Jurnal Kejuruteraan 37(3) 2025: 1163-1177
https://doi.org/10.17576/jkukm-2025-37(3)-07

The Malaysian Approach to Clinical Waste Management: Challenges, Regulations, and Environmental Impacts

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Received 14 August 2024, Received in revised form 26 December 2024
Accepted 26 June 2025, Available online 30 May 2025

ABSTRACT

Clinical waste (CW) treatment and disposal is a global concern for developing a sustainable society. Clinical waste refers to any liquid or solid waste containing infectious or potentially infectious materials from healthcare, laboratory, or research activities, including disease diagnosis, prevention, and treatment. This type of waste poses risks to healthcare staff, patients, and the surrounding community, increasing the potential for illness and damage. The World Health Organisation classifies medical waste into eight categories: infectious waste, sharps waste, pathological waste, pharmaceutical and cytotoxic waste, radioactive waste, and general waste. Hospitals, clinics, and healthcare facilities are primary sources of clinical waste. The COVID-19 pandemic has further exacerbated the situation by increasing the volume of waste generated in healthcare settings. In Malaysia, the Department of Environment (DOE) oversees the management of clinical waste under the Environmental Quality (Scheduled Waste) Regulation 1989. This regulation covers aspects such as labelling and identification, on-site storage and management, transportation, treatment, and disposal of clinical waste. This review article addresses key issues related to clinical waste management, including identification, classification, and the agencies involved. Additionally, it discusses the incineration process, and the environmental challenges associated with incineration plants.

Keywords: Clinical waste; clinical waste management; incineration; environmental; COVID-19

INTRODUCTION

The effective management of clinical waste (CW) has emerged as a pressing global challenge, further exacerbated by the challenges posed by the COVID-19 pandemic. The substantial surge in CW generation has strained healthcare systems worldwide, underscoring the critical need for robust and adaptive waste management strategies (Agamuthu & Barasarathi 2021). The improper handling and disposal of CW, which encompasses a diverse range of hazardous materials, including infectious agents, sharps, pathological waste, and chemicals, can have severe repercussions for both public health and the environment (World Health Organisation 2018). The potential for disease transmission and environmental contamination due to inadequate CW management practices necessitates a proactive and comprehensive approach to mitigate these risks.

Malaysia, like many other nations, faces the complexities of CW management. The escalating volume of CW, coupled with the diverse nature of healthcare facilities and waste streams, demands a robust and adaptive management approach (Pariatamby 2017). The Malaysian government has implemented various regulations and initiatives to address this challenge, including privatising CW management services and establishing dedicated treatment facilities. However, ongoing efforts are required to optimise CW management practices, enhance environmental sustainability, and ensure the protection of public health. The recent surge in CW generated by frontline medical facilities, with a staggering 111.94% increase compared to pre-pandemic levels, highlights the urgency of this issue (FMT Reporters 2021). The projection that CW volume could escalate to 173.25 tonnes per month if the pandemic persists further emphasises the need for immediate and effective action (FMT Reporters, 2021). The continuous growth in the number of new COVID-19 cases globally and nationally contributes to the escalating volume of CW, posing a significant challenge for healthcare systems and waste management infrastructure (Agamuthu & Barasarathi 2021; Worldometer 2021). Major cities across Asia, including Kuala Lumpur, have experienced substantial increases in CW generation, underscoring the widespread impact of the pandemic on waste management practices (Asian Development Bank 2020).

A healthcare facility, or hospital, is a complex environment where individuals of diverse ages, genders, ethnicities, and religions converge, alongside the facility's regular occupants - patients and staff. Each entity within this environment contributes to waste generation, and the volume and diversity continually escalate due to advancements in medical technology and evolving healthcare practices (Kanyal et al. 2021; Mane & Salunkhe 2013). Clinical waste (CW), defined as any waste generated during medical research, diagnosis, treatment, or immunisation or in the production or testing of biological products, constitutes a substantial portion of this waste stream. The COVID-19 pandemic has further intensified this issue, triggering a dramatic surge in CW generation across healthcare facilities globally. This unprecedented increase in CW, encompassing infectious waste, pathological waste, sharps, and chemical waste, has presented a formidable challenge for waste management systems worldwide, necessitating the development and implementation of innovative and adaptive strategies to ensure the safe and effective handling and disposal of this waste (Agamuthu & Barasarathi 2021).

The complexities of CW management extend beyond the immediate risks associated with handling and disposal. The collection and processing of CW, particularly in urban areas, can pose health risks to waste management workers and the general public while complicating recycling and resource recovery efforts (Dehghani et al. 2019). Ensuring the safety and well-being of all individuals involved in the CW management process is paramount, necessitating the implementation of stringent safety protocols and training programs. Furthermore, the environmental implications of CW management, particularly concerning the incineration process, warrant careful consideration.

Incineration, a widely adopted method for CW treatment, significantly reduces waste volume and effectively destroys harmful pathogens. However, it is crucial to acknowledge that incineration is not a 'final' disposal solution, as it generates ash that requires further management, typically through landfilling or other disposal methods (Ghasemi & Yusuff, 2016). The environmental implications of incineration, including emissions of greenhouse gases and potentially harmful pollutants, necessitate the adoption of advanced emission control technologies and the exploration of sustainable alternatives. Recent research has focused on developing and optimising alternative treatment technologies for CW, such as autoclaving, microwaving, and chemical disinfection (Retnaraj et al. 2021). These technologies offer potential advantages in terms of reduced emissions, lower energy consumption, and the possibility of resource recovery. The selection of appropriate treatment methods should be based on a comprehensive assessment of factors such as waste composition, environmental impact, cost-effectiveness, and regulatory compliance.

While the traditional "cradle to grave" concept of CW management has focused on disposal, there is a growing recognition of the potential for resource recovery and a more circular approach. The concept of 3Rs - reduce, recycle, and reuse - is gaining traction in CW management (Chartier et al. 2014; Datta et al. 2018; Kanyal et al. 2021). This paradigm shift emphasises minimising waste generation, exploring recycling opportunities, and identifying potential applications for CW byproducts. The limited space and high costs associated with land disposal of CW ash have further spurred the development of recycling technologies and the reuse of these ashes in various applications.

The potential utilisation of CW incineration byproducts, such as fly ash, presents an opportunity for resource recovery and a more circular approach to waste management. Research has shown that CW fly ash can be incorporated into construction materials, reducing the demand for virgin resources and minimising the environmental footprint of waste disposal (Ababneh et al. 2020; Kaur et al. 2019a). However, the safe and effective utilisation of these byproducts necessitates a thorough understanding of their chemical composition and potential leaching risks. Continued research and development in this area are essential to unlock the full potential of CW byproducts and contribute to a more sustainable waste management paradigm.

Effective clinical waste management is a multifaceted challenge that demands a comprehensive and adaptive approach. The COVID-19 pandemic has further highlighted the criticality of this issue, necessitating urgent action to address the escalating volume and complexity of CW generation. While incineration remains a widely used treatment method, it is essential to acknowledge its limitations and explore alternative technologies that offer potential advantages in terms of environmental sustainability and resource recovery. The safe and effective management of CW requires a holistic approach that encompasses waste segregation, treatment, disposal, and the utilisation of byproducts. By prioritising environmental considerations, public health protection, and resource recovery principles, we can pave the way for a more resilient and sustainable future in CW management.

METHODOLOGY

The process flow of this study, as illustrated in Figure 1, began with the identification of specific types of CW. The identified waste types were then classified, and subsequently, the CW was processed for suitable applications. The final step involved determining the general applications of the processed CW to promote its future use as a sustainable material.

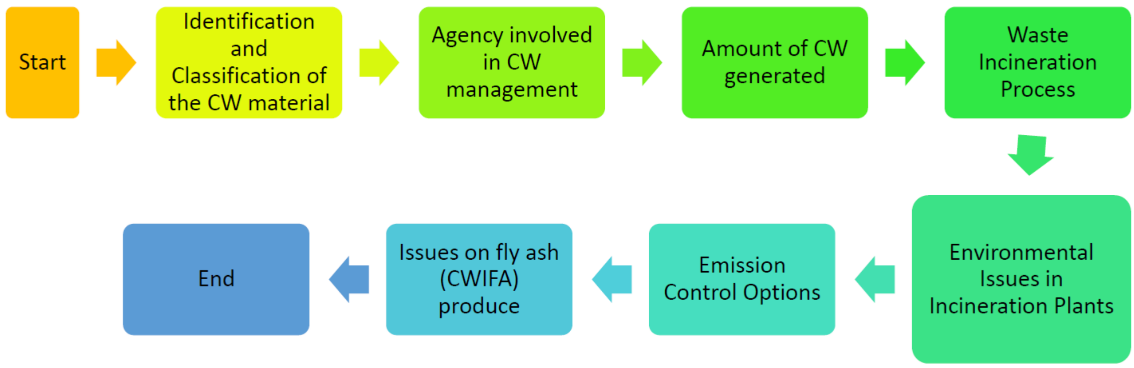

FIGURE 1. Flow chart of the CW Management process

RESULTS AND DISCUSSION

IDENTIFICATION AND CLASSIFICATION OF THE CW IN MALAYSIA

The effective management of clinical waste (CW) hinges on its accurate classification. In Malaysia, the primary waste streams subjected to incineration for treatment encompass municipal waste, hazardous waste (scheduled waste), and clinical waste (Hassan Halimah, 2014). The disposal of CW, particularly from hospitals, presents a significant challenge in developed nations due to the prohibitive costs associated with scheduled waste disposal. Addressing this challenge necessitates implementing comprehensive waste management measures, including identification, assessment, treatment, transportation, and disposal of hospital waste (Bandaso & Ayuningtyas 2019). The classification of CW in Malaysia encompasses general waste, hospital waste, pharmaceutical waste, hazardous chemicals, and radioactive waste, with CW often reported in conjunction with pharmaceutical waste. Figure 2 shows the category of CW in Malaysia. Adequate training is necessary to ensure adequate safety awareness and knowledge of appropriate protocols for controlling CW in hospitals. CW is a possible source of harmful bacteria; hence safe and reliable treatment is essential. There are recognised hazards associated with CW where exposure can result in disease or injury. This is because CW may be genotoxic, may hold infectious disease, contain hazardous chemicals, pharmaceutical residues, or radioactive compound, or and it may contain sharp items.

Although 75% to 90% of CW is non-hazardous waste, which is general waste, the remaining 10% to 25% of the waste is regarded as dangerous or CW and may carry various health risks (Pariatamby 2017). However, the amount of CW from most private clinics is less than 1 kg/day, which will increase the likelihood of disposal of CW as general waste (Ishak, 2014). Table 1 presents the primary general classification of the waste by the World Health Organisation, WHO (2013). Due to the heterogeneity within the waste stream, proper CW management is essential to avoid health risks and damage to the flora, fauna and the environment. The CW is divided into five categories, as shown in Figure 2. Under the Environmental Quality (Scheduled Waste) Regulations 2005, the category defines how waste is separated and the packaging and labelling requirements for that type of waste for transportation and disposal. Before deciding on the technology to treat CW, it is necessary to classify the CW. This is because the various CW must be controlled and treated differently, and it is essential to justify the waste volume and its type (Ghasemi & Yusuff, 2016; Prem Ananth et al. 2010). CW is presently handled using incineration technology, with the produced ash being disposed of in Malaysian landfills (Ghasemi & Yusuff 2016).

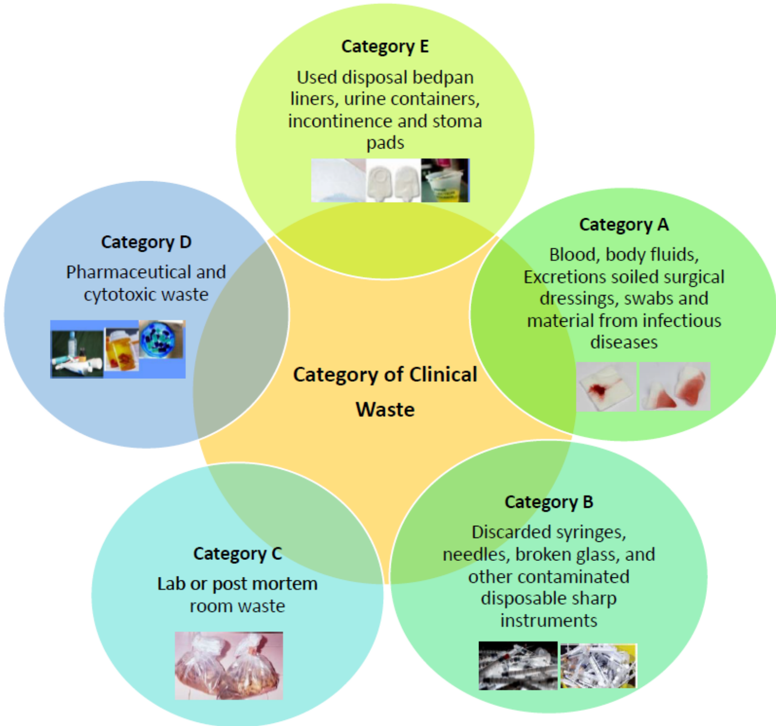

FIGURE 2. List the general classification of CW in Malaysia (Pariatamby, 2017)

TABLE 1. General Classification of CW (World Health Organisation (WHO), 2018)

Waste Categories	Description	Examples
General Waste	Domestic waste. No risk to human health	office paper, wrappers, kitchen wastes, general sweeping
Pathological	Tissues or fluids of human beings	Parts of the body; blood and body fluids; fetuses
Sharps	-	Needles, infusion sets, scalpels, knives, blades, broken and glass
Infectious Waste	Waste that alleged of pathogens	Cultivation of laboratory; separation wards waste; tissues (swabs), materials, or equipment that have been in contact with infected patients; excreta
Chemical Waste	Waste containing chemical substances	laboratory reagents; film Infectious Waste developer; disinfectants that are expired or no longer needed; solvents
Radioactive Waste	Radioactive material-containing waste	Unused radiation and research tests fluids; tainted vitreous materials, containers, or absorbent papers; urine and excreta from patients treated or examined with unsealed radionuclides
Pharmaceutical Waste	Waste that contains pharmaceutical products	Expired or no longer necessary pharmaceutical products; pharmaceutical products contaminated or containing pharmaceutical products (boxes)
Pressurised Containers	-	Gas cylinders, aerosol cans etc.
Genotoxic Waste	Waste that contains genotoxic substances	Cytostatic waste (often used in cancer therapy); genotoxic chemicals

AGENCY INVOLVED IN CW MANAGEMENT, MALAYSIA

More than a decade ago, there was a serious concern about the possible spread of pathogens and the environmental contamination of CW due to their improper handling and management. Before 1990, CW in Malaysia was viewed in the same way as any other solid waste in the hospital. However, privatisation is an effective and efficient way to improve the quality of CW management. Privatisation involves transferring accountability for management and regulation from the state to the private sector. A decision was made in 1993 to privatise this service for the 127 hospitals and organisations of the Ministry of Health (MOH) (Siru et al. 2006). In 1995, when Malaysia's CW management and hospital support services were privatised, regional and on-site CW incinerators were built. The privatisation of CW management in Malaysia commenced in 1997 In order to reduce Government's financial and administrative burden. The rationale behind privatisation of CW management was mainly economic. Privatisation was considered as an effective and efficient way to improve the quality of CW management in Malaysia. The collection and storage of CW have been demonstrated to be an effective way to improve the efficiency of the facilities. However, the major obstacles faced by the concession companies in Malaysia were the management of hospital waste and running costs (Razali & Ishak 2010).

The present contract of concession agreement was signed with five (5) concession companies with a 10-year concession period effective from 1 April 2015 until 31 March 2025 for 148 hospitals with a CW incinerators capacity of 20 to 500 kg/hr (Ministry of Health, 2017). Table 2 indicates the list of concession companies (CC) involved in the CW management process in terms of hospitals and zones. They were appointed to manage the public health care services including waste collection, transportation and disposal system (Ministry of Health, 2017). During the concession period of ten (10) years, the project cost is estimated at RM26.36 billion (Ministry of Health 2017). MOH have generated almost RM 200 million by managing almost 16,000 tonnes of CW in 2009 (Ambali et al. 2013; Asia-Pacific Economic Coorporation Secretariat, 2010). Based on the agreement signed between the concessionaires and the government in 1992, and the proposal submitted in 1997, it was specified that the fees charged for services involving the handling and management of CWs is RM5.20 per kg (JICA 1999; Ministry of Health 2017; Pariatamby 2017).

Kualiti Alam Sdn Bhd and Future NRG Sdn Bhd manage all CW from private hospitals and clinics. (Agamuthu & Barasarathi 2021). Kualiti Alam (KA) waste management centre is the company that has an exclusive right to construct and manage the scheduled wastes and clinical waste ashes (CWA) including CWIFA in Peninsular Malaysia (JICA, 1999; Zahar & Fazir, 2020). Meanwhile, all CW from Sarawak's healthcare facilities, whether private and public, is burnt at Trienekens (Sarawak) Sdn. Bhd (Trienekens. Scheduled & Hazardous Waste 2019) and In 2004, another facility was built in Sarawak by Trienekens Sdn Bhd to dispose of CWA (Ibrahim 2018). The CC shall pay KA the transportation cost and

treatment fee, which shall be determined following the agreed-upon rates as set out in schedules A and B. The treatment rate for incinerator ashes in Schedule B for inorganic waste via solidification is RM810 per 200-litre drum or RM4,124.52 per tonne (Kualiti Alam 2016). Meanwhile, transportation fees in Scheduled A vary from RM66.10 to RM230.11 per MT whether a Tipper Truck or Skid Bin is used (Kualiti Alam, 2016). However, KA may, at its discretion, review and modify such rates from time to time without assigning any cause (Kualiti Alam, 2016). The transportation cost is also charged in addition to the treatment fees as KA exclusively provides transportation from the factory to the Bukit Nanas plant. KA used multiple technologies in treatment and disposal based on proposed waste types that include incineration plants, physical and chemical treatment plants, solidification treatment plants, safe landfills and CW treatment centres.

The Department of Environment (DOE) is responsible for monitoring and controlling the CW management under the scheduled waste regulation 2005, Environmental Quality Act 1974, including its labelling and identification, on-site storage and management, transportation, treatment, and disposal (Che Jamin & Mahmood 2015; Pariatamby 2017). DOE monitored all activities that are handled by KA and CC. In Malaysia, CW management is using the "cradle to grave" concept. However, DOE has recently encouraged a new paradigm change in scheduled waste management from the cradle to the grave method, which was once viewed primarily as an unnecessary by-product cradle to cradle solution, which is now seen as future material recycling and resource recovery (Che Jamin & Mahmood 2015).

Figure 3 shows the agency involve and responsible for managing CW in Malaysia. Figure 3 shows the agency involve and responsible for managing CW from government healthcare facilities in Malaysia. In Malaysia, four agencies are responsible for the management of CW, beginning with the production of CW and ending with the disposal of the CWA. MOH, DOE, CC, and KA are the agencies involved. The costs associated with handling CW and CWA will rise as the amount of CW increases.

TABLE 2. List of CC by hospitals and zones in Procurement and Privatisation Division of MOH (Ministry of Health, 2017)

No.	Concession Companies	Number of Hospitals / Institutions	Zone / State Institution	Services Provided
1	Radicare (M) Sdn. Bhd.	46	Klang Valley and East Coast (Selangor, Federal Territory of Kuala Lumpur and Putrajaya, Pahang, Kelantan, and Terengganu)	Facilities Engineering Management Services (FEMS) Biomedical Engineering Management Services (BEMS) Cleaning Services (CLS) Laundry & Linen Services (LLS) Health Waste Management Services (HWMS) Facility Management Services (FMS)
2	Medivest Sdn. Bhd.	22	South (Melaka, Negeri Sembilan and Johor)	
3	Edgenta Mediserve Sdn. Bhd.	32	North (Perlis, Kedah, Penang, and Perak)	
4	Sedafiat Sdn. Bhd.	26	Sabah and Federal Territory of Labuan	
5	One Medicare Sdn. Bhd.	22	Sarawak	
	Total	148		

FIGURE 3. Agency involve and responsible for managing CW from government healthcare facilities in Malaysia

AMOUNT OF CW GENERATED IN MALAYSIA

In Malaysia, healthcare facilities are changing rapidly as facilities add and change activities each year to refocus and upgrade their operations. In Malaysia, CW is classified as scheduled waste under the Quality (Scheduled Waste) Regulations, 2005, including all groups and categories of CW that are collected and processed on-site from the same generation sources, which are SW404 and SW403 SW409, SW421 and SW410 (Pariatamby, 2017). All materials used in the health procedures dealing with COVID-19 are treated as CW. The ashes produced from the incinerator are also considered scheduled waste (SW406). Table 3 shows the Clinical waste (CW) classification under the environmental quality (scheduled wastes) regulations, 2005. Table 4 presents the quantity of CW generated in Malaysia from 2013 to 2019. The table shows that the amount of pathogenic waste, CWs and quarantine materials increases with the increasing population and economy. Healthcare services are improved, as is the development of specialised health services in hospitals and clinics, as well as the growth of patients and awareness of how to manage the CW properly. However, the quantities of the other wastes are inconsistent, depending on their use in the current year. Figure 4 shows the quantity of CWs at the incinerator, microwave, and secured landfill (SW 404), and the volume of CW disposed of in incinerators increased in 2019 by approximately 86% compared to 2013.

Sources of CW are mainly generated from medical, nursing, dental, pharmaceutical, veterinary or similar practices, research, treatment, teaching or research, or blood collection for transfusion, which is under control by the MOH (Agamuthu & Barasarathi 2021; Pariatamby 2017). The production of CW is closely linked to healthcare size and the development of healthcare services. Several considerations, such as type and size of healthcare facilities, specialisation, range of operations, location of healthcare facilities, number of beds, bed occupancy rate, number of patients, reusable goods, waste management plan, influence waste production (Tabasi & Marthandan 2013). CWs are categorised according to their source, typology, and risk factors for managing, storing, and utilising different disposal and treatment methods.

TABLE 3. Clinical waste (CW) classification under the environmental quality (scheduled wastes) regulations, 2005

Scheduled waste code	Type of CW
SW404	Pathogenic waste, CW, and quarantined materials
SW403	Discarded drugs containing psychotropic substances or containing substances that are toxic, harmful, carcinogenic, mutagenic or teratogenic
SW421	A mixture of scheduled wastes
SW424	A mixture of scheduled and non-scheduled wastes
SW406	Clinker/slag/ashes from Incinerator

TABLE 4. Quantity of CW generated as Scheduled waste (Department of Environment Malaysia, 2019)

Year	SW 404 (MT/Year)	SW 403 (MT/Year)	SW 421 (MT/Year)	SW 424 (MT/Year)	SW 406 (MT/Year)
2020	39,883.32	100,767.14	2,934.31	22.81	6,279.55
2019	33,756.99	471.20	5,589.70	6.32	2,948.81
2018	30,757.04	267.02	3,856.07	8.70	5,652.5
2017	28,375.24	458.97	3,389.63	12.23	976.34
2016	23,844.91	14,250.60	3,593.56	4.88	2,656.09
2015	25,523.33	282.31	1,654.47	2.35	3,618.54
2014	21,976.12	447.97	8,802.58	9.08	2,091.65
2013	18,152.95	1,470.14	19,083.09	1.07	2,231.85

OVERVIEW OF WASTE INCINERATION IN MALAYSIA

Incineration is a waste treatment method that is utilised for a wide range of wastes. The purpose of waste incineration is to reduce the volume and hazardous qualities of waste while also capturing or destroying possibly harmful element emitted during the process. The energy can be recovered by incineration procedures that produce hot flue gases. Material such as mineral and/or chemical can also be recovered depending on the type of waste. Treatment of CW is important before it is disposed of in the ground due to its impacts on human health and toxic pollutants into the environment (World Health Organisation (WHO 2018). The treatment of CW could be autoclave, incineration and chemical disinfection. All the CW storage bins is transported by dedicated lorries from the CC on a daily basis to a specific site to incinerate the CW. Incineration is the final steps in CW management. All CW collected and been transported to the incinerator plant were burned into ashes (Omar et al. 2018). All the CW waste will be incinerated and the ash is disposed of after incineration. Hence, the need for incineration to decontaminate the CW by subjecting it to thermal destruction process at high temperature (1100–1600°C) under controlled operational conditions. The products of combustion are ash residue, water and carbon dioxide (Olanrewaju & Fasinmirin 2019).

KA integrated waste treatment facility is Malaysia's first comprehensive waste treatment plant and comprises of high temperature incinerators, chemical and physical treatment systems. The KA incineration plant in Bukit Nenas, Negeri Sembilan is the only off-site incinerator in the country and handles most of this category's waste (Hassan Halimah 2014). The need for more CW incinerators is ever increasing compared to the amount of CW generated. Few regional and onsite clinical waste incinerators were developed after privatisation took place in 1997. In 1995, when Malaysia's CW management and hospital support services were privatised, regional and on-site CW incinerators were built. There are five regional CW incinerators that have a capacity to burn 200 to 500kg/hr located in Taiping, Perak (2 units); Bukit Minyak, Melaka (2 units); and Teluk Panglima Garang, Selangor (1 unit). Another seven small on-site medical waste incinerators with capacity; five 20 kg/hr and two 50 kg/hr.(Consumers' Association of Penang, 2001; Hassan

Halimah, 2014). Waste incineration technology is used to reduce waste, destroying contaminated hospital disposals as well as hazardous waste to produce energy. In Malaysia the main types of waste to which incineration is applied as a treatment are municipal wastes, hazardous wastes (schedule waste) and clinical wastes.

Pyrolysis (non-oxidative thermal decomposition), gasification (partial oxidation) and incineration (full oxidative combustion) are three main types of thermal waste treatment commonly available. The reaction conditions for this thermal treatment are given in Table 5.

TABLE 5. Typical reaction conditions and product from pyrolysis, gasification and incineration process (Hassan Halimah, 2014)

Parameter	Pyrolysis	Gasification	Combustion (normally called as incineration process)
Reaction temperature (°C)	250 - 700	500 - 1600	800 - 1450
Pressure (bar)	1	1 - 45	1
Atmosphere	Inert/nitrogen	Gasification agent: O_2, H_2O	Air
Stoichiometric ratio (n)	0	<1	>1
Main product from the process			
Gas phase	H_2, CO, H_2O, N_2 and hydrocarbons	H_2, CO, CO_2, CH_4, H_2O and N_2	CO_2, H_2O, O_2 and N_2
Solid phase	Ash, coke	Slag, ash	Ash, slag
Liquid phase	Pyrolysis oil and water	NA	NA

INCINERATION PROCESS IN MALAYSIA: CW THERMAL TREATMENT PLANT

CW is usually treated with incineration technology, and incinerated ash is disposed of in Malaysian landfills. In Malaysia, all CW is filtered at the hospitals or clinics, collected, and sent by CC's vehicles to be disposed of at twelve incinerators around Malaysia. All the CC are monitored via the Electronic Scheduled Waste Management System (eSWIS) under DOE to ensure proper disposal and adherence to rules (Hossain et al. 2011). The CWs collected and delivered to the incinerator plants are then burnt to ashes (Omar et al. 2012, 2018). CW must also be subjected to high-temperature incineration to kill the bacteria and contaminants found in the waste. It is predicted that variables such as feed rate of waste and combustion temperatures play a significant role in affecting the performance of the incineration process (Baharun et al. 2005).

Incineration is the primary disposal method of CW, and it is a waste treatment method that requires burning organic waste materials (Ghasemi & Yusuff 2016). There are limits on incineration and landfilling of CW, as such waste can be a major means of dioxin and furan emissions (Ghasemi & Yusuff 2016). Besides, CW includes general waste, and acute CW shall be sterilised at the point of generation to reduce nosocomial infections (Sohrab Hossain et al. 2013). There is a need to limit the quantity of ash and unburned waste that can be disposed of, particularly at landfill sites, which pose a danger to humans and the environment (Hossain et al. 2011). Incinerators contribute to the decrease of 80 – 85% of the rigid solid mass of the actual waste (Rahman 2013). The lifetime of the incinerator is usually 25 to 30 years, and a long-term lock-in is required to recover the initial investment costs for the creation and operation of waste treatment plants (Rahman, 2013).

One of Malaysia's largest CW incinerators is operated by RADICARE (M), Sdn. Bhd., located at Teluk Panglima Garang, Selangor, was established and operated since 1997. However, the new replacement incinerator was built in March 2018 to replace the old existing incinerator with rotary kiln technology incineration system and a flue gas thermal oil heat exchanger. This incineration system is designed with a waste feeding system, ash removal and storage and an air pollution control system. Besides, during the incineration process, there are two chemical dosings in the dry scrubber, which is sodium bicarbonate ($NaHCO_3$) (0.054 MT/hr) and activated carbon (0.005 MT/hr). This incinerator is designated to incinerate CW with a maximum capacity of 15 MT / day and produced bottom ash and fly ash. This incinerator received CW, SW 404 (Pathogenic, CWs and quarantined materials), SW 403 (Discarded drugs containing psychotropic substances), SW 409 (Used containers contaminated with chemicals), SW 421 (mixture of scheduled waste) and SW 410 (Rags, plastics, papers or filters contaminated with scheduled wastes) (Tri Ecoedge Sdn Bhd 2018). This incinerator received an average amount of 1.022 MT/year (2.8 MT/day) of CW from government hospitals, private clinics, and health centres (Tri Ecoedge Sdn Bhd, 2018). The actual feeding of the CW into the incineration system is in batches. This incinerator generates bottom ash (0.3 MT/day) and fly ash (0.24 MT/day). After incineration, the ashes produced (SW 406) are appropriately stored in quantity not exceeding 20 tonnes or 180 days at the designated storage area before disposal.

The CW compositions include plastic, paper, surgery dress, diapers, absorbents, and gloves. The highest weight percentages composition of CW received from hospitals is plastic. The significant portion of the plastic waste consists of heavy materials such as glucose bottles, kidney dialysis bottles, syringe, plastic plates, arising from operation theatres and tubes, and plastic and dialysis materials in the bottles and plates. Most of the syringes with needles are packed in a plastic drum, consisting mainly of large quantities of these lighter-weight materials. Figure 4 shows the composition of the CW incinerator at Radicare Sdn Bhd, Telok Panglima Garang (Tri Ecoedge Sdn Bhd 2018).

The waste was fed into the ram feeder to the guillotine door and straight to the rotary kiln for combustion. The ash evacuation chamber is at the end of the rotary kiln, where the bottom ash is discharged into the ash container. Besides, the rotary kiln links to the secondary combustion chamber to serve as a flue gas collector. The flue gas from the secondary chamber system undergoes the pre-cooling process by using flue gas thermal oil. The purpose of the flue gas pre-cooling system is to reduce flue gas temperature and avoid slagging by the heat exchanger (Tri Ecoedge Sdn Bhd, 2018). Then, the flue gas enters the dry scrubbing to remove any acidic gases, particulate matters, trace organics and heavy metals using sodium bicarbonate and activated carbon. The sodium bicarbonate and activated carbon are injected according to the loss in weight, and it will dose the chemical flow with an adjustable feeding rate according to the quantity and quality of the flue gas. The reaction of sodium bicarbonate and activated carbon led to the neutralisation of acid and the absorption of heavy metals and dioxins. After that, the flue gas enters the baghouse filter to remove particulate and dust. This flue gas is called fly ash and is collected at the hopper. It is evacuated automatically by rotary airlocks into a sealed container with an automatic lid. The treated air is pulled by the fan and emitted through the chimney stack, which is 21 m in height, as part of the air pollution control system (Tri Ecoedge Sdn Bhd 2018). This incinerator was designed according to EU standards and complied with the emission standards by DOE, Environmental Quality (Clean Air) Regulations 2014. Besides, this incinerator, complete with an emergency bypass stack for safety precaution, releases the pressure within the system via heat release during an abnormal scenario. Figure 5 shows the flow diagram of the existing incineration of CW, and Figure 6 portrays the incineration process. Table 6 details the polluting elements, their categories and sources as well as the emission limits and the actual emissions at the filter bag of the incinerator. At the end of the incineration process of the clinical waste, ashes are produced. The ashes are significantly important for future applications. A review of the potential future application of the ashes is provided in the following sub-section.

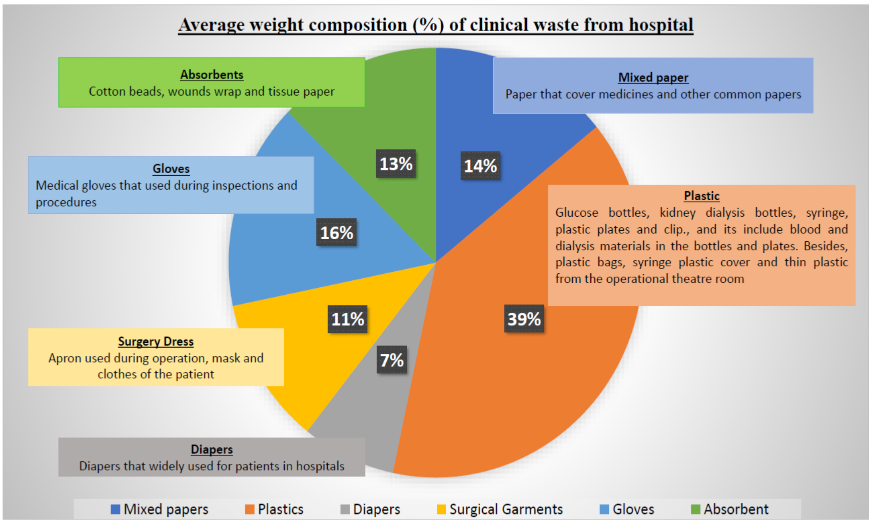

FIGURE 4. Composition of CW Received at Radicare Sdn Bhd, Telok Panglima Garang (Tri Ecoedge Sdn Bhd, 2018)

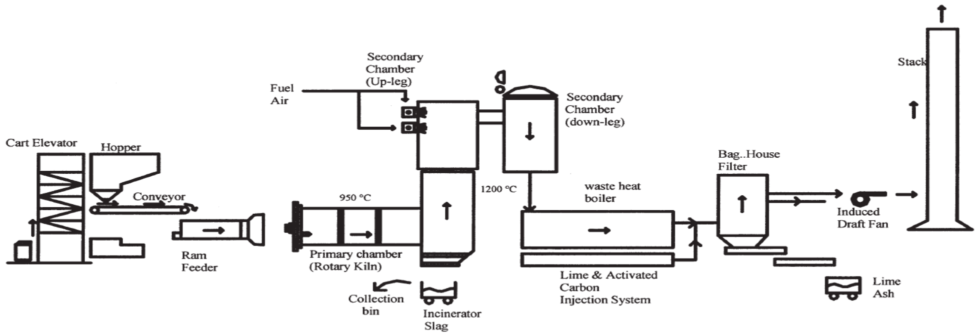

FIGURE 5. Flow diagram of the existing incineration of CW (Azni et al. 2005)

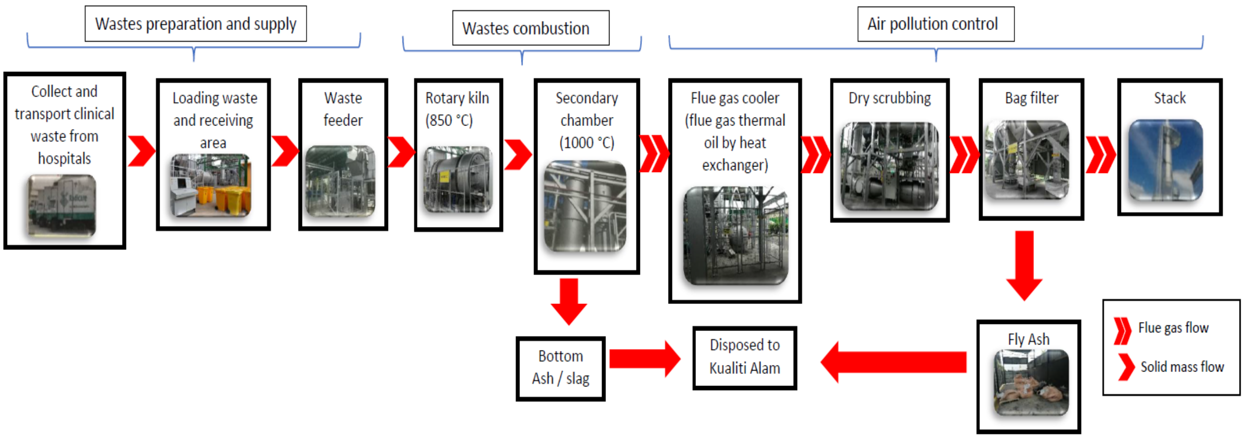

FIGURE 6. Proses of incinerated CW at Radicare Sdn Bhd, Telok Panglima Garang, Malaysia

TABLE 6. Sources and Gas Emission by incinerator

Pollution	Category	Sources[1]	Emission Limit[2] (mg/Nm^2)	Emission at filter bag[3] (mg/Nm^2)
HCL	Acid gases	PVC, other chlorinated hydrocarbons	10	8.5
HF		Fluorinated hydrocarbons	1	0.85
SO_x (SO_2)		Rubber and other components containing sulphur	50	42.5
NO_x (NO_2)		Acrylonitrile, amine	200	180
TOC (CH_4)	CO, total organic carbon, dioxins, furans	Various sources	10	8.5
CO			50	30
PCDD/PCDF (TEQ)			0.1 (ng/Nm^2)	0.05 (ng/Nm^2)
Particulate	particles (dust)	Powder, sand, dust caused by gas-solid, gas–gas reaction and paper dust caused by incomplete combustion	10	5

continue ...

... cont.

Cd + Th	Heavy metals	Coatings, battery, stabiliser/ softener,	Total 0.05	0.005
Hg		Thermometer, electronic elements, battery	0.05	0.02
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V		Various sources of Galvanised material, stainless steel, Ni-Cd batteries, etc	Total 0.5	0.1

[1] Source of pollution from municipal solid waste incineration process and generation of bottom ash and fly ash (Youcai, 2017)
[2] Emission Limit standards by DOE, Environmental Quality (Clean Air) Regulations 2014
[3]Emission at filter bag of the clinical waste incinerator at Radicare Sdn Bhd, Telok Panglima Garang (Tri Ecoedge Sdn Bhd, 2018)

ENVIRONMENTAL ISSUES IN INCINERATION PLANTS

Emissions to air and water (including odour), raw material consumption, and process residue and by-product manufacturing are the main environmental challenges that come directly from the incineration process (Hassan Halimah 2014). Noise and vibration are also concerns, as are energy consumption and production, fugitive emissions, and the minimisation of hazardous waste storage, handling, and processing risks. Among the mentioned environmental concerns, raw material consumption remains a significant concern for incineration plants. Significant advancements in methods for cleaning flue-gases (fly ash) have resulted in significant reductions in emissions to the atmosphere. Table 7 shows the source of air pollutant emission.

TABLE 7. Source of Air Pollutant Emission (Hassan Halimah, 2014)

Pollutant	Sources
Carbon Monoxide	Produced when there is insufficient oxygen locally and/or insufficiently high temperature of combustion to carry out full oxidation to carbon dioxide.
Total Organic Carbon (TOC)	chemical reactions take place during the incineration of organic waste and some of are incomplete and leads to an extremely complex pattern of compounds in trace amounts.
Hydrogen Chloride, HCl	In the incineration process, the organic component of these compounds is destroyed and the chlorine is converted to HCl. PVC contains 50% of the chlorides.
Hydrogen Fluoride, HF	The main sources of HF emissions are probably fluorinated plastic or fluorinated textiles and, in individual cases, the decomposition of CaF2 during the incineration of sludge.
Hydrogen Iodide and Iodine, Hydrogen Bromide and Bromine	Bromine compounds can still be found in some electronic devices as flame protection agents and iodine can be contained in medicines or may be used for the treatment of metal surfaces.
Sulphur Oxides, Sox	The proportion of SO_3 can be around 5% at the inlet to the flue gas treatment system. Common sources of sulphur in some waste streams are: waste paper; plaster board (calcium sulphate), and sewage sludges.
Nitrogen Oxides, NOx	The NO and NO2 emitted from waste incineration plants originates from the conversion of the nitrogen contained in the waste and from the conversion of atmospheric nitrogen from the combustion air into nitrogen oxides.
Nitrous Oxides, N2O	Nitrous oxide can be emitted if insufficient temperature for the combustion process is applied (e.g. less than 850 °C) and there is an insufficient oxygen concentration.
Dust	Dust emissions from waste incineration plants mainly consist of the fine ash from the incineration process that are entrained in the gas flow.
Mercury and Mercury Compounds	Mercury can still be found notably from batteries, thermometers and dental amalgam.
Cadmium and Thallium Compounds	Common sources of cadmium are electronic devices (including accumulators), batteries, some paints and cadmium-stabilised plastic. Hazardous wastes may contain high concentrations of Cd and Tl compounds.

Other Heavy Metal Compounds	The retention of other heavy metal depends largely on an effective separation of dust as they are bound in dust due to the vapor pressures of their compounds, as contained in the flue-gas (mainly oxides and chlorides).
Polychlorinated Biphenyls	PCBs are efficiently destroyed if a sufficiently high incineration temperature (above 1200 °C) and suitable processes are used.
Polyaromatic Hydrocarbons	Polyaromatic hydrocarbons are well known as products of incomplete combustion.
Polychlorinated Dibenzo-Dioxins and Furans (PCDD/F)	Dioxins and furans (PCDD/F) are a group of compounds, some of which are of extreme toxic and are carcinogenic. Their production and release are not specific to waste incineration but occurs in all thermal processes under certain process conditions.
Ammonia	Ammonia emissions can arise from the overdosing or poor control of NOx reduction reagents.
Methane CH4	It can be assumed that, if combustion is carried out under oxidative conditions, methane levels in the flue-gas will be almost zero and consequently not emitted to air.

EMISSION CONTROL OPTIONS

The main emission from incineration plants is NOx, acid gases (HCl, HF and SO_2), dust, PCDD, PCDF and heavy metals. The alternatives available in controlling these pollutants are by reduce of dust emission by; cyclones and multi cyclones, electrostatic precipitators (ESP's) and bag filters. The techniques normally used in incinerator plant during reduction of acid gas emission, PCDD/PCDF emission and mercury emission as below (Hassan Halimah, 2014):

1. Reduction of Acid Gas Emission

The reduction of HCl, HF and SO_2 emission in flue gas can be reduced using techniques Addition of Alkaline Reagents. Addition of alkaline reagent reacts in the furnace with acid gases to reduce acid gas loads passing to flue gas treatment systems.

2. Reduction of PCDD/PCDF Emission

Activated carbon is injected into the gas stream where it mixes with flue-gas. Normally carbon is combined with sodium bicarbonate alkaline agent. The absorption of PCDD/F on activated carbon results in emission of PCDD/F below 0.1 ng/Nm3 TEQ.

3. Reduction of Mercury Emission

Activated carbon injection This technique involves the injection of activated carbon upstream of a bag filter for mercury absorption. Usually, 95% removal efficiency for metallic Mercury can be obtained resulting in emissions to air below 0.03 mg/Nm^3.

ISSUES ON FLY ASH (CWIFA) PRODUCE FROM INCINERATION PROCESS

At present, disposal in an environmentally sound manner is the main concern associated with incineration. Incineration of CW produces CWIFA that contains a high composition of toxic compounds which are classified as hazardous wastes (Manupati et al. 2021). CWIFA generated indeed needs treatment before it can be safely disposed of at particular landfill sites (Hossain et al. 2011). The cement-based stabilisation/solidification process seems to be the best treatment option for CWIFA wastes to treat the toxic compounds (Ababneh et al. 2020). It is a norm that CWIFA is disposed of in landfill sites (Kaur et al. 2019a). However, the utilisation of CWIFA in construction is being encouraged to reduce the landfill area required and to conserve the non-renewable natural raw materials such as those required in the production cement (Ababneh et al. 2020; Sobiecka et al. 2014; Tzanakos et al. 2014). CWIFA can be used as a partial replacement for cement. In the past decades, CWIFA was used extensively as pozzolanic material. The study used an incinerator with rotary kiln technology to incinerate CW which generates CWIFA as residues. However, there have been greater awareness and fears of the risks that the CWIFA may pose on human health and the environment due to the possible leaching of toxic substances into the environment (Rajan et al. 2019; Rajor et al. 2012; Rozumová et al. 2015; Sobiecka et al. 2014).

Since the CWIFA materials have no commercial value for different reasons, most of these materials end up in landfills because of no incentive for recycling or reuse. However, CWIFA's potential usage would lower the construction cost and could substantially contribute towards reducing environmental hazards. Therefore, the need to find uses for the CWIFA and the associated environmental concern of using CWIFA as material in the cement-based system have been identified. CWIFA could be potentially used as a partial cement substitute in the cement-based system and showed good strength values (Ababneh et al. 2019). The use of industrial by-products for the partial replacement of cement has the dual advantages of reducing greenhouse gas impact on the environment and acts as an alternative for the disposal of industrial by-products. The potential of using CWIFA in the manufacture of Portland cement mortar will be established. The cement production is an energy-intensive industry and a significant contributor to climate change by generating carbon dioxide and other greenhouse gases (Gavali et al. 2019). Thus, CWIFA could be utilised as alternative supplementary binder to reduce Portland cement consumption and reduce non-renewable raw materials extraction.

CONCLUSIONS

The COVID-19 pandemic has undeniably amplified the global challenge of clinical waste management, underscoring the urgent need for robust and adaptive strategies. The substantial surge in CW generation has strained healthcare systems worldwide, highlighting the critical importance of effective waste management practices to safeguard public health and the environment. Malaysia, like many other nations, grapples with the complexities of CW management, necessitating a proactive and comprehensive approach. The Malaysian government's initiatives, including privatisation and the establishment of dedicated treatment facilities, demonstrate a commitment to addressing this challenge. However, continuous efforts are required to optimise CW management practices, enhance environmental sustainability, and ensure the protection of public health. The exploration of innovative technologies and the promotion of a circular economy approach, encompassing resource recovery and the utilisation of CW byproducts, can contribute to a more sustainable and resilient future in CW management.

The present study offers valuable insights into the complexities and challenges of clinical waste management in Malaysia, particularly in the context of the COVID-19 pandemic. The findings highlight the substantial increase in CW generation, the diverse nature of healthcare waste streams, and the critical role of various agencies in managing this waste. The study also underscores the environmental implications of CW management, particularly concerning the incineration process and the potential for resource recovery from CW byproducts.

However, the study has certain limitations. The focus on incineration as a primary treatment method, while reflective of current practices, may have precluded a more in-depth exploration of alternative technologies. Additionally, the study could be enhanced by incorporating a more detailed analysis of the economic and social implications of CW management, including the costs associated with different treatment and disposal methods and the potential impact on public health and well-being.

Future research should aim to address these limitations by conducting a comprehensive assessment of various CW treatment technologies, including their environmental impact, cost-effectiveness, and social acceptability. Furthermore, exploring the potential for resource recovery and the development of innovative applications for CW byproducts can contribute to a more sustainable and circular approach to CW management. The integration of advanced technologies, such as real-time waste tracking systems and data analytics platforms, can also enhance the transparency and efficiency of CW management processes.

In conclusion, the effective management of clinical waste is an ongoing challenge that requires continuous innovation, collaboration, and a commitment to sustainability. By prioritising environmental considerations, public health protection, and resource recovery principles, Malaysia can pave the way for a more resilient and sustainable future in CW management.

ACKNOWLEDGEMENTS

The authors would like to thank Ministry of Health for the scholarship of this study. Besides, The authors would like to thank Clinwaste Sdn Bhd and Radicare Sdn Bhd for the material (CWIFA), encouragement, support and information regarding this study.

DECLARATION OF COMPETING INTEREST

None.

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