to the several regional allowances, the international agreements and conventions (Table 26.2) relevant to medical-waste management must be considered when preparing the policy. The international agreements and conventions are usually followed by the development of coordination centres spread across different countries. The centres are responsible for delivering training and facilitating technology transfer regarding waste management to assist the implementation of the agreements and conventions.

#### *26.4.1.2 The guiding principles*

The guidance documents for aiding a state to establish the national policy related to medical-waste management are available internationally. The creation of the documents involves several world organizations, such as WHO, UN organizations and NGOs. The documents are not specific to the medical textile and medical-related waste but can also be implemented to other types of waste. There are five principles, as summarized in Table 26.3, which underlies effective waste management and must be implemented every time a national policy is created.

#### *26.4.1.3 Regulated medical waste*

In 1980, the medical waste's regulatory framework was developed by the US EPA. But, since the composition of the waste was different between each state, the US EPA no longer plays a central role in regulating the medical waste. The waste regulations are now enacted as State Medical-Waste Regulations, and nearly all 50 states have their own regulations. Even so, the US EPA still actively regulates the regulation governing the emissions from the incineration of medical or infectious wastes (ENTeR, 2016). The other regulatory scheme related to the medical waste are as follow:

- Occupational Safety and Health Administration (OSHA) Regulations. The Regulations are concerning several aspects of medical-waste management, such as categorizing the waste, containers requirement for holding or storing the medical waste, labelling the waste container and employee training.
- Department of Transportation (DOT) Regulations: The regulations are mostly concerning the transportation or shipping of medical wastes.

### ***26.4.2 European Union directive regulations***

The WHO and European Union (intrinsically the WHO's European Centre for Environment and Health) are known as the two big-organizing bodies that set up an

**Table 26.2** International agreements and conventions governing the medical-waste management.

| Treaty name | Remarks | References |
|---|---|---|
| The basel convention[a] | Provided by UNEP[b], the protocol's main objective is to protect public health and the environment against the adverse effect of medical wastes and other hazardous wastes. According to the protocol, the textile and medical textile wastes are classified as B3 wastes (Annex IX), that is, wastes containing principally organic constituents and should not be mixed with other wastes. The transboundary movement of such wastes only can be permitted when their disposal and transport are environmentally sound. | Peiry (2013); UNEP (2019) |
| The bamako convention[c] | The convention aims to protect African nations by prohibiting the import of hazardous waste into Africa from any route. The bamako convention was created as a response to the basel convention (i.e., Article 11), which prohibits the trade of hazardous waste to less developed countries, especially the African continent. The convention was provided by UNEP and had 25 parties, which mostly came from African nations. | UNEP (1991) |
| The stockholm convention[d] | The stockholm convention is a global treaty created to protect public (human) health and the environment, especially from persistent organic pollutants (POPs). The convention is mainly emphasized industrial sectors, including the textile industries. The development of the convention was in the assistance of UNIDO[e], which was responsible for assisting the countries in implementing the treaty. | UNEP (2006) |
| The environment and sustainable development conferences | The report was formulated to propose long-term strategies for achieving sustainable development. The report's main concept is the development to meet current needs without causing damage to the environment that can possibly hinder future generations from meeting their own needs. The full text can be found in the world commission on environment and development report. | Chartier et al. (2014) |

**Table 26.2 Continued**

| Treaty name | Remarks | References |
|---|---|---|
| United Nations committee of experts on the transport of dangerous goods | This United Nations (UN) regulation was prepared by the subcommittee on UN Economic and Social council (ECOSOC). While the regulations were not obligatory, they have received international acceptance and serve as the basis of several international agreements. The regulations cover the transport of almost all dangerous goods models but do not cover the use or disposal of the dangerous goods. The dangerous goods must meet the regulated packing and labelling requirement before internationally transported. | UNECE (2011) |
| United Nations Economic commission for Europe (UNECE) | The agreement concerning the International carriage of Dangerous Goods by Road (ADR). The ADR briefly declared that the dangerous goods carried by road vehicles must be packed and labelled according to the codes in the regulations' annexes. | UNECE (2017) |
| Aarhus Convention of the UNECE | The agreement is made to connect environmental rights and human rights. The agreement also encourages the embodiment of the sustainable development through active participation of all stakeholders, including people and government. | UNECE (2000) |

[a]In full: Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal.
[b]UNEP stands for United Nations Environment Programme.
[c]In full: Bamako Convention on the Ban on the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa.
[d]In full: Stockholm Convention on Persistent Organic Pollutants.
[e]UNIDO stands for United Nations Industrial Development Organization.

international working group to establish various practical guides addressing health care waste management in developing countries. The group was established in 1995 and embraced private sector representatives involved in waste management-related activities. The European Union (EU) has published a document *Strategic Agenda on Textile Waste Management and Recycling* as a practical document to accommodate the vision of the expert network on textile recycling (ENTeR) on textile waste management into tangible elements (ENTeR, 2016). The management of the medical textile is included as one element in ENTeR's strategic agenda. As stated in the agenda, medical textile wastes cannot be placed in the bins of undifferentiated-waste, and therefore, their management has directly affected the cost plan for the companies or organizing bodies (e.g., hospitals or medical centres).

**Table 26.3** The five principles underlying an effective and controlled waste management (Chartier et al., 2014).

| Principle | Remarks |
|---|---|
| Polluter pays | The principle regulates that waste's producers are responsible for the safe disposal of the produced waste, including legally and financially responsibility. |
| Precautionary | The principle is persuasively governing the health and safety protection defined under the 15th principle of the 1992 Rio declaration on environment and development (United Nations, 1992). The principle disallows the lack of full scientific certainty reasoning for postponing cost-effective measures to prevent environmental damage. |
| Duty of care | The engagement of all parties at all levels (i.e., production, storage, transfer, treatment and final disposal of the waste) is crucial in the effective employment of this principle. The parties should be appropriately licensed to handle the categories of waste. The principle is engaging the ethical responsibility of the waste handling and managing personnel. |
| Proximity | It is recommended to appoint the closest possible location (inside the territorial limits) to the waste source for disposal to minimize the risk involved in the transportation unless there are several safety considerations. |
| Prior informed consent principle | The principle obliges that consent from the affected communities and other stakeholders must be obtained. They require to be informed regarding the hazards and risks of waste management at all levels. |

#### *26.4.2.1 Legal and policies area*

Disposable and reusable medical textile are two highly used products in health-related activities. However, direct political involvement and strife have increased controversy over the use of disposable and reusable medical textiles. Each of its proponents claims competitors' products weaknesses and the advantages of their products for economic gain purposes. Regardless of its disposable or recyclable form, the medical textile and textile wastes cannot be disposed of as a general solid waste; further sorting shall be applied to the wastes. The policies related to the waste management (including the medical textile waste) by EU has the main objective to protect the natural resource by avoiding the generation of waste and recycling the waste (Healthcare Environmental Resources Center, 2015). The regulations by the EU are directly applicable to the member-states, and therefore, should be implemented into the national policy, which is as follow:

- The European Waste Framework Directive (Directive, 2008/98/EC), a central directive in the waste management field. The Directive proposed several principles related to waste management, which has the main objective of minimizing and preventing waste generation to reduce

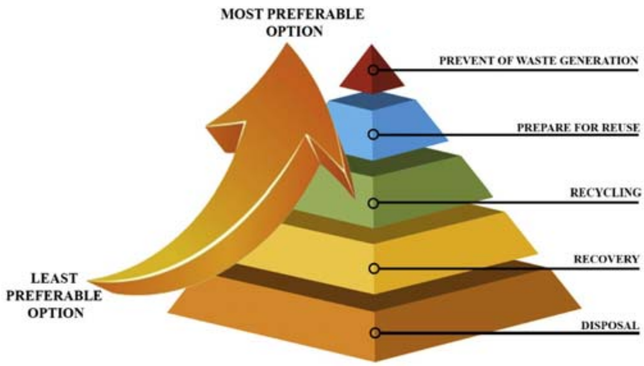


**Figure 26.5** The five-stage waste management hierarchy in the European Waste Framework Directive.

the adverse effect of the waste on humans and the environment (i.e., water, soil, plans and animals). The Directive also sets up a five-stage waste management hierarchy (Fig. 26.5) that the EU Member States shall apply to prepare the national policy.

- Regulation (EC) No. 1013/2006 of the European Parliament and Council related to the shipment or transportation of waste. The wastes should be labelled and should meet the specific conditions before shipped between countries.
- Decision 2000/532/EC is related to the waste list, including the hazardous and general waste. As listed in Annex III of the Decision, the hazardous waste should be managed according to the above-mentioned Waste Framework Directive.
- EU Circular Economy Package by the European Council. The package is launched with the principal objective to prevent waste generation and promote recycling in Europe.

### 26.4.3 England and Wales hazardous waste regulations

The Hazardous Waste Regulations was developed in July 2005 to regulate and control hazardous waste in England and Wales (Environmental Protection of England and Wales, 2005). The waste directive regulations were developed to ensure safe disposal and recovery of the waste that the waste management processes do not endanger the environment and human health. According to regulations, the waste producers who produce more than 500 kg of hazardous waste should register their existence to the Environment Agency. The producer of hazardous wastes should provide a detailed description of the waste to facilitate the later waste management, that is including the quantity of the waste, the chemicals composition and their concentrations, the hazard code according to the List of Waste (LoW) code, the container specification and the destination of the disposal. According to the regulations, the medical textile wastes can be categorized as the H9, H13 and H14 (as mentioned in Schedule 3-Annex III about the properties of wastes which render them hazardous), that is the wastes which are potential to cause adverse effect to human or other living organisms. The waste's hazardous properties were made based on the criteria given in the Regulations of Council Directive 67/548/EEC of 27 June 1967 and 79/831/EEC(38).

### 26.4.4 British Columbia hazardous legislation guide

The legislation guide consists of 22 chapters that describe the definition, identification, handling, storage, transportation and disposal system of hazardous wastes. According to the guide, hazardous wastes are wastes that potentially harmful to human health or the environment (Oliver, 2016). A special technique was then required to eliminate or minimize the hazard. The guide was developed on the basis of several acts and regulations, including the Environmental Management (EM) Act, hazardous waste (HW) Regulation, Environmental Assessment Act, and Reviewable Projects Regulations. A comprehensive framework related to the regulation of the hazardous wastes in British Columbia (BC) was specially set up in the EM Act and detailed in the HW Regulation, which includes: (1) registration of any activities which involve the generation of hazardous waste, (2) requirements of the hazardous waste facilities, (3) the sets up of containers for storing and transporting the wastes, (4) licensing of the waste carriers and (5) requirements for specific types of hazardous waste. The regulation's main objective is to prohibit the exposure of wastes that can potentially cause pollution to the environment, except the hazardous wastes which are in accordance with the regulations (The Government of British Columbia, 2008).

## 26.5 Conclusion

The regulatory frameworks and national policies for the management of hazardous waste, including medical textiles, have the same primary objective: to prevent and minimize waste generation. The prevention and minimization of waste generation are to protect human health and the environment from the adverse effects of the waste. The regulation regarding the medical textile wastes may not specifically be written, but their managements are implied in the regulations. Medical textile wastes should be differentiated from the general solid wastes since they contain infectious matters that are potentially harmful to humans and the environment. And therefore, special techniques should be applied to their disposal according to the available directives in each state. Several waste management options are available, including landfilling, incineration, composting and reusing. The effectiveness and success of the waste management cannot be achieved in the absence of all stakeholders' full-involvement, that is the government, health care related bodies, NGOs and households. Although standard regulations for medical textile waste management may differ from country to country, every country should have a minimum approach to regulate their medical waste. The regulated medical wastes (RMW) need to be rendered noninfectious before they can be disposed of as general-solid wastes to minimize their impacts on the public health and environment.

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