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Review

Clinical solid waste management practices and its impact on human health and environment – A review

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ABSTRACT

The management of clinical solid waste (CSW) continues to be a major challenge, particularly, in most healthcare facilities of the developing world. Poor conduct and inappropriate disposal methods exercised during handling and disposal of CSW is increasing significant health hazards and environmental pollution due to the infectious nature of the waste. This article summarises a literature review into existing CSW management practices in the healthcare centers. The information gathered in this paper has been derived from the desk study of open literature survey. Numerous researches have been conducted on the management of CSW. Although, significant steps have been taken on matters related to safe handling and disposal of the clinical waste, but improper management practice is evident from the point of initial collection to the final disposal. In most cases, the main reasons of the mismanagement of CSW are the lack of appropriate legislation, lack of specialized clinical staffs, lack of awareness and effective control. Furthermore, most of the healthcare centers of the developing world have faced financial difficulties and therefore looking for cost effective disposal methods of clinical waste. This paper emphasizes to continue the recycle-reuse program of CSW materials after sterilization by using supercritical fluid carbon dioxide (SF-CO2) sterilization technology at the point of initial collection. Emphasis is on the priority to inactivate the infectious micro-organisms in CSW. In that case, waste would not pose any threat to healthcare workers. The recycling-reuse program would be carried out successfully with the non-specialized clinical staffs. Therefore, the adoption of SF-CO2 sterilization technology in management of clinical solid waste can reduce exposure to infectious waste, decrease labor, lower costs, and yield better compliance with regulatory. Thus healthcare facilities can both save money and provide a safe environment for patients, healthcare staffs and clinical staffs.

Contents

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1. Introduction

In the last few decades, human activities and changes associated with lifestyles and consumption patterns have resulted in the generation of huge volumes of different types of wastes (Oweis et al., 2005). The wastes have threatened the survival of humans and other living things, as well as all natural resources that are necessary for human existence. Consequently, in little more than two decades ( ) public concern over the waste management and the pollution problems associated with waste generation have attracted significant attention and a great deal of research has been conducted to evaluate appropriate waste treatment options, so as to minimize environmental pollution and maximize resource recovery (Williams, 2005). In recent years, concern over the solid waste from healthcare facilities (HCFs) (i.e., hospitals, clinics, pathological laboratories, pharmacies and other supported healthcare services) has increased throughout the world (DenBos and Izadpanah, 2002). This is because waste from HCFs, arising principally from hospitals and clinics, is potentially dangerous since it can spread diseases because of the infectious nature of the wastes, and/or cause injury through the mismanagement of clinical solid waste (Abd El-Salam, 2010; Al-Khatib and Sato, 2009).

It is well known that inappropriate clinical waste management is pressing both health hazards and environmental pollution, facing many healthcare centers of this developing world (Bdour et al., 2007; Coker et al., 2009; Sawalem et al., 2009). Improper clinical solid waste management practice impacts both directly and/or indirectly to healthcare staffs, patients and hospitals environment (Patwary et al., 2009a; Tamplin et al., 2005). Diseases like cholera, dysentery, skin infection, infectious hepatitis can spread epidemic way due to the mismanagement of clinical solid waste (Coker et al., 2009). Therefore, it is urgent to determine appropriate methods for the safe management of clinical solid waste.

The main aims of this review are as follows:

(i) Summarizes the information of clinical solid waste generation and disposal options in the world, particularly, in some developing countries.
(ii) Determine the risk assessment on unsafe handling of clinical solid waste.
(iii) Determine the best appropriate technology for the safe disposal of clinical solid waste.

The poor management of clinical solid waste is a significant problem in most economically developing countries. However, many researchers in developing countries have investigated the existing healthcare waste management practices in selected healthcare centers within their countries (Bdour et al., 2007; Coker et al., 2009; Hassan et al., 2008; Marincovic et al., 2008; Nemathaga et al., 2008; Patwary et al., 2009a,b). They argued that the successful clinical waste management represents a challenge in their countries due to insufficient financial investment, lack of awareness and effective control, lack of trained clinical staffs in the waste management framework. In addition, absence of healthcare waste management guideline and legislation in country level and unavailability of suitable treatment and disposal option may further obstruct in the waste management efforts. Therefore, the present review study was conducted to summarize the available information and knowledge on existing clinical solid waste management practices with respect to shortcoming issues, particularly, in some parts of the developing world and attempts to make recommendation for implementation of sustainable and appropriate strategy. The information gathered in the paper was collected from the desk study of open literature survey. Further, the study took into account the shortcoming issues of existing clinical solid waste management practice including waste generation, handling, segregation, risk assessment during handling and treatment to determine the best appropriate technology for safe management of clinical solid waste. The information was summarized in the study on the basis of following criteria.

(i) Critically look into article's study design.
(ii) Consideration of factors approached during waste handling and disposal.
(iii) Inclusion of information on waste management procedures.
(iv) Analyze the shortcoming issue of clinical solid waste management.

2. Definition and classification of clinical waste

The waste generated in HCFs has not any clear definition. There are currently several terms used to describe waste that is generated from healthcare facilities (Table 1). It can lead to problems as it is important to have a specific definition of those wastes derived from healthcare premises. This is because there are practical considerations to differentiate between the wastes and waste from HCFs, and in relation to choosing the right method of waste disposal which flow from a clear understanding (Bendjoudi et al., 2009; Moritz, 1995; Nemathaga et al., 2008). In literature, the terms 'Clinical waste', 'Health care waste', 'Infectious waste' and 'Medical/Hospital waste' are typically encountered, they may have similar meanings or be subsets of one another, which substantially inhibits using and comparing data from different countries (Bendjoudi et al., 2009; Diaz et al., 2008; Jang et al., 2006; Lee et al., 2002; Mato and Kaseva, 1999; Moritz, 1995; Nemathaga et al.,

Table 1
Definition and general classification of waste arising from healthcare facilities.

Reference	Definition	Classification
Shinee et al. (2008)	Health care waste	General waste and medical Waste
Nemathaga et al. (2008)	Hospital waste	General waste, medical waste and sharp
Cheng et al. (2009)	Medical waste	Infectious waste and general medical waste
Lee et al. (2004)	Medical waste	General waste and special waste
Miyazaki and Une (2005)	–	Infectious waste and non-infectious waste
Sawalem et al. (2009)	Hospital waste	General waste and Hazardous waste
Mohamed et al. (2009)	Healthcare waste	Hazardous and non-hazardous waste
Abd El-Salam (2010)	Medical waste	Domestic waste and hazardous waste
Kaisar Alam Sarkar et al. (2006)	Hospital waste	Hazardous and non-hazardous waste
Ruoyan et al. (2010)	Healthcare waste	Medical waste and general waste
Tsakona et al. (2007)	Medical/ Hospital waste	Infectious and municipal waste
Jang et al. (2006)	Medical waste	Tissues and other
Patwary et al. (2009a,b)	Medical waste	Hazardous and non-hazardous waste

2008). For example, Lee et al. (2002) used the term medical waste to deal with all types of wastes produced by HCFs. It includes all type of wastes generated by HCFs, such as hospitals, clinics, physician office and other medical laboratory and research facilities (Hall, 1989; Jang et al., 2006). But medical waste is always considered as a subcategory of healthcare waste, which potentially indicates the infectious waste except sharps (Lee et al., 2002). Nemathaga et al. (2008) delineated the definition of hospital waste is any type of waste generated from healthcare facilities. This includes both non-clinical and clinical waste constituents. The World Health Organization, 1994 refers to the waste generate from HCFs as healthcare waste (HCW). According to Bendjoudi et al. (2009), HCW results from the treatment, diagnosis, or immunization of humans and/or animals at hospitals, veterinary and health-related research facilities, and medical laboratories. This type of waste contains infectious waste, toxic chemicals and heavy metals, and may contain substances that are genotoxic or radioactive. Generally, small portion of total healthcare waste bears the infectious agent. Clearly, 10–25% of total healthcare wastes are infectious (Bendjoudi et al., 2009; Mohee, 2005; Pruss et al., 1999), therefore waste arising from HCFs cannot be defined as infectious waste. Besides, all waste cannot be addressed as clinical waste; there are some categories of waste which do not fall in the definition of clinical waste (Moritz, 1995). However, to overcome this problem, HCW can be classified as non-clinical waste (non regulated HCW, also can define as general waste), and clinical waste (special waste, regulated HCW) (Lee et al., 2002, 2004; Mato and Kaseva, 1999; Mato and Kassenga, 1997). The HCW can be further characterized as shown in Fig. 1 (Lee et al., 2004). Non-clinical waste is defined as such waste that is not posing any risk to human health or environment. Examples of non-clinical waste include packaging materials such as cardboard, office paper, leftover food, cans etc. Clinical waste is defined by the Controlled Waste Regulations (1992) as (HMSO, 1992):

(a) Any waste which consists entirely or partly of human or animal tissue, blood or other body fluids, excretions, drugs or other pharmaceutical products, swabs or dressings or syringes, needles or other sharp instruments, being waste which unless rendered safe may prove hazardous to persons coming into contact with it.
(b) Any other waste arising from medical, nursing, dental, veterinary, pharmaceutical or similar practice, investigation, treatment, care, teaching or research or the collection of blood from transfusion, being waste which may cause infection to any person coming into contact with it.

Clinical wastes include different types of wastes such as infectious waste, radioactive waste, chemical waste, pathological waste,

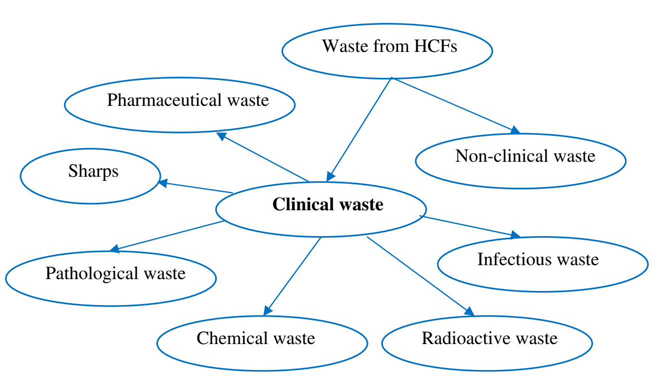

Fig. 1. The categories of waste from HCFs.

Table 2
Examples of types of clinical waste.

Category	Examples
Infectious waste	Lab cultures and stocks of infectious agents, wastes from isolation wards, tissues, materials or equipment that have been in contact with infected patients
Pharmaceutical waste	Expired or unnecessary pharmaceuticals and drugs
Pathological waste containing human tissues or fluids	Body parts, human foetuses, blood, other body fluids
Chemical waste	Solid, liquid and gaseous chemicals from diagnostic and experimental work, cleaning materials
Radioactive waste	Radioactive substances including used liquids from radiotherapy or lab work
Sharps	Needles, syringes, blades, broken glass, scalpels etc.

pharmaceutical waste and sharps (DoE, 1998). Examples of different types of clinical waste are given in Table 2 (Lee et al., 2002; Mato and Kaseva, 1999; Mato and Kassenga, 1997; Nemathaga et al., 2008; Shinee et al., 2008).

3. Source of clinical waste

The principle sources of clinical waste are hospitals and clinics, particularly those providing acute services, i.e., offering Operating Theatres, Maternity ward, Accident & Emergency, Mortuary, Intensive Care, Isolation Wards, Pharmacy, Pathology Laboratories and other research facilities (Bendjoudi et al., 2009; Blenkharn, 1995; Da Silva et al., 2005; Marincovic et al., 2008). Other sources of clinical waste are ambulance services, public health laboratories, blood donation centers and blood banks, practice center of doctors, dentists, veterinary surgeons, immunization/vaccination clinics and hospitals, clinics and nursing homes providing community care, care of the elderly and services related to mental health and learning disabilities (Hagen et al., 2001; Marincovic et al., 2008; Pruss et al., 1999).

There has been an increase in the amount of clinical waste coming from households. This is due in part to changes in health care policies. The establishment of home health and medical care services has, in recent years, become a basic requirement for the population (Blenkharn, 2008; Harsh et al., 2010). Both medical devices and instruments are used while treating patients at home, thereby producing a variety of waste materials. Self-injecting diabetics and people changing colostomy bags at home can also generate significant quantities of clinical waste (Blenkharn, 2008). The wastes generated from the treatment of patients suffering from infectious diseases may spread infection either through direct contact or indirectly through the environment. Waste materials originating from home health and medical care services are still included in general household waste materials, even when the wastes are infectious (Blenkharn, 2008; Miyazaki et al., 2007). However, the management of household infectious waste material has not received any attention yet, even in developed country like Japan (Miyazaki et al., 2007).

4. Clinical waste generation

Generally, quantities of the waste generation rate in healthcare centres depends on type of healthcare establishment, availability of instrumentation, general condition of HCFs area, ratio of disposable item in use and number of patient care (Alagoz and Kocasoy, 2008; Bdour et al., 2007; Cheng et al., 2009; Mato and Kaseva, 1999; Mohee, 2005). Also, the economic, social and cultural status

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of the patients might change the amount of waste generation (Askarian et al., 2004; Hassan et al., 2008). Among the factors, the number of day-care patients has significant effect on waste generation rate (Bdour et al., 2007; Patwary et al., 2009a). For example, Bdour et al. (2007) reported that, due to higher number of day-care patients, public healthcare facilities produce larger amount of healthcare waste than private healthcare facilities. Patwary et al. (2009a) argued that, due to higher number patients care, public hospitals produce more healthcare waste than private hospitals, but total waste and the proportion of clinical waste per bed is similar in both public and private hospitals. This may happen because of mismanagement of HCW and lack of segregation of waste for shorting the clinical waste in surveyed hospitals. Marincovic et al. (2008) reported that the healthcare waste generation rate depends on the size and the type of the medical institution, but also that it differs from country to country based on the level of economic development. The a developed countries generate higher amounts of healthcare waste than that of the developing countries (Marincovic et al., 2008; Nemathaga et al., 2008; Pruss et al., 1999). Data from World Health Organization also reveal that North America produces 7–10 kg of healthcare waste per bed/day, whereas South America produces 3 kg of waste per bed/day. This difference was also found in Europe and Asia. Western Europe produces 3–6 kg, whereas Eastern Europe 1.4–2 kg of waste per bed/day. In Asia, richer countries produce 2.5 kg per bed/daily, and poorer countries 1.8–2 kg per bed/daily (Pruss et al., 1999). From the available data it is evident that amount of healthcare waste generation rate depends on the level of economic development of the region. It is also notice that, due to higher level of economic development, the North America produce largest amount of waste. This may be due to the developed nation's lifestyle demands consumption of a high amount of goods and services which tend to generate a higher amount of waste (Marincovic et al., 2008). Furthermore, the use of disposable instruments and packaging materials rather than the use of reusable items in healthcare centers in developed countries has increased the amount waste generation.

In contrast, the proportion of clinical waste generation rate among total waste in healthcare facilities depends on several factors such as waste management plan, segregation activities at waste generation source (Alagoz and Kocasoy, 2008). Cheng et al. (2009) reported that the total amount of healthcare waste generation is much higher at medical centres and private hospitals, but the proportion of clinical waste is much higher at local hospitals. This is due to poor segregation methods followed during sorting the clinical waste in local hospital, which contaminated the non-clinical waste, hence clinical waste generation increased.

The contribution of clinical wastes to the total waste stream varied from about 12.5–69.3% (Abd El-Salam, 2010; Da Silva et al., 2005; Hassan et al., 2008; Nemathaga et al., 2008; Sawalem et al., 2009; Shinee et al., 2008). Healthcare waste generation rate in different countries is given in Table 3. It is evident from the Table 3 that developing countries in Africa (South Africa, Algeria, Egypt, Libya) and Asia (Bangladesh, Mongolia) continent generate lower amount of HCW, but the proportion of clinical waste among total waste much higher than that of middle develop countries in Europe continent (Croatia, Greece). This is because, the developed nations are following advanced legislation and guidelines during waste collection, and state of various possible ways during waste handling, storage and transportation to minimize the clinical waste generation (Alagoz and Kocasoy, 2008; Almuneef and Memish, 2003; Tudor, 2007). On the other hand, clinical wastes have not yet fully appreciated in the developing countries, are still handled and disposed together with non-clinical waste (Alagoz and Kocasoy, 2008). Though, in the beginning, minor proportion of the total waste may be considered as clinical waste. Later, cross-contamination may occur due to mixing with the non-clinical waste, rendering the entire load of clinical waste (Blenkharn, 1995; Patwary et al., 2009a).

Waste generation source, quantity and quality of waste generation are the key issues to decide an effective clinical waste management practice (Coker et al., 2009; Shinee et al., 2008; Da Silva et al., 2005). Therefore, it is important to minimize waste generation rate at each generation source. On this basis, appropriate segregation and sorting of clinical waste at generation source can be an effective solution.

5. Handling of the clinical solid waste

Unless clinical waste is properly handled and disposed, it can present risks to healthcare staffs, the public and the environment

Table 3
Average health care waste generation rate in different countries/cities hospitals.

Country/City	Waste generation rate	Non-clinical waste, %	Clinical waste %	Generation period	Number of sample	Region	References
Algeria	0.7–1.22 kg/bed/day	75–90	10–25	16 September to 10 October, 2006	10	Africa	Bendjoudi et al. (2009)
Libya	1.3 kg/patient/day	72	26		14	Africa	Sawalem et al. (2009)
South Africa	0.60 kg/patient/day	60.74	39.26	April and July, 2003	2	Africa	Nemathaga et al. (2008)
Taiwan	2.41–3.26 kg/bed/day	N/A	N/A	N/A	150	Asia	Cheng et al. (2009)
Brazil	2.63 kg/bed/day	80–85	15–20	September 2001 to March 2002	N/A	South America	Da Silva et al. (2005)
Jordan	6.10 kg/patient/day*	N/A	N/A	March to September, 2004	14	Asia	Bdour et al. (2007)
Ulaanbaatar, Mongolia	1.4–3.0 kg/patient/day	70.67	29.43	January and February 2005	56	Asia	Shinee et al. (2008)
Dhaka, Bangladesh	1.71 kg/bed/day	79	21	Over 5 months in 2006	69	Asia	Patwary et al. (2009a,b)
Croatia	2.4 kg per capita	86	14	N/A	151	Europe	Marincovic et al. (2008)
El-Beheira Governorate, Egypt	2.07 kg/bed/day	60.10	38.9	6 months period in 2008	8	Africa	Abd El-Salam (2010)
Sylhet city Bangladesh	0.934 kg/bed/day	63.97	36.03*	July 2003 to June 2004	17	Asia	Kaisar Alam Sarkar et al. (2006)
Binzhou District, China	1.22 kg/bed/day	N/A	N/A	December 2006 to January 2007	6	Asia	Ruoyan et al. (2010)
Greece	8.4 kg/bed/day	83.33	16.67	N/A	N/A	Europe	Tsakona et al. (2007)

* Maximum generation rate cited in the literature; N/A: Data is not available.

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(Al-Khatib and Sato, 2009; Shinee et al., 2008). Numerous studies have been conducted in many countries to define the best appropriate clinical waste management plan in order to minimize the health hazards and associate environmental pollution (Alagoz and Kocasoy, 2008; Bdour et al., 2007; Bendjoudi et al., 2009; Cheng et al., 2009; Da Silva et al., 2005; Hassan et al., 2008; Sawalem et al., 2009; Shinee et al., 2008). Consequently, many developed countries have devised codes of practices and guidelines for handling and disposal such waste (Bdour et al., 2007; Da Silva et al., 2005; Lee et al., 2004). Although significant progress has been found, yet it still requires further modification in all aspect of clinical waste management practices. However, in most developing countries, clinical waste has not received adequate attention despite the fact that clinical waste labeled as hazardous or infectious (Alagoz and Kocasoy, 2008; Coad, 1992; Da Silva et al., 2005; Jang et al., 2006; Tsakona et al., 2007).

The management of clinical solid waste is considered as problematic due to its enormous volume of generation, serious threat for the human health as well as disposal cost (Bendjoudi et al., 2009; Da Silva et al., 2005; Diaz et al., 2008; Jang et al., 2006; Saini et al., 2004). WHO (2000) defines that CSW as any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animal, in research pertaining thereto, or testing of biological, including but not limited to: soiled or blood-soaked bandages, culture dishes and other glassware. It also includes discarded surgical gloves and instruments, needles, lancets, culture, stocks and swabs used to inoculate cultures and remove body organs (Nemathaga et al., 2008; Jang et al., 2006; Oweis et al., 2005; WHO, 2000).

Clinical solid waste may contain potential pathogenic micro-organisms (Alagoz and Kocasoy, 2008; Coad, 1992; Da Silva et al., 2005; Pruss et al., 1999; Saini et al., 2004). Therefore, clinical solid waste is perceived by many as hazardous or infectious (Blenkharn, 1995; Miyazaki and Une, 2005; Phillips, 1999; Salkin, 2003). Although surveys refer that about 10–25% of waste contains the infectious agent (Bendjoudi et al., 2009; Mohee, 2005; Shinee et al., 2008), but Saini et al. (2004) confirmed that non-clinical waste contain more pathogen than clinical waste, and the microbial flora present in clinical waste and non-clinical waste are similar. Besides, there is a possibility of the contamination of non-clinical waste with infectious agents during unsafe handling, collection, storage and transportation (Blenkharn, 1995; Shinee et al., 2008). Hence, effective attention must be placed during treating healthcare waste so that clinical waste cannot mix with non-clinical waste during management. Consequently, clinical solid waste should be handled, storage, transported and disposed of in a controlled manner to safeguard public health and to prevent environmental pollution. Infectious pathogenic micro-organisms may infect the human body during unsafe handling via direct conduct (puncture, abrasion or cut in the skin) or indirect conduct (mucous membranes, inhalation or ingestion) (Pruss et al., 1999). Particular concern on the handling of sharps items because it represent the most acute potential hazards to health (Alagoz and Kocasoy, 2008). But, the management of clinical solid waste, particularly in developing countries is often poor and fraught with difficulties.

In developing countries, clinical solid waste has been handled and disposed together with the non-clinical waste, which is creating inevitable risks to the health care workers, publics and the environment (Alagoz and Kocasoy, 2008; Bendjoudi et al., 2009; Da Silva et al., 2005; Marincovic et al., 2008; Shinee et al., 2008). WHO in 2002 conducted an investigation survey on management of healthcare waste in 22 developed countries. Results showed that the proportion of healthcare facilities that do not use proper waste disposal methods ranges from 18% to 64% (WHO, 2004). Studies reported that healthcare workers are not educated enough and most of them have not had any special training on the management of clinical waste (Coker et al., 2009; Diaz et al., 2008; Shinee et al., 2008). Generally, they use two hands during collection and sorting the waste l (Shinee et al., 2008). Most of the healthcare institutions do not have appropriate color coded bags or containers for sorting the different types of waste (Alagoz and Kocasoy, 2008). Some of the healthcare centers in Nigeria and Mongolia used plastic bags, paper bags or card board boxed to collect the clinical solid waste (Coker et al., 2009; Shinee et al., 2008). Besides, healthcare waste are not sorted because of the high fee of their disposal cost, therefore both clinical and non-clinical waste are mixed together and dump illegally (Alagoz and Kocasoy, 2008; Coker et al., 2009; Shinee et al., 2008). Even most of the hospitals have not any special place for the storage the clinical waste prior to disposal. Wastes are placed in an unsecured area until collected and is fully accessible to the animals (Alagoz and Kocasoy, 2008; Da Silva et al., 2005).

6. Knowledge on risks and lack of information

These poor management aspects are found due to the economic problem of the developing countries that prevent the government from adequately support to clinical waste management (Da Silva et al., 2005). The potential microbiological risks associated with the clinical waste are still unfamiliar to healthcare workers. This is because of the literature on the role of infectious clinical waste as reservoir of diseases is extremely limited (Salkin, 2003). Although, there have been a few reports documented on the infectious risks on clinical waste management, but, unfortunately scientifically substantiated evidence on the actual content of micro-organisms, survival of micro-organisms in clinical waste and the infectious risks to healthcare workers and general public are extremely rare. Furthermore, the available information is restricted to develop country, and therefore does not reflect the exposure, practices, and risk situations in developing countries (Salkin, 2003).

The infectious risk posed by CSW to human health and the environment, which needs to be assessed, is the potential presence of pathogenic micro-organisms. CSW may contain a great variety of pathogenic micro-organisms (EA, 2003; Pruss et al., 1999; Saini et al., 2004). Person involved in the treatment of clinical waste are exposed to infectious agents through several routes including skin penetration, skin contact, or by the aerogenic route (EA, 2003; Pruss et al., 1999). According to Pruss et al. (1999), the possible micro-organisms and the infected routes in the human body are given in Table 4. Recently, a study was conducted in South Korea to investigate the types of micro-organisms in various clinical wastes as well to characterize the survivals life of micro-organisms in clinical waste (Park et al., 2009). Study shows that a number of micro-organisms, including *Pseudomonas* spp., *Lactobacillus* spp., *Staphylococcus* spp., *Micrococcus* spp., *Kocuria* spp., *Brevibacillus* spp., *Microbacterium oxydans*, and *Propionibacterium acnes*, are available in various clinical wastes. Alagoz and Kocasoy (2008), conducted microbiological analysis of healthcare waste to determine the quantity of infectious microorganism by colony count methods. Coliform bacteria, *Escherichia coli*, *Enterobacter*, *Pseudomonas* spp., *Staphylococcus aureus*, *Bacillus cereus*, *Salmonella* spp., Legionella and yeast and moulds were detected in healthcare waste.

7. Treatment of clinical waste

The WHO directed that the selection of clinical waste disposal methods must be cost effective, easily implemented and environmental friendly. Pruss et al. (1999) also point out that a proposed waste disposable method must have-(i) minimal risk assessments for proposed waste management facilities, (ii) minimal human

Table 4
The possible micro-organisms and the infected routes in the human body. Source: Pruss et al. (1999).

Example of causative organisms	Type of infection	Transmission vehicles
Enterobecteria, e.g. *Salmonella*, *Shigella* spp, Vibrio cholera, Helminths	Gastroentic infections	Faeces and/or vomit
Mycobacterium tuberculosis, measles virus, *Streptococcus pneumonia*	Respiratory infections	Inhaled secretions, saliva
Herpesvirus	Ocular infection	Eye secretions
Neisseria gonorrhoeae; herpesvirus	Genital infections	Genital secretions
Streptococcus spp.	Skin infections	Pus
Bacillus anthracis	Anthrax	Skin secretions
Neisseria meningitidis	Meningitis	Cerebrospinal fluid
Human immunodeficiency virus (HIV)	Acquired immunodeficiency syndrome (AIDS)	Blood, sexual secretions
Junin, Lassa, Ebola, and Marburg viruses	Haemorrhagic fevers	All bloody products and secretions
Staphylococcus spp	Septicaemia	Blood
Coagulase-negative *Staphylococcus* spp.; *Staphylococcus aureus*; *Enterobacter*, *Enterococcus*, *Klebsiella*, and *Streptococcus* spp.	Bacteraemia	Blood
Candida albicans	Candidaemia	Blood
Hepatitis A virus	Viral hepatitis A	Faeces
Hepatitis B and C viruses	Viral hepatitis B and C	Blood and body fluids

health impacts (iii) minimal environmental impacts, and (iv) cost effective. At present years, a significant concern has burgeoned over the existing disposal methods on the inactivation viable pathogen micro-organisms in clinical waste (Blenkharn, 2006a; Nema and Ganeshprasad, 2002; Park et al., 2009; Salkin, 2003). Therefore, the proposed waste disposable method must have the capability of inactivating infectious micro-organisms so that the wastes does not pose any hazard of infectious diseases for anyone exposed to it (Tsakona et al., 2007). Relatively, several technologies have been conducted to treat clinical waste for the inactivation of potentially pathogenic micro-organisms so that the waste no longer poses a danger to public health and safety. But none of these practices are able to adequately inactivate the micro-organisms, since each practice has its own weakness and disadvantage (Nemathaga et al., 2008), thereby the urgency to find an efficient method to preserve human health and environment. It is found form literatures that the most common disposal methods of clinical solid waste, particularly in developing countries, are open dumping, landfill or incineration (Abd El-Salam, 2010; Al-Khatib and Sato, 2009; Bendjoudi et al., 2009; Coker et al., 2009; Nemathaga et al., 2008; Sawalem et al., 2009; Shinee et al., 2008). Some other disposal methods are utilized in the management of clinical wastes are steam sterilization or autoclaving, chemical sterilization, microwaving, etc. (Da Silva et al., 2005; Shinee et al., 2008). The most common methods utilized in healthcare centers to dispose clinical waste in different countries are shown in Table 5.

Table 5
The most common disposal methods of clinical waste in healthcare centers of different countries.

Country	Disposal methods	References
Algeria	Open dumping Incineration	Bendjoudi et al. (2009)
Mongolia	Open dumping or open burning Incineration Autoclaving	Shinee et al. (2008)
South Africa	Landfill Open dumping Incineration Autoclaving	Nemathaga et al. (2008)
Palestinian-Territory	Open burning Incineration Thermal Disinfection	Al-Khatib and Sato (2009)
Bangladesh	Dumping	Hassan et al. (2008) Patwary et al. (2009b)
Nigeria	Dumping Burning Incineration	Coker et al. (2009)
Mauritius	Incineration Sanitary Landfill	Mohee (2005)
Libya	Dumping incineration	Sawalem et al. (2009)
Brazil	Landfill Incineration Autoclave	Da Silva et al. (2005)
Kingdom of Bahrain	Landfill Incineration Autoclave	Mohamed et al. (2009)
El-Beheira Governorate, Egypt	Dumping Incineration	Abd El-Salam (2010)
Greece	Recycling-reuse Pyrolitic combustion landfill	Tsakona et al. (2007)
Korea	Incineration Autoclave Recycling	Jang et al. (2006)
Malaysia	Landfill Incineration Recycling	Personal investigation

7.1. Open dump and open burning

Open dump is the most common method of clinical waste disposal in developing countries (Al-Khatib and Sato, 2009; Coker et al., 2009). This is probably less expensive and no other alternative methods are available at this reasonable cost. Though, this method also is the least cost option, but open dumping has long been recognized as a potential infection source of public health and environmental pollution (Al-Khatib and Sato, 2009). It is uncontrolled and inadequate disposal option of clinical waste, since the waste accessible to scavengers and animals (Coker et al., 2009; Pruss et al., 1999). Therefore, clinical waste should not be deposited on or around open dumps. This is because this uncontrolled clinical waste transmits infectious pathogenic micro-organisms to the environment either via direct contact through wounds, inhalation, or ingestion, or indirect contact through the food chain or a pathogenic host species (Pruss et al., 1999). Also wind easily blows over the dumped waste, dispersing air pollutants to nearby communities (Coker et al., 2009; Nemathaga et al., 2008).

Burning is aimed to reduce the volume of waste and stopping the spread of papers (Nemathaga et al., 2008). The burning itself is a potential source of generating toxic emissions. This is more likely since wastes such as plastics, syringes and paper are burned together (Nema and Ganeshprasad, 2002). There is high chance that toxic chemicals like dioxins and furans are generated and separating air pollutants (Kaisar Alam Sarkar et al., 2006; Nemathaga et al., 2008).

7.2. Landfill

In general, landfill is an easy and low cost waste disposal method. But, if a landfill is not properly managed, it raises human health risk and environmental pollution concern (But et al., 2008; Narayana, 2009). However, landfill is considered an unsophisticated disposal method, which requires careful segregation of waste so that it does not pose significant health effects on public health and environment (Moritz, 1995; Visvanathan, 1996). In developing countries, landfills are operated like an open dump. The clinical waste is dumped in the landfill mixed with non-clinical wastes, and later burned (Nemathaga et al., 2008). Landfill produces waste products in three phases during the waste degradation process. These are solid (i.e., degraded waste), liquid (i.e., leachate, which is water polluted with waste), and gas (usually referred as landfill gas) (But et al., 2008). Further, these three waste products may pollute the three principle media of environment, as shown in Fig. 2. Therefore, landfill is not a safe solution to treatment of the clinical waste. This is because landfills can produce gas and contaminated water, as well as wind-blown litter and dust, and attract vermin. Besides, land disposal of clinical solid waste is often done in low lying areas of an open land, which may prone to flooding, increasing the possibility of surface water contamination during the rainy season (Narayana, 2009). The main potential impacts on health arise from inhaled landfill gas and exposure to groundwater contaminated by landfill leachate (UNEP, 1996; Williams, 2005). Although landfill gas consists mainly of methane and carbon dioxide, it can contain a large number of other gases at low concentrations, some of which are toxic (Williams, 2005). The major components of landfill gas, methane and carbon dioxide, are 'greenhouse gases (GHGs). Both gases are major constituents of the world's problem GHGs; however while carbon dioxide is readily absorbed for use in photosynthesis, methane is less easily broken down, and it is considered 20 times more potent as a GHG (Johannessen, 1999). Leachate, on the other hand, poses a threat to surface and ground water systems (Williams, 2005). Leachate from landfill sites tends to have highly variable concentrations of wide range of salts, halogenated organic compounds, trace metals and organic acids, which may contaminate with surrounding soil and water (The World Resource Foundation, 1996). It has also been reported that leachate from solid waste landfill site may be mutagenic and carcinogenic (Kjeldesen et al., 2002).

Landfills of clinical waste are a potential threat to the human health and the quality of the environment, although the full extent of this threat has not been scientifically evaluated. In many countries, clinical wastes are restricted to dispose in landfill, unless it is disinfected from infectious micro-organisms as to pose any risk to human health (Nema and Ganeshprasad, 2002). For instance, clinical waste has come to European landfills under strictly control because of infectious nature of the waste and public abhorrence (Blenkharn, 2006b; Fisher, 2005).

Several studies in the literature have reported on risk assessment that is related to environmental issue especially regarding

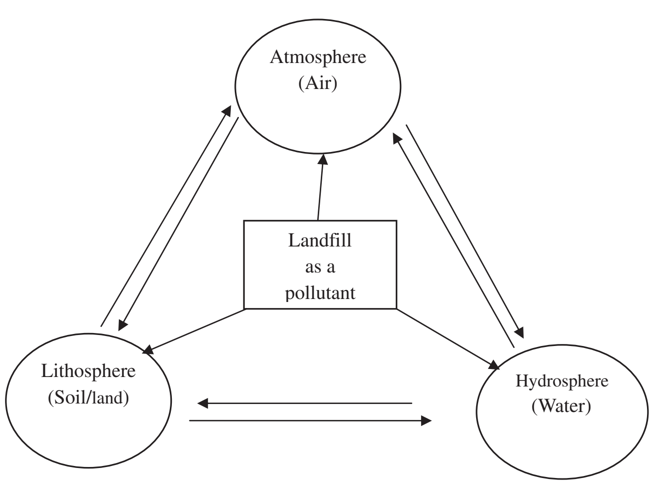

Fig. 2. Three principle environmental media and fundamental pathways for landfill to travel through (Source: But et al., 2008).

the environmental pollution by landfill leachate and gas. But, very few studies in the literature have reported on infectious risk of human health and the pathway of infection through clinical waste landfill. Blenkharn (2006a) reported that *staphylococcus aureus*, *Enterococcus* spp., *Salmonella* spp. and other *enterobacteriaceae* are found in landfill leachate many weeks after clinical waste deposit in landfill. Therefore, landfill can be considered as a prolonged survival and dispersal of pathogen micro-organisms from clinical waste (Blenkharn, 2006a). In another study, Hale Boothe et al. (2001) determined 43 different species of bacteria and yeast in landfill leachate and bulk material during an engineering aerobic bioreduction process. Among the bacteria species, some of them are associated with human infections.

Landfill is the common option for the general waste disposal methods. Besides, it also takes part as a secondary option for other waste disposal methods. Furthermore, landfill continues to be a common method of waste disposal despite the high potential to pollute the environment and human health infection. Therefore, it is bearing the importance to think about proper engineered landfill to minimize the risk assessment of the landfill hazards to preserve the environment and the human health. From this aspect, waste can be dispose in a 'Sanitary landfill', after it has been properly sorted. Sanitary landfill is a modern engineering landfill where waste is allowed to decompose into biologically and chemically inert materials in a setting isolated from the environment (Chen et al., 2003; Pruss et al., 1999).

7.3. Incineration

The numerous advantages of incineration have led to its worldwide use as the preferred means of treating and disposing clinical solid waste (Ananth et al., 2010; Jang et al., 2006; Lee et al., 2004). Incineration is a high-temperature dry oxidation process that converts the waste into residual ash and gases. It is particularly useful in the treatment of pathological waste and sharps, as these components of the waste stream are rendered unrecognizable. This process is usually selected to treat wastes that cannot be recycled, reused, or disposed of in a landfill site. Incineration emits lots of harmful pollutants including particular concern carbon monoxide (as a result incomplete combustion), hydrogen chloride, metals (e.g. mercury lead, arsenic, cadmium) (WHO, 2005) dioxin and furan (Lee et al., 2004; Ruoyan et al., 2010; Shinee et al., 2008; WHO, 2005). Many of these pollutants, dioxins in particular, can be carried long distance from their emissions source and accumulate in soil, water, and food source, and pollute them (Toxics Action Group, 2001).

The successful incineration of clinical solid waste within a safe waste management program depends on the form of collection containers, maintenance support, acceptable energy sources, and understandable operational instructions (Rogers and Brent, 2006). It is reported that a properly designed incinerator can completely burn waste and leave minimum residual in the form of ashes, whilst minimizing the exposure risks to emissions through the correct placement of the units in relation to the clinic and the surrounding communities (Nemathaga et al., 2008). Unfortunately, especially in developing country's hospitals, most of the incinerators are in poor design and have operational problems (Coker et al., 2009; Da Silva et al., 2005; Sawalem et al., 2009). The incinerators are local made and it is constructed from burned bricks and cement (Nemathaga et al., 2008). Waste is burned using coal as fuel, which cannot produce require temperature to properly burn the waste (Nemathaga et al., 2008). Therefore, high amount of ash is generated because of incomplete burning of waste.

Incineration is an inappropriate technology for most developing countries due to high financial start-up cost and occupational capital required to implement incineration facilities (Blenkharn, 2005;

Coker et al., 2009; Nemathaga et al., 2008; Sawalem et al., 2009). Besides, there is still need some quantity of ash and unburned waste to be disposed of especially at the landfill, which poses significant hazard for the human being and for the environment (Mohamed et al., 2009; Williams, 2005). Another distinct concern on the risk of infectious micro-organisms, many people still believe that if infectious clinical waste is incinerated, the emission from stack gas and the ash may have infectious micro-organisms even if the most modern incineration plant is used (Blenkharn, 1995; Saini et al., 2004). Besides, exposure of diseases within the population of an incineration plant is difficult to undertaking (Pleus and Kelly, 1996). Different authors demonstrated that the emission of viable micro-organisms with the exhaust gas from several modern incinerators (Blenkharn and Oakland, 1989; Scott and Jones, 1990; Toxics Action Group, 2001). Blenkharn and Oakland (1989) studied the exhaust gases of a hospital incinerator during normal operation. Flue gas temperatures varied over the range 186–305 °C. Study reported that bacteria was recovered from the base of the exhaust stack of about 400 cfu m^{-3}, but no sampling was performed at the top of the flue stack where the flue gas was discharged. The recovered bacteria which were isolated were gram positive (*Bacillus* spp., *Staphylococcus aureus* and coagulase negative staphylococci) and low number gram negative species (i.e., *Pseudomonas fluorescens*). Dugenest et al. (1999) conducted a study to determine viable micro-organisms in the municipal solid waste incinerator during aging the ash. Study reported that bottom ash contained $(1.07 \pm 0.04) \times 10^7$ cell/g micro-organisms in dry bottom ash. The greatest number of micro-organisms was found during the first month, and the number of micro-organisms increased until about 5 months. Therefore many developed countries of the world are bringing an end to waste incineration and are turning to alternative technology of incinerator due high maintain cost and serious negative environmental impact (Eriksson et al., 2005; Lopes et al., 2004; Karagiannidis et al., 2010; Marincovic et al., 2008; Rand et al., 2000; UNEP, 1996).

7.4. Autoclaving

Since 1876, autoclaves have been used for the sterilization of various kinds of infectious hospital waste (Salkin, 2003). Autoclaves are generally used to treat sharps, items contaminated with blood, residues from surgery and from isolation wards, bandages, gauze, linen, gowns, and other similar materials and non-chemical laboratory wastes. The autoclaves have a temperature range of 50–250 °C, but they are operated at 160 °C as the optimum temperature to kill bacteria.

Autoclave of clinical waste is considered as an alternative technology of the incinerator, but it is viewed as a more costly method than incineration (Al-Khatib and Sato, 2009; Jang et al., 2006). This is because, autoclaving is the double treatment option of clinical solid waste, since autoclaving wastes require another treatment method for final disposal (Jang et al., 2006). Furthermore, it cannot handle large quantities of hazardous waste. Besides, autoclave cannot treat a variety of chemical and hazardous substances such as wastes from chemotherapy treatment, mercury, volatile and semi-volatile organic compounds, radioactive wastes, and other hazardous chemical wastes (Lee et al., 2004). It is not suitable to treat large body parts, animal carcasses, or other large items that, because of their mass and other characteristics, which make it difficult or time consuming for the entire material to reach the prescribed temperatures (Pruss et al., 1999).

7.5. Microwaves

Microwaves are electromagnetic waves with frequencies between radio and infrared waves. It is important that the waste is wet, either as a result of naturally occurring moisture or by the addition of steam, in order to create the thermal process. Some treatment processes utilise microwaves to heat water to form steam, which is then applied to the clinical waste stream. Some systems apply low frequency radio waves to inactivate micro-organisms contained within the waste. The microwaves heat the clinical waste from the inside of the materials to their external surfaces.

However, microwaving clinical waste might be economically competitive compared to the incinerator (Lee et al., 2004). Nevertheless microwave technology is not suitable for large scale treatment. The treatment cost is also expensive and is not affordable for the developing countries. Surveys also reported that microwaving of clinical waste refers inadequate microorganism sterilization capability (Cha and Carlisle, 2001; Lee et al., 2004).

8. Determination of suitable method

It is apparent that the existing clinical waste management is not able to adequately preserve human health and environmental contamination from infection. The transmission of blood-borne viruses and respiratory, enteric and pathogenic infections through improper clinical waste disposal is not well described in the literature. Surveys showed that if the incineration is properly handled, it would be a suitable treatment method to treat clinical solid waste (Jang et al., 2006; Shinee et al., 2008). But the exposure of harmful pollutants produced from the incineration of clinical waste is still fearful (Jang et al., 2006; Lee et al., 2004). Shinee et al. (2008) argued that if the incineration is considered as an interim solution for the treatment of clinical waste, the existing low-temperature incinerators should be banned, and modern incinerators equipped with proper air pollution control units can be used as one of the methods to treat and dispose clinical solid waste. The problems are typical of any developing country that cannot afford to buy more environment friendly incinerators with the latest technology. Because of its potential for producing dioxins, furans and heavy metals from incineration of clinical waste, autoclaving and microwaving have been considered as a positive alternative clinical waste treatment method of incineration. However, autoclaving and microwaving are not generally applicable for the disposal of pathological, radioactive, laboratory and chemotherapy waste (Lee et al., 2004). The specific clinical waste management therefore has been of major concern due to the potentially high risks to human health and the environment. Even in less developed and transitional countries, the waste disposal options are also inconsistent (Shinee et al., 2008).

In some developing countries, it is a common scene that poor scavengers, women and children collect some of the medical wastes (e.g. syringe-needles, saline bags, blood bags etc.) for reselling despite the deadly health risks (Coker et al., 2009). Surveys reveal that incidence of diseases are prevalent among waste handlers; compare to incidences other hospital staff (Marincovic et al., 2008; Coker et al., 2009). A study reported that in USA, waste handlers in handling clinical waste have a 2.4–7 times more chance of getting infected by HIV compared to other staff in healthcare facilities (Turnberg, 1996). Waste handlers are infected by some other common diseases because of unsafe handling of clinical waste are Cholera, Typhoid fever, Hepatitis, Turberculosis, Bronchitis, Diarrhoea, skin infection etc. (Coker et al., 2009; Marincovic et al., 2008). Some hazards are associated with handling and transport as (HCWH, 2001):

– needle-stick
– injuries due to other sharps, such as broken glass
– ergonomic issues especially related to lifting

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– blood splatter during waste handling
– aerosolized pathogens (disease causing micro-organisms released as aerosols or tiny droplets suspended in air) during loading, compaction, or break up of untreated waste spills
– chemical and hazardous drug exposure

Other hazards depend on which treatment technology is used:
– hot surfaces that cause burns
– steam from a treatment chamber
– elevated temperatures in the work area due to insufficient cooling and ventilation
– volatile organic compounds and other chemicals released into the workplace
– toxic pollutants from a short exhaust stack
– ionizing radiation from irradiative processes
– non-ionizing radiation such as from microwaves
– noxious odors
– noise pollution

The continuously increasing treatment and disposal cost of clinical waste and its hazards of the human health and environment are related to the misclassification and the improper disposal of waste (Blenkharn, 2005; Diaz et al., 2008; Lee et al., 2004). Surveys reported that appropriate management reduces infectious wastes generation, minimize the health hazards and environmental pollution as well saving disposal cost (Blenkharn, 2005; Lee et al., 2004; Sabour et al., 2007). Survey also reveals that general waste requires lower disposal costs and that is ten to twenty times less than that of clinical wastes (Park and Jeong, 2001). Furthermore, healthcare waste contains enormous volumes of reusable and recyclable materials (Marincovic et al., 2008). It is being also reported that only a fraction of healthcare waste requires special attention and that the development of reusing and recycling programs waste can serve as a means of reducing rising quantities of waste generation and treatment cost (Blenkharn, 2005; Jang et al., 2006; Lee et al., 2004; Ozbek and Sainin, 2004; Park and Jeong, 2001; Patil and Shekdar, 2001; Tsakona et al., 2007; Tudor, 2007). If the waste can be reused or recycled, the disposal costs would reduce and return money by selling recyclable materials. The recycling and reuse of clinical waste materials are therefore, very important to reduction the waste generation as well as reduction the disposal cost (Cheng et al., 2009; Lee et al., 2002, 2004; Tudor, 2007). Recycling is the most desirable way to reduction the waste generation and to prevent materials from entering the waste stream. Currently, many hospitals in develop countries like USA, UK are operating recycle program to recycle uncontaminated solid waste materials like office paper, cardboard, metal cans and selected glass (Lee et al., 2002; Tudor, 2007). To operate a recycling program at a hospital, Lee et al. (2002) suggested that recyclable materials must be come from a non-infectious patient so that the waste is never contaminated with any infectious agent. On this basis, waste should be segregated and classified at the generation source during collection in healthcare centers (Blenkharn, 2005; Lee et al., 2004; Sabour et al., 2007). If the waste is not properly classified or segregated, the recycling-reuse of clinical solid waste would be dangerous to waste collecting staffs because of major concern over the infectious nature of clinical solid waste. However, it appears that most healthcare centers of developing countries face difficulties on the handling and management of clinical solid waste because of insufficient economic investment, lack of regulatory trained hospital staffs and specific materials (i.e., Color coded plastic bags, waste bin) for separation of infectious wastes at the generation source. Therefore, it is impossible for HCFs at developing countries to provide effective segregation and classification of clinical waste, hence successful recycling-reuse program. On this basis, it is high time to think about any effective sterilization technology to sterilize the clinical waste at the generation source (Marincovic et al., 2008; Tsakona et al., 2007). There are many advantages over the effective sterilization of clinical waste at the generation sources during initial collection, such as

– Waste can be treated as non-clinical waste.
– Waste will be free from infectious pathogenic micro-organisms.
– Waste will not pose any threat for clinical staff and hospitals environment.
– Handling of clinical waste during collection, storage and transportation will be carried out by non-specialized clinical staff.
– Segregation and classification of waste will be carried out at the point initial collection by non-specialized clinical staff.
– Recycling-reuse program of clinical waste will be carried out successfully.

9. Supercritical fluid carbon dioxide sterilization

The definition of the term ‘sterilization’ is the complete destruction or removal all living microorganism on or within a substances, including bacteria or spores, viruses, and fungi (Maurer, 1978; Williams, 2005; Zhang et al., 2006a). The most common sterilization techniques used are stream autoclaving, ethylene oxide, and ionizing radiation (Dempsey and Thirucote, 1989; Matthews et al., 2001; Zhang et al., 2006a). Though, all these methods assure a satisfactory microbial inactivation, but have a number of limitations (Nik Norulaini et al., 2008; Spilimbergo et al., 2003). For instance, in the case of thermally or hydrolytically liable polymers, autoclaving can destroy the temperature sensitive materials (White et al., 2006). Furthermore, all these techniques are very expensive and difficult to manage and control because of the extremely high temperature and pressure required (Spilimbergo et al., 2002, 2003; White et al., 2006). Therefore, above sterilization method are not suitable for the sterilization of clinical solid waste, since the heat sensitive reusable waste materials may destroy with the high temperature. Hence, it is bearing urgency to determine low temperature sterilization technology, where supercritical fluid (SCF) sterilization technology is highly promising.

SCF is any compound at a temperature and pressure above the critical values (above critical point). Above the critical temperature of a compound the pure, gaseous component cannot be liquefied regardless of the pressure applied. The critical pressure is the vapor pressure of the gas at the critical temperature. In the supercritical environment only one phase exists. The fluid, as it is termed, is neither a gas nor a liquid and is best described as intermediate to the two extremes. This phase retains solvent power approximating liquids as well as the transport properties common to gases. Like a gas the SCF shows lower viscosity and higher diffusivity relative to the liquid (Baiker, 1999). These properties facilitate mass transfer phenomena, such as matrix extraction or impregnation. Like a liquid, the SCF shows density of a value high enough for exerting salvation effects. A SCF is dense but highly compressible, thus, any pressure change results in density alteration and, consequently, in solvent power variation (Zhang et al., 2008). In the vicinity of the critical point, the compressibility is high, and a small pressure change yields a great density modification. A comparison of typical values for density, viscosity and diffusivity of gases, liquids, and SCFs is presented in Table 6.

Several SCFs have been used in both commercial and development processes, of which the most commonly used carbon dioxide (CO_2) (Temtem et al., 2009). CO_2 has been widely uses SCF due to many advantageous features such as effective against microorganism, low critical parameters (31.1 °C, 73.8 bar), low cost and non-toxicity, non-flammable, available in abundance, recyclable, environment friendly (Nik Norulaini et al., 2008; Spilimbergo and Bertucco, 2003; Spilimbergo et al., 2003; Temtem et al., 2009;

Table 6
Comparison of physical and transport properties of gases, liquids, and SCFs (Source: Baiker, 1999).

Property	Density (kg/m^3)	Viscosity (cP)	Diffusivity (mm^2/s)
Gas	1	0.01	1–10
SCF	100–800	0.05–0.1	0.01–0.1
Liquid	1000	0.5–1.0	0.001

Zhang et al., 2006a)., Since the critical values of pressure and temperature are relatively low, the gas is relatively easy to handle under supercritical conditions (Elvassore et al., 2000; Enomoto et al., 1997; Spilimbergo et al., 2002, 2003). Furthermore, SF-CO_2 presents high dissolving power, high diffusivity and low viscosity for the microbial inactivation makes it widely used in supercritical fluid sterilization technology, and attract interest to be continues (Kincal et al., 2005; Nik Norulaini et al., 2008; Paulaitis et al., 1983; Spilimbergo et al., 2002, 2003; White et al., 2006).

SF-CO_2 is effective against any short of micro-organisms, as it impacts target micro-organisms both physically and chemically (Jimenez et al., 2008; Kamihira et al., 1987; Kim et al., 2009; Spilimbergo et al., 2002). Surveys have revealed that SF-CO_2 potentially used to sterilize biomedical device for being effective against bacteria (Dillow et al., 1999; Spilimbergo et al., 2002), Viruses (Fages et al., 1998), and spores (Zhang et al., 2006b), although in some cases additives have been used to achieve terminal sterilization, namely hydrogen peroxide (Zhang et al., 2006a), peracetic acid (White et al., 2006). Furthermore, this technology sterilizes the heat sensitive biomedical device without any damage and lowering its quality (Dillow et al., 1999; Kamihira et al., 1987; Zhang et al., 2006a). For instance, Dillow et al. (1999) carried out their experiments with few bacteria and a colony of spores using SC-CO_2. They injected these bacteria into biodegradable polymers, treated them with CO_2 and were successful in their inactivation resulting in no damage in these sensitive polymers (Dillow et al., 1999). In recent years, due to its ability of killing micro-organisms in moderate pressure and low temperature, SF-CO_2 has been receiving interest as a power sterilization technology in various fields (Spilimbergo et al., 2007; White et al., 2006; Zhang et al., 2008). Sterilization of various micro-organisms using SF-CO_2 at different experimental conditions is shown in Table 7.

So, it can be concluded that SF-CO_2 sterilization technology is receiving potential interest with regards to the inactivation of the micro-organisms in clinical solid waste. Furthermore, recycling-and-reuse programs of clinical solid waste can be carried out without any risk of infection. Clearly, clinical solid waste materials such as medical tools and equipments made from metallic or plastic components, and plastic materials, paper, cardboard, etc can be reused and recycled, respectively, after SF-CO_2 sterilization. Therefore, the adoption of SF-CO_2 sterilization technology in the management of clinical solid waste can reduce exposure to infectious waste, decrease labor, lower costs, and yield better compliance with regulatory and accrediting agencies. Thus HCFs can both save money and provide a safer environment for patients, healthcare staffs and clinical staffs. Therefore, waste management plan in HCFs can be changed by the following strategies: (i) Where possible use reusable items rather than disposable items, which can be disinfected and reused. (ii) Sterilize reusable items using

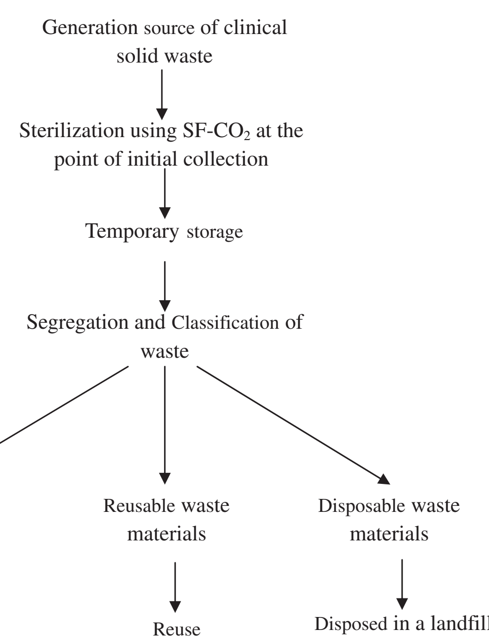

Fig. 3. The possible clinical solid waste management plans to hospital after the adoption of SF-CO_2 sterilization technology.

Table 7
List of micro-organisms processed by SCF-CO_2.

Micro-organisms	Experimental conditions				References
	Pressure bar	Temperature °C	Time min	Additive	
Salmonella enterica	80–250	35–55	15–30		Kim et al. (2009)
Bacillus subtilis spores	70-150	36-75	120 min		Spilimbergo et al. (2003)
Baker's yeast *Escherichia coli* *Staphylococcus aureus* Conidia	203	35	120	C_2H_5OH Or CH_3COOH	Kamihira et al. (1987)
Lactobacillus brevis *Saccharomyces cerevisiae*	250	35	–		Ishikawa et al. (1995)
Geobacillus stearothermophilus and *Bacillus atrophaeus* spores	304	40	60	H_2O_2	Hemmer et al. (2006)
Saccharomyces cerevisiae (Yeast)	70–210	Supercritical condition	15		Lin et al. (2008)
Pseudomonas fluorescens	103–483	40	15–35		Werner and Hotchkiss (2006)
Staphylococcus aureus and *Escherichia coli*	276	40	60	H_2O_2	Jimenez et al. (2008)
Salmonella typhimurium	80–150	35–45	10–50		Kim et al. (2007)
Bacillus pumilus spores	275	60	240	H_2O_2	Zhang et al. (2006b)
Bacillus atrophaeus spores	275	40	240	H_2O_2	Zhang et al. (2006c)

SF-CO_2, quality assurance, proper monitoring, and validation of cleaning, disinfection for patient care, and reused the pre-sterilized single-use items. (iii) Recycling the plastic materials. The possible clinical solid management plan for HCFs can be followed after the adoption of SF-CO_2 sterilization technology as shown Fig. 3.

10. Conclusion

In this review, existing clinical solid waste management practices has been investigated to determine appropriate management technology for the management of clinical solid waste in healthcare centers. The main priority has been given on the handling and disposing of clinical solid waste by taking into consideration both infectious risk and economic factors. It is observed that the generation of clinical solid waste has been increasing due to the wide acceptance of single-use disposable items. The existing waste management practices, particularly in third world countries, are considered as inadequate. The clinical and non-clinical materials are mixed together before they properly disposed of due to (i) insufficient financial investment, (ii) lack of awareness of health care staffs, (iii) lack of skilled clinical staffs. Therefore, healthcare centers are not able to segregate the clinical solid waste prior to disposal, which exacerbates health effects and high disposal cost. This review study reveals a serious need to adopt effective sterilization technology in management of clinical solid waste prior to final disposal. Hence, adopting the supercritical fluid carbon dioxide sterilization to sterilize the clinical solid waste at the point of initial collection is highly recommended to prevent infection and contamination. Consequently, waste would not bear any infectious risk and therefore, collection, segregation and recycling-reuse program of clinical solid waste materials can be carried out with nonskilled clinical staffs. Accordingly, healthcare centers can provide a safe environment for the patients, healthcare staff and waste handlers. Furthermore, the adoption of SF-CO_2 sterilization technology in management clinical solid waste would reduce exposure to infectious waste, decrease labor, minimize the management costs, and yield better compliance with regulatory.

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