



Overview of technologies for the treatment of infectious and sharp waste from health care facilities



World Health Organization

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ISBN 978-92-4-151622-8

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Cover photos (descending order): Ute Pieper (1, 3, 5, 6); Arabella Hayter, WHO (2, 4)

Design and layout: L'IV Com Sàrl

Printed in Switzerland

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Abbreviations

BOR	Bed occupancy rate
HEPA	High efficiency particulate air
ISWA	International Solid Waste Association
SDG	Sustainable Development Goal
TEQ	Toxic equivalent
UN	United Nations
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
WASH	Water, sanitation and hygiene
WHA	WHA World Health Assembly
WHO	World Health Organization

Acknowledgements

The lead author of this document was Dr Ute Pieper. Ms Arabella Hayter, Dr Maggie Montgomery and Mr Bruce Gordon (Water, Sanitation, Hygiene and Health Unit, WHO HQ) provided technical inputs and review.

A number of professionals, including from WHO, UNICEF and the health care waste working group of the International Solid Waste Association (ISWA) reviewed and contributed to this document. The input of the ISWA working group was coordinated by Ms Jennifer MacDonald.

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1. Introduction

Safe health care waste management, including segregation, collection, transport, treatment and waste disposal, is fundamental to wider efforts to provide safe and quality health care. Safe health care waste management practices also support a number of the UN Sustainable Development Goals (SDGs), including Goal 3 on health, Goal 6 on safely managed water and sanitation, Goal 7 on climate change and Goal 12 on sustainable consumption and production. According to new global data released by WHO/UNICEF in 2019, there is no or very limited safe management of health care waste in a large proportion of facilities. The data, representing over 560 000 facilities from 125 countries, indicate that 40% of health care facilities do not segregate waste. In least developed countries, the situation is far worse with only 27% of countries having basic (segregation and safe waste destruction) services.¹

In parallel, WHO/UNICEF have published global guidance on the practical steps that need to be taken to solve the crisis. These steps include developing national roadmaps, setting targets and regular monitoring, improving infrastructure and maintenance, developing the health workforce and engaging communities.² Case studies are used to illustrate these steps, including examples of waste recycling schemes and use of non-incineration technology.

The purpose of this document is two-fold. The first is to provide criteria for selecting technologies to facilitate decision making for improved health care waste management in health care facilities. The second is to provide an overview of specific health care waste technologies for the treatment of *solid infectious and sharp waste* for health care facility administrators and planners, WASH and infection prevention control staff, national planners, donors and partners. For each technology, details on its operation, effects on the environment and health, requirements for installation, capacities

¹ WHO/UNICEF, 2019. WASH in health care facilities: global baseline 2019 report. https://www.who.int/water_sanitation_health/publications/wash-in-health-care-facilities-global-report/en/. To view the global, regional and country data visit www.washdata.org.

² WHO/UNICEF, 2019. WASH in health care facilities: Practical steps to achieve universal access to quality care. https://www.who.int/water_sanitation_health/publications/wash-in-health-care-facilities/en/

for treating waste, examples of consumables and advantages and disadvantages are described.

Infectious waste: Waste that contains pathogens and poses a risk of disease transmission e.g., waste contaminated with blood and other body fluids; laboratory cultures and microbiological stocks; waste including excreta and other materials that have been in contact with patients infected with highly infectious diseases, particularly those in isolation wards.

Sharp waste: Items that could cause cuts or puncture wounds e.g., hypodermic, intravenous or other needles; auto-disable syringes; syringes with attached needles; infusion sets; scalpels; pipettes; knives; blades; broken glass.

Source: WHO 2014

This document is particularly focused on resource-limited settings of low and middle-income countries. The document describes environmentally friendly technologies which advance climate mitigation strategies and help to meet commitments enshrined in global environmental conventions.

The waste-management hierarchy

- The preferred approach is to *avoid* generating waste and thus minimise the quantity entering the waste stream.
- Where practicable and safe, those waste items that can be *recovered* for secondary use is the next most preferable method.
- Waste that cannot be recovered must then be dealt with by the least harmful options, such as *treatment or land disposal* to reduce their health and environmental impacts.

Source: WHO 2014

This document is based on the WHO guidelines “Safe management of wastes from health care activities” (WHO 2014) and the UNEP “Compendium of Technologies for Treatment/Destruction of Health care Waste” (UNEP 2012a). The UNEP Compendium provides detailed process descriptions and information on types of waste treated, ranges of capacities, pathogen destruction, emissions, operational details, installation requirements, and maintenance needs for generic treatment technologies. This document also takes into account other UN documents, including WHO policy

and core principles on health care waste management (WHO 2004, 2007), the recommendations of the Stockholm Convention on waste incineration (UNEP 2007), the World Health Assembly (WHA) Resolution on WASH in Health Care Facilities (WHA, 2019) and input from manufacturers of treatment technologies.

Stockholm Convention

The Stockholm Convention recommends that priority consideration should be given to alternative processes, techniques or practices that have similar usefulness, but which avoid the formation and release of dioxins and furans (UNEP 2007). Non-incineration waste treatment technologies should always be implemented wherever possible. WHO calls on all stakeholders to uphold the Stockholm Convention and work towards incrementally improving safe health care waste management practices to protect health and reduce harm to the environment (WHO 2007). To this end WHO recommends that:

Governments should:

- Allocate a budget to cover the costs of establishment and maintenance of sound health care waste management systems
- Request donors, partners and other sources of external financing to include an adequate contribution towards the management of waste associated with their interventions
- Implement and monitor sound health care waste management systems, support capacity building, and ensure worker and community health.

Donors and partners should:

- Include a provision in their health program assistance to cover the costs of sound health care waste management systems.

All concerned institutions and organizations should:

- Promote sound health care waste management
- Develop innovative solutions to reduce the volume and toxicity of the waste they produce which is associated with their products
- Ensure that global health strategies and programs take into account health care waste management.

WHA Resolution on water, sanitation and hygiene (WASH) in health care facilities

At the 2019 World Health Assembly (WHA), Member States unanimously approved a resolution to work towards universal access to WASH, including safe management of health care waste in health care facilities.³ The resolution calls upon Member States and specifically Ministries of Health to conduct national assessments and analyses, develop roadmaps, set targets and implement standards. All 194 Member States have committed to report on progress every two years and external validation will be provided through regular reports on coverage levels through the WHO/UNICEF Joint Monitoring Programme and on policies and financing through the WHO-led UN Global Assessment and Analysis of Sanitation and Drinking-water (GLAAS).

In support of the resolution, and as part of global efforts to coordinate and catalyze efforts to improve WASH in health care facilities and safe management of health care waste, WHO, UNICEF and partners are committed to act. Specifically, efforts are focused on meeting the following targets:

- *Basic services:* By 2022, 60% of all health care facilities globally and in each SDG region will have at least basic WASH services⁴, 80% have basic WASH services by 2025, and 100% by 2030.
- *Higher service levels:* By 2022, higher levels of service are defined and monitored in countries where universal basic WASH services have been achieved already. By 2030, higher levels of WASH services are achieved universally in 80% of those countries.

Country progress will be tracked according to these targets and updates made available on the WASH in health care facilities knowledge portal.⁵ In addition, efforts to improve waste

³ WHA, 2019. Resolution on Water, Sanitation and Hygiene in Health Care Facilities. http://apps.who.int/gb/ebwha/pdf_files/WHA72/A72_R7-en.pdf

⁴ WASH includes, water, sanitation, hand hygiene, health care waste management and environmental cleaning. For a full definition see WHO/UNICEF 2018, Core Questions and Indicators for monitoring WASH in health care facilities in the Sustainable Development Goals.

⁵ The knowledge portal can be found at www.washinhealthcare.org. Users are encouraged to contribute content for the site, including submitting resources and making commitments.

management and reduce the environmental impact of such practices are being addressed through climate smart and green health care facility initiatives, vaccine waste reduction efforts and patient safety campaigns.



2. Priority considerations

To ensure sustainability, technologies should be selected according to the economic, environmental and social context. To choose the most appropriate technology, benchmarking, expert opinions and participatory assessment by relevant stakeholders should be considered (UNEP 2012b). The following steps can be used to select the best technology:

1. Baseline data collection
 - Legal requirements (national and international)
 - Volume of waste generated
 - Availability of resources water, electricity, fuel)
 - Available space and security for the treatment technology
 - Availability of collection and safe disposal of treated waste
 - Budget for capital, operation and maintenance costs
 - Use of decentralised or centralised waste treatment
2. Calculation of treatment capacity required
3. Mapping and screening of eligible technology options
4. Submission of bidding documentation and evaluation criteria (in cases of public bidding), including:
 - Experiences in the country/region, technical certificates, use of local or regional services, process for procuring spare parts, technical training, maintenance contracts, technical drawings, housing requirements, availability of documents in local language, costs (including equipment, transport to the site, installation and commissioning, operation), delivery time and proven experience in installing and maintaining the technology in a similar context
5. Decision making (evaluation of bids)

Table 1 provides a comparison of types of technologies available on the market which comply with the Stockholm and Basel Conventions. Table 2 compares interim treatment technologies which do not meet the two conventions. Tables 1 and 2 rate available technologies according to environmental impact, capital and operational costs

(● = low, ●● = medium, ●●● = high, ●●●● = very high). Table 1 covers those technologies which comply with the Stockholm and Basel Conventions, while those listed in Table 2 do not meet these requirements and are considered interim solutions.

Table 1. Comparison of infectious and sharp waste treatment technologies which comply with the Stockholm and Basel Conventions

Type of technology	Capacity (kg/h)	Environmental impact	Capital costs	Operating costs
Vacuum autoclave	5–3000	●	●	●
Autoclave with integrated shredding	5–3000	●	●●	●●
Batch wise microwave	1–210	●	●	●●
Continuous microwave	100–600	●	●●	●●
Frictional heat treatment	10–500	●	●●	●●
Sodium hypochlorite treatment	600–3000	●●	●●●	●●
Ozone treatment	45–1000	●	●●●	●
Incineration including flue gas treatment	50–3000+	●●	●●●●	●●●●

Table 2. Comparison of interim waste treatment technologies used in low-resource settings

Type of technology	Capacity (kg/h)	Environmental impact	Capital costs	Operating costs
Automated pressure pulsing autoclave	5–50	●	●	●
Dual chamber incinerator	5–500	●●	●●	●●
Single chamber incinerator	5–500	●●●	●	●
Open burning	N/A	●●●●	N/A	N/A

N/A: not applicable.

3. Selection of treatment technologies

This section highlights criteria for selecting waste technologies, including consideration of trade-offs to help guide health facility administrators, district health managers and national policy-makers. The guidance manual on the “Application of the Sustainability Assessment of Technologies Methodology” provides a detailed and comprehensive tool on how to select suitable solutions (UNEP 2012b).

The choice of treatment system is contextual and involves consideration of:

- Relevant national and international regulations and requirements
- Environmental and occupational safety factors
- Waste characteristics and quantity
- Technology capabilities and requirements
- Cost considerations
- Operation and maintenance requirements

Treatment technologies should comply with **national standards and international conventions** including the Stockholm Convention and the Basel Convention (for those countries that have ratified or acceded to the Convention).⁶ With regards to **environmental and occupational safety**, the recommendations in the WHO policy paper on health care waste management (WHO 2004), the Basel Convention Technical Guidelines for Environmentally Sound Management of Biomedical and Health care Wastes (UNEP 2003), and the Stockholm Convention Guidelines on Best Available Techniques and Provisional Guidance on Best Environmental Practices (UNEP 2007) should be taken into account. In some very low resource settings it may be difficult to meet international conventions and/or national standards, especially for waste destruction. In such cases, every effort should be made

⁶ Stockholm Convention - Number of Parties: 181; Status of ratification Stockholm Convention: <http://chm.pops.int/Countries/StatusofRatifications/PartiesandSignatoires/tabid/4500/Default.aspx> Basel Convention – Number of Parties 186: <http://www.basel.int/Countries/StatusofRatifications/PartiesSignatories/tabid/4499/Default.aspx>

to incrementally improve how waste is managed and destroyed to reduce, as much as possible, risks to human and environmental health. A plan should be put in place to ensure that over time, capacities and resources are available to meet national standards and international safeguards.

The **characteristics and quantity of waste** generated will vary according to the type or level of facility, between rural and urban areas, according to differences in services provided, scale, organizational complexity, availability of resources, and the number of clinical and non-clinical staff. Regulations or policies on waste classification as well as segregation practices affect waste generation rates. Furthermore, the quantity of waste that must be treated depends on whether waste is destroyed at a facility (decentralized treatment) or if waste from several health facilities is combined for treatment (centralized treatment). “Green procurement” (e.g. sourcing commodities with less packaging and/or reduced use of materials) can also reduce the amount of overall waste.

If a new treatment technology is needed, it is essential to know the predicted quantity of waste that will be generated to select the appropriate technology. To calculate the quantity of waste, average waste generation rates are calculated on a weekly basis to account for daily variations in a given week and lower activities at weekends. However, data are often provided in kilograms (kg) per day or kg per year. Kilograms per occupied bed per day and kg per outpatient per day are used to compare health care facilities with different levels of activities. If inpatient occupancy rates and the daily number of outpatients are not available, the total number of beds is often used to estimate kg of waste per bed per day.

Table 3 provides estimates that can be used to calculate infectious waste generation in low and middle-income countries when local data are not available. There is large variability in the volume of waste generated at a single type of facility and thus a facility assessment of waste is highly recommended before selecting a treatment technology. More specific data of different health settings and countries can be found in the WHO guidelines (WHO 2014, Chapter 2.9) and the UNEP compendium (UNEP 2012a, Chapter 7).⁷

⁷ Note: about 85% of the waste produced by health care providers is regarded as general non-hazardous waste. Implementing rigorous segregation of hazardous and non-hazardous waste can avoid over-sizing of equipment and result in cost savings (WHO 2014).

Table 3. Infectious health care waste rates

Facility	Infectious health care waste generation rate
Hospital	0.5 kg/bed per day
Clinic	0.07 kg/patient per day
Basic health unit	0.01 kg/patient per day

Source: UNEP 2012a.

Based on the amount of infectious and sharp waste generated, the required **capacity of the waste treatment technology** can be calculated. The waste generation rate per day (see Table 3) should be multiplied by the average number of patients per day or number of beds x bed occupancy rate.

Examples: Calculation of quantity of infectious waste generated and required treatment capacity

1. Hospital

Assumptions:

- 100 bed hospital; 100% bed occupancy rate (BOR); 1-hour cycle time, 6 hours waste treatment per day; 7 treatment days per week; 0.5 kg infectious waste per bed per day.

Calculation:

- $100 \text{ beds} \times 100\% \text{ (BOR)} \times 0.5 \text{ kg /bed/day} \times 1.2 \text{ (safety margin)} = 60 \text{ kg infectious waste per day}$
- $60 \text{ kg} / 6 \text{ working hours} = 10 \text{ kg per hour}$

Result:

This hospital needs a technology with a minimum treatment capacity of **10 kg per hour**.

2. Clinic (primary health care facility – outpatients only)

Assumptions:

- 10 patients per day, 0.07 kg infectious waste per patient, maximum storage of infectious waste: 2 days (48 hours).

Calculation:

- $10 \text{ patients} \times 0.07 \text{ kg/patient} \times 1.2 \text{ (safety margin)} = 0.84 \text{ kg infectious waste per day}$
- $2 \text{ days of storage} \times 0.84 \text{ kg per day} = 1.68 \text{ kg every two days}$

Result:

This clinic needs a technology with a minimum treatment capacity of **2 kg (every two days)**.

A safety margin of 20% should be added to the total to cover fluctuations in waste generation rates.

The amount of waste generated per day (kg/day) should be divided by the number of working hours per day of the waste treatment equipment to achieve the minimum treatment capacity needed (kg/h). If the treatment technology is only operated on specific days (e.g. Monday to Friday) the required capacity can be adapted. The cycle time of treatment technology is defined as the time needed for adding in waste, treating, and removing waste. An additional hour for the start-up of the treatment system should be considered.



Examples of annual operation costs of water and electricity:

Hospital with 100 beds using an alternative non-incineration technology for the treatment of infectious and sharp waste.

Assumptions:

- Non-incineration technology: 10 kg per cycle and 21,900 kg waste per year
- Manufacturer's data: 5 kWh average electricity consumption per cycle and 50 litres of water consumption per cycle

Example 1:

- Costs of consumables for the hospital: 0.1 USD per kWh and 1.0 USD per cubic meter water (1 m³ = 1000 litre; 1 litre costs 0.001 USD).

Calculation of electricity and water costs:

- Electricity and water costs of 1 cycle:
 - » $(5 \text{ kW} \times 0.75 \text{ h/cycle} \times 0.1 \text{ USD/kWh}) + (50 \text{ l/cycle} \times 0.001 \text{ USD/l}) = 0.375 \text{ USD/cycle} + 0.05 \text{ USD/cycle} = 0.425 \text{ USD/cycle}$
- Costs of the treatment of 1 kg of waste:
 - » $0.425 \text{ USD}/10 \text{ kg} = 0.0425 \text{ USD/kg}$
- Cost per year:
 - » $0.0425 \text{ USD/kg} \times 21,900 \text{ kg} = 930.75 \text{ USD}$

Example 2:

- Water is trucked to the hospital and electricity is generated by a diesel generator
- Costs of consumables for the hospital: 2 USD per kWh and 0.5 USD per cubic meter water (1 m³ = 1000 litre; 1 litre costs 0.0005 USD).

Calculation of electricity and water costs:

- Electricity and water costs of 1 cycle:
 - » $(5 \text{ kW} \times 0.75 \text{ h/cycle} \times 2.00 \text{ USD/kWh}) + (50 \text{ l/cycle} \times 0.0005 \text{ USD/l})$
 - » $= 7.50 \text{ USD/cycle} + 0.025 \text{ USD/cycle} = 7.525 \text{ USD/cycle}$
- Costs of the treatment of 1 kg of waste:
 - » $7.525 \text{ USD}/10 \text{ kg} = 0.7525 \text{ USD/kg}$
- Cost per year:
 - » $0.7525 \text{ USD/kg} \times 21,900 \text{ kg} = 16,479.75 \text{ USD}$

Result: The annual operation cost of the selected treatment technology for water and electricity for example 1 is **930.75 USD per year** and for example 2 is **16,479.75 USD per year**.

The **capital cost and annual operation and maintenance cost** of the technology must also be considered. Capital costs cover the equipment purchase including taxes, costs associated with shipment (including customs fees), insurance, site preparation (including provision of water, electricity and waste water drainage) and indirect costs like project management, architecture and engineering, permits and legal fees (UNEP 2012a).

Operation costs include labour, spare parts, waste bags/containers, electricity, water, fuel and waste disposal. The annual operation costs of consumables like water, electricity and fuel are based on:

- the consumption of the selected treatment option
- the number of cycles needed to treat the generated waste amount and
- the total cost of all consumables.

Maintenance and repair of treatment technologies are essential to ensure optimal operation. Maintenance requirements vary considerably according to the type of technology used and the manufacturer. The annual maintenance costs are estimated at 3-5% of the investment costs of the treatment technology. A detailed maintenance schedule should be provided by the manufacturer during commissioning and as part of operator training. When purchasing new equipment, provision for sufficient warranty time (at least 1 year) should be included, as well as essential and most commonly needed spare parts. Consumables kits should be easily accessible in-country. Proper user training, including basic maintenance and process validation and efficiency test kits (if applicable), should be provided by the manufacturer, an authorized service company or by the technician/operator of the treatment equipment in case of locally built incinerators.

Note: After selection of a waste treatment equipment, the end users must accept responsibility for addressing future maintenance, repair and infrastructure needs of the selected waste treatment equipment as specified by the vendor/manufacturer.

4. Technology specifications and requirements

Waste treatment requirements are defined in the “Technical Guidelines on Environmentally Sound Management of Biomedical and Health care Wastes” (UNEP 2003) based on the Basel Convention and the “Guidelines on Best Available Techniques and provisional guidance on Best Environmental Practices relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutant” (UNEP 2007). The Basel and the Stockholm Convention guidelines both state that waste treatment techniques which minimize the formation and release of chemicals or hazardous emissions should be given priority over other technologies. A general description of different treatment processes (low-heat thermal, chemical based, and open burning) can be found in Annex 1.

In the following section, the majority of current available health care waste treatment options are covered, grouped as follows:

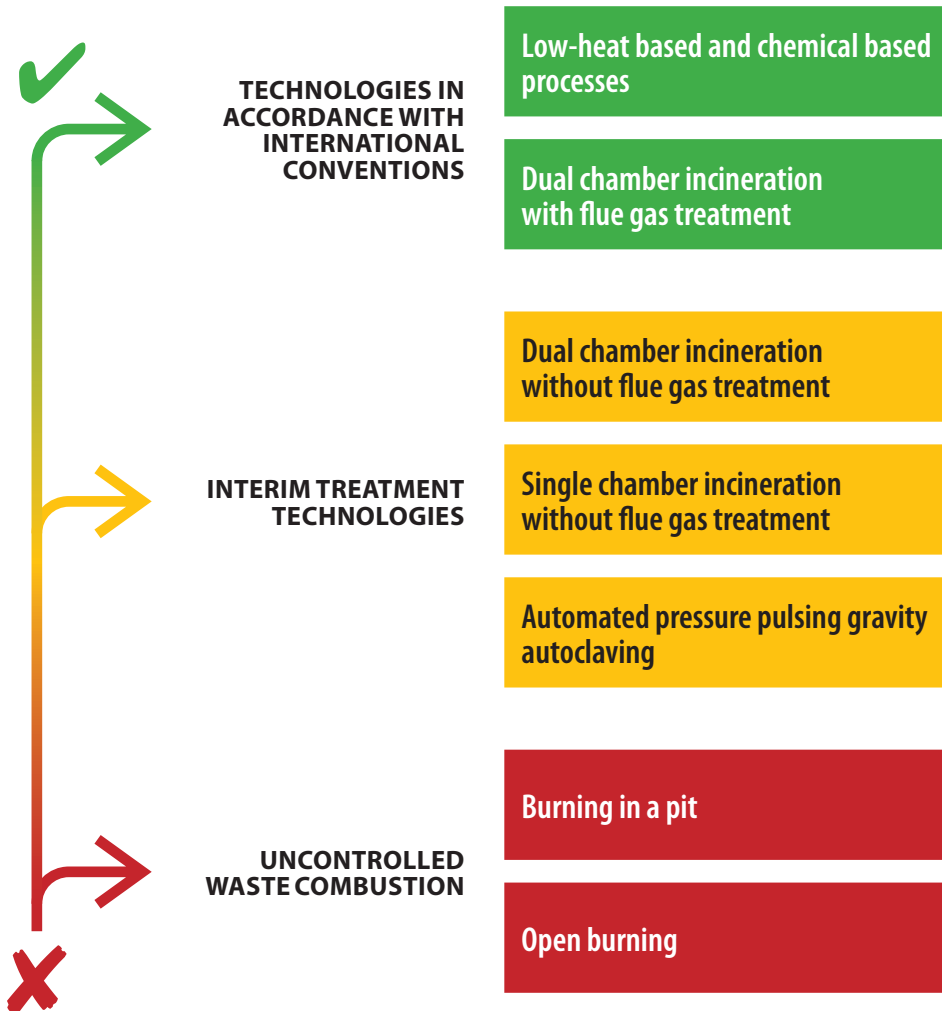
1. **Preferred options:** Technologies in accordance with International Conventions
 - Low-heat thermal-based processes
 - Autoclaves
 - Vacuum autoclaves without shredder
 - Autoclaves with integrated shredder
 - Microwave-based technologies
 - Frictional heat treatment
 - Chemical-based processes
 - Sodium hypochlorite-based technologies
 - Incineration with flue gas treatment

2. **Interim solutions:** Technologies used to incrementally improve practices and move towards meeting international standards
 - Automated pressure pulsing gravity autoclaving
 - Dual and single chamber incinerators

3. **Last resort option:** Where there are no alternative treatment options
 - Burning in a pit and open burning

The following treatment options represent the most relevant technologies and should not be considered as a complete database. Data on the average consumption of energy, water etc. have been provided by the manufacturer listed.

Figure 1. Treatment technologies ladder



4.1 Low-heat based processes

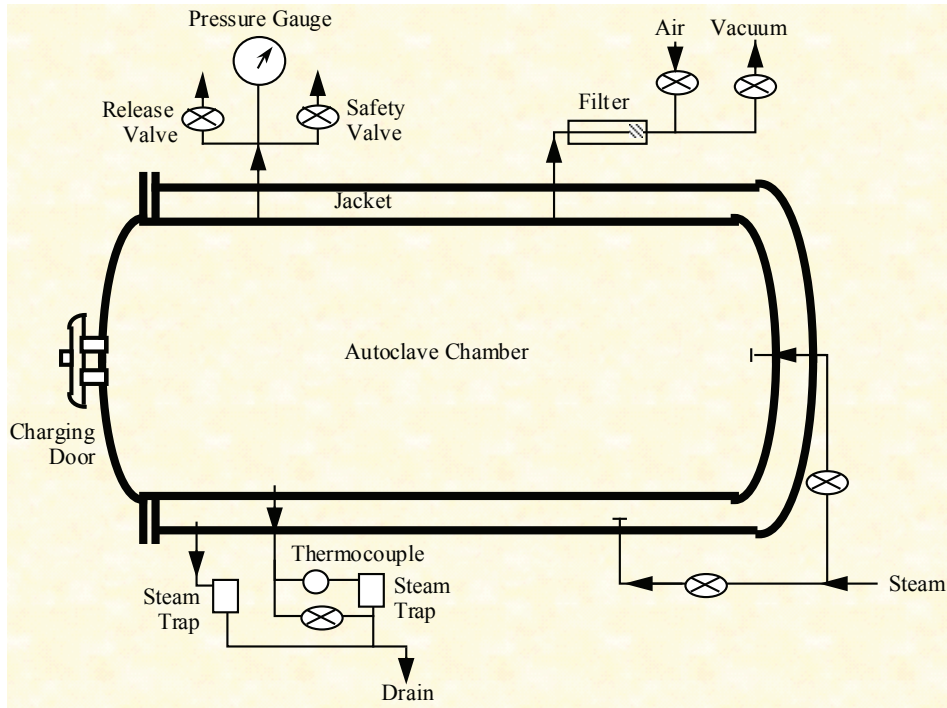
4.1.1 Autoclaves

An autoclave consists of a metal vessel designed to withstand high pressures, with a sealable door and an arrangement of pipes and valves through which steam is introduced into and removed from the vessel. Because air is an effective insulator and a key factor in determining the efficiency of steam treatment, removal of air from the autoclave is essential to ensure penetration of heat into the waste. Waste treatment autoclaves must also treat the air removed at the start of the process to prevent pathogenic aerosols from being released. This is usually done by treating the air with steam or passing it through a specific filter (e.g. High Efficiency Particulate Air (HEPA) filter or microbiological filter) before being released. The resulting condensate must also be decontaminated before being released to the waste water system.

4.1.1.1 Vacuum autoclaves

Modern waste autoclaves use a vacuum pump and/or a steam ejector to evacuate air before introducing steam, to ensure safe decontamination of the waste. One option is pre-vacuum autoclaves, which evacuates air once before injecting steam (Figure 3). Autoclaves which use a fractionated vacuum process to remove air are a safer option. This process evacuates air and admits steam several times to ensure that as much air as possible from the chamber is removed so that there is better steam penetration in the waste and better homogeneity of temperature during the decontamination phase (Figure 4). A drying phase after treatment is added to protect the operator against steam when opening the door. Waste is decontaminated at 121 °C to 134 °C therefore the waste bags used in autoclaves must be heat resistant and must allow steam to enter the bag. Polyethylene bags – the most widely available type – can resist 121 °C, but polypropylene bags are needed for machines operating at 134 °C. After treatment, the waste is considered non-hazardous and can be disposed accordingly.

Figure 2. Vacuum autoclave



Source: UNEP 2012a.

Figure 3. Pre-vacuum process

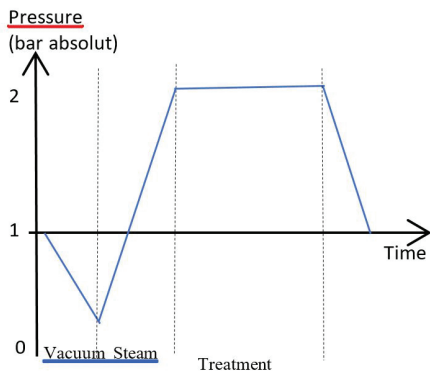
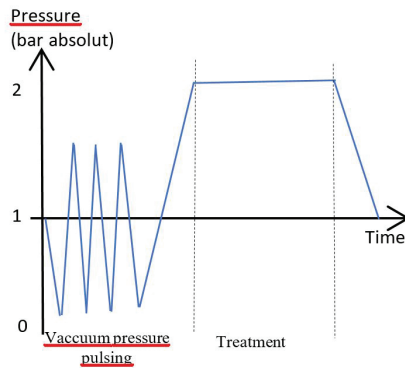


Figure 4. Fractionated vacuum process



The use of vacuum autoclaves includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none"> ✓ Low environmental impacts ✓ No hazardous residues ✓ Complies with Stockholm Convention ✓ Some treated wastes can be recycled 	<ul style="list-style-type: none"> ✗ Reliable solid waste collection required ✗ Reliable water and electricity connection needed ✗ Water needs to be of certain quality to protect the equipment ✗ Temperature resistant waste bin or bags are needed ✗ Residue recognizable, can cause injuries (e.g. sharps)

Health and environmental aspects

Autoclaving is an environmentally friendly technology. Low-heat thermal processes like autoclaving produce significantly less air pollution than incineration processes, therefore there are no specific pollutant emission limits for autoclaves. However, the air evacuated from the treatment chamber needs to be filtered and the condensate decontaminated to prevent occupational health hazards.

Installation requirements

- Electricity: 380/400 Volt (smaller ones might require 220/230/240 Volt)
- Water connection
- Quality of water for steam generation: soft water/demineralised water⁸
- Waste water connection
- Compressed air

Capacities and consumptions

Waste treatment autoclaves can range in size from 5 to 3000 kg/hour. The cycle time includes the time needed for adding waste, air evacuation, steam exposure, and waste removal. Table 4 provides some examples of capacities and consumption of a fractionated autoclaving process. The data are approximate and based on maximum load capacity per cycle, and with standard configuration of parameters.⁹

⁸ Exemplary minimum water quality requirements: total hardness: < 3°dH (< 0,5 mmol CaO/l), total salt: < 500 mg/l, Chloride content: < 100 mg/l, pH value: 5 – 8 (manufacturer provided information)

⁹ The standard configuration of parameters including items such as the temperature/pressure and holding time for the treatment process. The figures may change, if for example, the waste is wet or the water too warm. Each manufacturer/process has its own specific standard parameters.

Table 4.

Capacity (kg/cycle)	40	70	150	500	800
Cycle time (minutes)	50	50	50	55	60
Energy consumption (kWh/cycle)	7	17	21	40	56
Water consumption (l/cycle)	200	240	360	950	1800

Data provided by: Matachana Group, Spain.

4.1.1.2 Autoclaves with integrated shredding

Autoclaves with integrated grinding or shredding are steam-based systems, which have been developed to improve the transfer of heat into waste, achieve more uniform heating of waste, render the waste unrecognisable and/or make the treatment system a continuous process. These systems are sometimes referred to as advanced autoclaves, hybrid autoclaves or advanced steam treatment technologies (WHO 2014). Pre-shredding allows better steam penetration and efficacy. The process might also include pre-vacuum or fractionated vacuum phase for extra safety. At the end of the cycle, the waste is considered non-hazardous and can be disposed accordingly. Some waste may also be suitable feedstock for recycling.

The use of autoclaves with integrated grinding or shredding has the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none"> ✓ Low environmental impacts ✓ No hazardous residues ✓ Reduction of volume ✓ Residue is unrecognizable ✓ Complies with Stockholm Convention 	<ul style="list-style-type: none"> ✗ Reliable water and electricity connection needed ✗ Water needs to be of certain quality to protect the equipment ✗ Higher costs and maintenance (internal moving parts) ✗ Requires a skilled operator

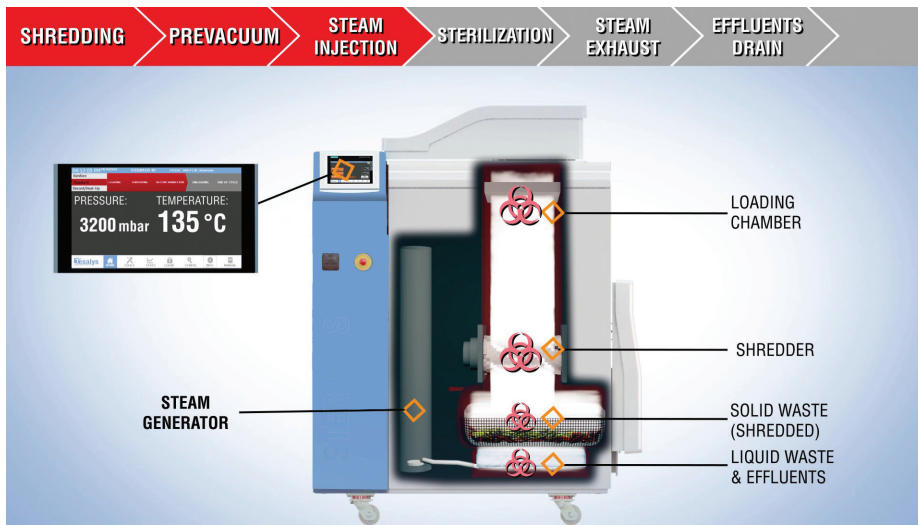
Health and environmental aspects

Since low-heat thermal processes like hybrid autoclaves produce significantly less air pollution than incineration processes, there are no specific pollutant emission limits for hybrid autoclaves. The system needs to be completely enclosed to prevent emitting aerosols during the waste shredding process.

Installation requirements

- Electricity: 400 Volt
- Water connection
- Quality of water for steam generation: soft water/demineralised water
- Waste water connection
- Compressed air

Figure 5. Autoclaves with internal shredder



Credit: Tesalys/Sterishred, France

Capacities and consumptions

Capacities of autoclaves with integrated shredding range from 5 to 3000 kg/hour. The cycle time includes the time needed for complete treatment including adding waste, shredding, steam exposure, and waste removal. The tables below provide some examples of capacities and consumption for autoclaves using a built in steam generator and an external steam source. The data are approximate and based on maximum load capacity per cycle, and with standard configuration of parameters.

	2.5	5	10	15
Capacity (kg/cycle)	2.5	5	10	15
Cycle time (minutes)	30	30	30	45
Energy Consumption (kWh/cycle)	1	2.5	4	15
Water consumption (l/cycle)	5	10	15	85

Data provided by: Tesalys/Sterishred, France. Energy is calculated with a built-in generator.

Capacity (kg/cycle)	15	23	53	165	375
Cycle time (minutes)	30	30	30	35	45
Energy Consumption (kWh/cycle)	0.55	1.4	1.7	4	9
Water consumption (l/cycle)	5	15	25	35	50

Data provided by: Ecodas, France. Energy is calculated without a built-in generator.

4.1.2 Microwave-based technologies

Microwave treatment is essentially a steam-based process, as treatment occurs through the action of moist heat and steam generated by microwave energy. Water contained in the waste is rapidly heated by microwave energy at a frequency of approximately 2450 MHz and a wavelength of 12.24 cm. In general, microwave treatment systems consist of a treatment area or chamber into which microwave energy is directed from a microwave generator where the waste is heated up to 100 °C. Microwave systems may be impacted by the altitude of the location where the microwave is used. In higher altitudes, due to less pressure, it may take longer to reach 100 °C, which results in longer treatment times. After treatment, the waste is considered as non-hazardous waste and can be disposed accordingly.

4.1.2.1 Batch wise microwaves

A typical batch wise microwave system treats waste in batches in a closed waste decontamination unit. Some units require special reusable, fully enclosed, microwavable containers in which the waste is collected beforehand. Microwave systems may have multiple programmable cycles corresponding to different treatment temperatures or levels of disinfection.

The use of batch wise microwaves for the treatment of infectious and sharp waste includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none"> ✓ Low environmental impacts ✓ No hazardous residues ✓ Complies with Stockholm Convention 	<ul style="list-style-type: none"> ✗ Reliable solid waste collection required ✗ Reliable electricity connection needed ✗ Waste needs a minimum humidity or water needs to be added ✗ Special waste bins are needed

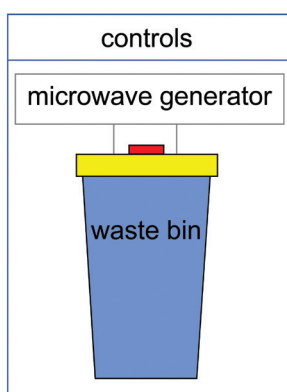
Health and environment

Microwaving is an environmental friendly technology. Waste water is decontaminated during the process. Air emissions from microwave units are minimal. There are no pollutant emission limits specific for microwaves.

Installation requirements

- Electricity: 400 Volt (smaller ones might require 220/230/240 Volt)
- Water connection
- Quality of water: tap water
- Waste water connection

Figure 6. Batch Wise Microwave



Capacities and consumption

Batch wise microwave systems range in capacity from 1 to 210 kg per hour. The cycle time includes the time needed for adding waste, processing, and waste removal. The table below provides examples of capacities and consumption. The data are approximate and based on maximum load capacity per cycle, and with standard configuration of parameters.

	3	6	10	20
Capacity (kg/cycle)	3	6	10	20
Cycle time (minutes)	45	45	45	45
Energy consumption (kWh/cycle)	0.9	1.8	2.3	3.5
Water consumption (l/cycle)	0.5	1.0	1.5	2.5

Data provided by: Meteka GmbH, Austria.

4.1.2.2 Continuous Microwave Technologies

A typical continuous microwave system consists of an automatic charging system, hopper, shredder, conveyor screw, steam generator, microwave generators, discharge screw and controls. The equipment includes hydraulics, HEPA filter and microprocessor-based controls. Waste bags are introduced into the hopper where steam may also be injected. To prevent the release of airborne pathogens, air is extracted through a HEPA filter as the waste bags are loaded. After the hopper lid is closed, waste goes through a shredder. The waste particles are conveyed through a large metal auger (conveyor screw) where they are further exposed to steam and heated to 100°C by several microwave generators. Waste is then kept in a holding section where medical wastes are maintained at 100°C for 50 minutes.

The use of continuous microwaving technology includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none">✓ Low environmental impacts✓ Residue is non-hazardous✓ Residue is unrecognizable✓ Reduction of waste volume✓ Complies with Stockholm Convention	<ul style="list-style-type: none">✗ Reliable electricity connection needed✗ Higher costs and maintenance (internal moving parts)✗ Waste needs a minimum humidity or water needs to be added

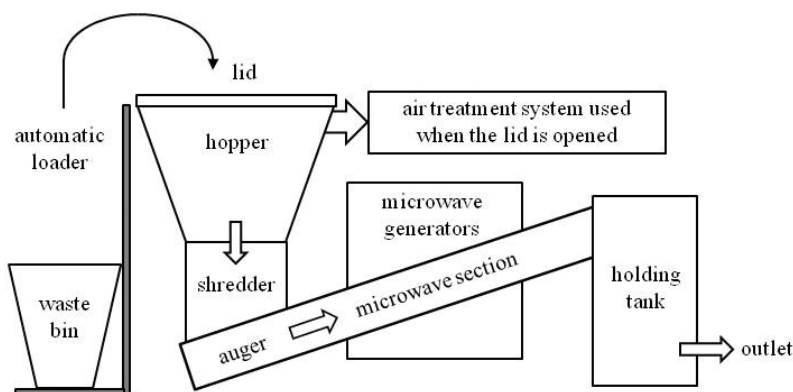
Health and environmental aspects

Microwaving is an environmentally friendly technology. Waste water is decontaminated through the process. Air emissions from microwave units are minimal. There are no pollutant emission limits specific for microwaves. The system needs to be completely enclosed to prevent emission of aerosols during the waste shredding process.

Installation requirements

- Electricity: 380/400 V
- No other requirements

Figure 7. Continuous microwaving process



Credit UNEP 2007

Capacities and consumptions

Continuous microwave technologies are available in the range of 100 to 800 kg per hour. The cycle time includes the time needed for adding waste, steam exposure, and waste removal. The table below provides some examples of capacities and consumption. The consumption is based on a maximum load capacity, per cycle and with standard parameters configuration:

Capacity (kg/batch):	100	175	300	500
Continuous System: Waste decontaminated in (minutes):	60	60	60	60
Energy Consumption (kWh/cycle):	20	45	60	100

Data provided by: AMB ecosteryl, Belgium.

4.1.3 Frictional heat treatment

Frictional heat can also be used to destroy health care waste. The technology is based on the use of heat generated by friction and impact of the waste by rotor blades, supplemented by resistance heaters to ensure that the temperature can be adjusted if required. The waste is heated up to 150°C, while the waste is shredded into small, unrecognizable pieces. Heat is provided by heaters or generated by a rotor operating at high speeds (typically 1000 to 2000 rpm). A moist environment is kept inside the chamber by negative pressure.

To decontaminate the waste, it is kept between 135°C and 150°C for several minutes. Vapours generate flow through heat exchangers where the water is condensed. They continue to a filter group (activated carbon and HEPA filters) before being released to the environment.

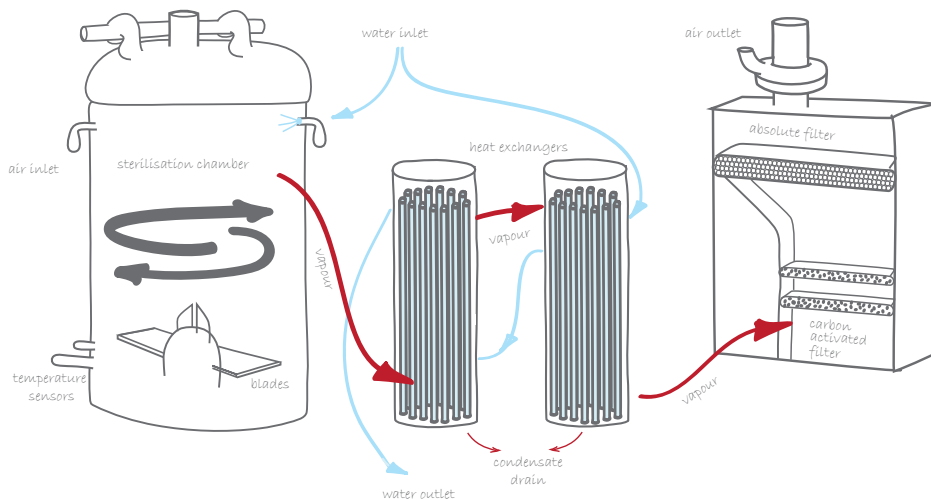
The use of frictional heat treatment includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none"> ✓ Low environmental impacts ✓ Residue is non-hazardous ✓ Reduction of waste volume ✓ Residue is unrecognizable ✓ Complies with Stockholm Convention 	<ul style="list-style-type: none"> ✗ Reliable electricity connection needed ✗ Higher maintenance (internal moving parts)

Health and environmental aspects

Frictional heat treatment is an environmentally friendly technology. No hazardous emissions or effluents are generated. There are no specific pollutant emission limits for frictional heat treatment systems. The system needs to be completely enclosed to prevent emitting aerosols during the waste shredding process.

Figure 8. Frictional heat treatment process



Credit: Newster System Srl, Italy

Installation requirements

- Electricity: 400 Volt – 50 Hz
- Water connection: Yes
- Quality of water: Running water (should meet the quality specified by manufacturer)
- Waste water connection: Yes

Capacities and consumptions

Frictional heat treatment systems range in capacity from 10 to 600 kg per hour. The cycle time includes the time needed for adding in waste, frictional heat exposure, and waste removal. The table below provides some examples of capacities and consumption. The consumption is based on a maximum load capacity per cycle and with standard configuration of parameters:

Capacity (kg/cycle)	11–13	18–20	45–50	55–60
Cycle time (minutes)	40–50	30–45	45–50	35–45
Energy consumption (kWh/cycle)	10–12	12–14	30–35	35–40
Water consumption (l/cycle)	5–15	15–40	30–50	75–90

Data provided by: Newster System Srl, Italy.

4.2 Chemical-based processes (automated)

4.2.1 Sodium Hypochlorite-based technology

This chemical-physical treatment technology ensures the disinfection of infectious wastes by using the oxidation power of sodium hypochlorite (NaClO). Contrary to manual treatment of infectious waste by chemicals, the process is automated and controlled continuously, to ensure effective and safe decontamination of waste. This is still a technology with limited evidence and examples of effective application. The system automatically controls chemical-physical parameters during the oxidation process (pH, temperature and conductivity). The waste is fed into the system by a conveyor belt or directly into the shredder where it is shredded under negative pressure conditions and in an oxidizing atmosphere. The air is filtered by a HEPA filter. During the oxidation process in the reactor, an air-aspiration system passes all the gases into a liquid chemical trap (neutralization), and then through carbon filters, so there are no hazardous emissions into the atmosphere. After

decontamination, the waste is neutralised with sodium thiosulfate to ensure that no free chlorine remains.

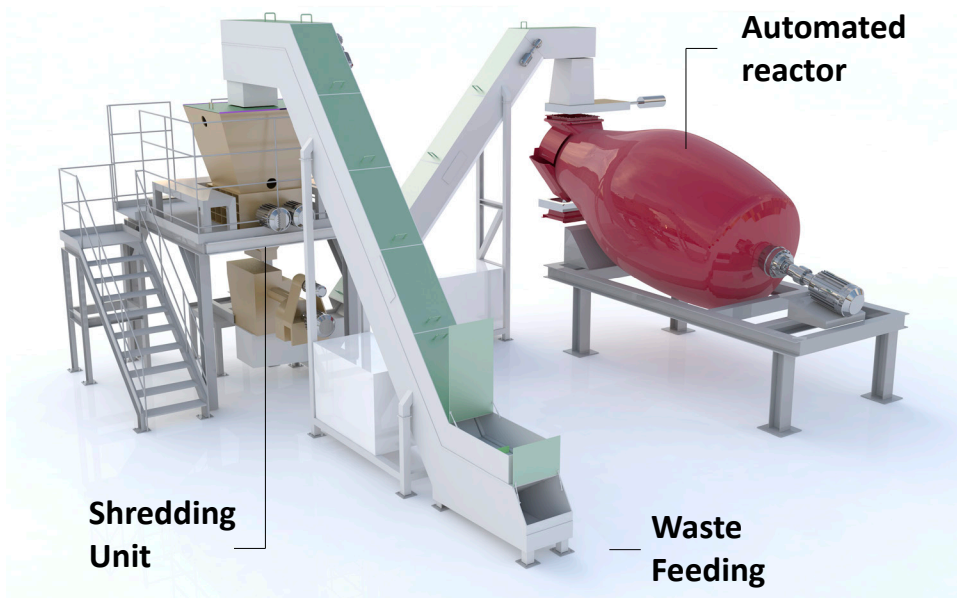
The use of automated sodium hypochlorite treatment has the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none">✓ Low environmental impact✓ No hazardous residues✓ Reduction of waste volume✓ Residue is unrecognizable✓ Complies with Stockholm Convention	<ul style="list-style-type: none">✗ Real time monitoring of chemical concentration is difficult✗ Strict occupational safety measures are necessary✗ Higher costs and maintenance (internal moving parts)

Health and environmental aspects

Sodium hypochlorite is a strong oxidizer and oxidation reactions are corrosive. Solutions burn the skin and cause eye damage, especially when used in concentrated forms. The system must therefore be enclosed and automated. Strict occupational health and safety measures are needed to protect workers and the environment.

Figure 9. Sodium hypochlorite treatment system



Credit: ATHISA, Spain

Installation requirements

- Input: sodium hypochlorite and sodium thiosulfate
- Electricity connection: 380/400 V
- Water connection
- Waste water connection

Capacities and consumptions

Sodium hypochlorite treatment systems range in capacity from 600 to 3000 kg per hour. The cycle time includes the time needed for loading waste, treatment and waste removal. The table below provides some examples of capacities and consumption. The consumption is based on a maximum load capacity per cycle and with standard configuration of parameters:

Capacity (kg/batch)	600	3000
Cycle time (minutes)	180	180
Energy Consumption (kWh/cycle)	180	360
Water consumption (l/cycle)	600	3000
Sodium hypochlorite 12–15% (l/cycle)	150–300	750–1350
Sodium thiosulfate 95% (l/cycle)	1.5–3	4.5–6

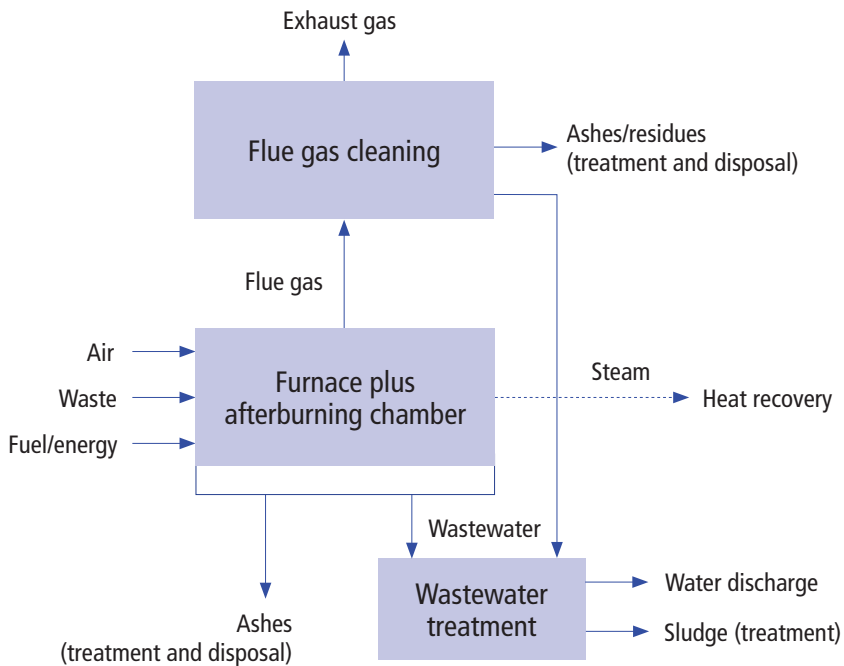
Data provided by: ATHISA, Spain.

4.3 Incineration

In accordance with the Stockholm Convention, the Best Available Technology (BAT) should be used. BAT, with a suitable combination of primary and secondary measures results in dioxin and furan air emissions no higher than 0.1 ng I-TEQ³/Nm¹⁰ (at 11% O₂) and less than 0.1ng I-TEQ/l for wastewaters discharged from the facility (UNEP 2007). *Primary measures* for high-heat thermal incinerators include two burning chambers (850 °C/1100 °C), an auxiliary burner, sufficient resident time of air in the second chamber, sufficient oxygen content and high turbulence of exhaust gases. Additional flue gas treatment systems *are needed as secondary measures*. There are few small and medium-sized incinerators available on the market which operate in accordance with the Stockholm Convention. In most low-income countries, no laboratories are available to analyse dioxin

¹⁰ TEQ: Toxic equivalents report the toxicity-weighted masses of mixtures of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs)

Figure 10. Incineration process including flue gas treatment



Credit: UNEP 2007

and furans, so performance cannot easily be monitored. High-tech incinerators require reliable controls of combustion parameters, a flue gas cleaning system (dust removal, ceramic filters, cyclonic scrubbers and electrostatic precipitators) and waste water treatment. They are therefore also very expensive. Smaller installations exist, but at least 100,000 tons of waste per year are needed to make them efficient and cost effective (WHO 2007).

As this document is aimed at low and middle-income countries, where high-tech incineration in accordance with the Stockholm Convention is not considered realistic, it is therefore not included in this guide. Other burning options are outlined in the next chapter.

5. Technologies in low resource settings

In low-resource or emergency settings, transitional methods can be used while working towards putting the systems and resources in place to install, operate and maintain more advanced technologies. Such methods may not fulfil the requirements of the Stockholm Convention (UNEP 2007) and therefore should be considered only as an interim solution. In some countries, where basic WASH services in health care facilities are lacking, they may not have any waste destruction at all besides open burning. There, the objective would be to incrementally improve this through construction of a locally made incinerator made of bricks or using a barrel. Furthermore, in emergency situations like outbreaks of infectious diseases, the volume of waste rises quickly and needs to be considered in the selection of waste treatment technologies.

5.1 Automated pressure pulsing gravity autoclaves

Automated pressure pulsing gravity-displacement autoclaves take advantage of the fact that steam is lighter than air. Steam is introduced under pressure into the chamber forcing the air downward into an outlet port of the chamber. Such autoclaves use pressure pulsing to lower the risk of air remaining in the chamber and hindering decontamination. Pressure pulsing involves repeatedly pressurising the autoclave with steam, then releasing it to flush out air pockets. A vacuum is not generated. As a minimum requirement, the exhaust air and condensate should be discharged to a closed sewer system, a soak away pit, or ideally the autoclave should be equipped with a HEPA filter. Simple gravity-displacement autoclaves without pressure pulsing should not be used for the safe decontamination of infectious waste, as there is a risk that this waste cannot be reached by the steam with the result that the waste may not be decontaminated (Stolze, Kühling 2009). Manual pressure pulsing is possible, but effectiveness of the decontamination is highly dependent upon operator behaviour.

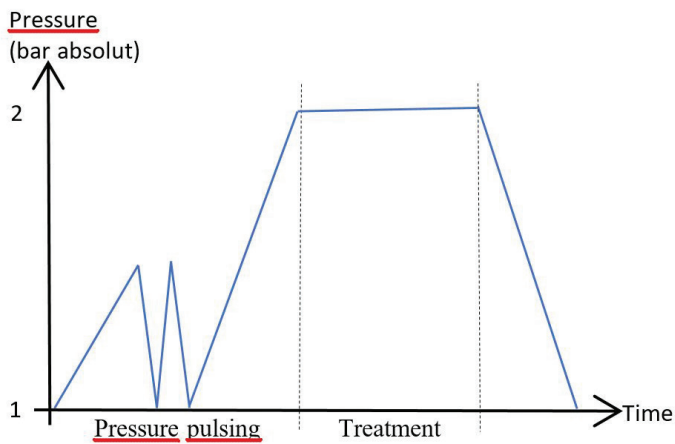
Health and environmental aspects

Like the other steam-based systems, this is a low-heat thermal process, which produces significantly less air pollution than incineration processes. There are no specific pollutant emission limits for autoclave systems. However, there is a higher risk that waste is not completely decontaminated if air remains within the waste.

Installation requirements

- Electricity: 220/230/240 Volt
- Water connection: optional
- Quality of water for the steam generation: demineralised
- Waste water connection

Figure 11. Pressure pulsing gravity autoclave



Credit: Ute Pieper

Capacities and consumptions

Capacities vary from 5 to more than 50 kg per hour. Consumption data are not available.

The use of automated pressure pulsing gravity autoclaves for the treatment of infectious and sharp waste includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none"> ✓ Low environmental impacts ✓ No hazardous residues ✓ Complies with Stockholm Convention 	<ul style="list-style-type: none"> ✗ Reliable electricity connection needed ✗ Efficiency of waste decontamination is closely related to the type of waste treated (small lumen and porous material may not be decontaminated)

5.2 Burning options

While non-incineration technologies are the preferred options, in many facilities in low- and middle-income countries this is not possible because of a lack of reliable water, energy, and solid waste collection services. In all countries, however, efforts should be made to incrementally improve health care waste management and engage in multi-sectoral efforts to strengthen systems change.

5.2.1 Dual chamber incineration without flue gas treatment

A dual chamber incinerator without flue gas treatment consists of a primary combustion chamber and a secondary chamber. The waste is thermally decomposed through medium-temperature combustion processes producing solid ashes and gases. Waste is burned in the primary combustion chamber at or above 850 °C. Multiple oil or gas burners maintain the temperature in the primary chamber. The vapours produced in the primary chamber are directed into a secondary chamber which has one or more burners to bring the temperature to the 1100 – 1200 °C required for chlorinated wastes such as health care waste. The resulting flue gas is not treated.

For an incinerator with minimal controls, a well-trained operator must monitor and adjust primary and secondary chamber temperatures, charging rate, and air levels in the primary and secondary combustion chambers.

The use of dual chamber incinerators without flue gas treatment includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none"> ✓ Reduction of waste volume ✓ Residue is unrecognizable 	<ul style="list-style-type: none"> ✗ High environmental and health impact (air emissions and risk of burns) ✗ Bottom and fly ash is potentially hazardous ✗ Not in accordance with the Stockholm Convention

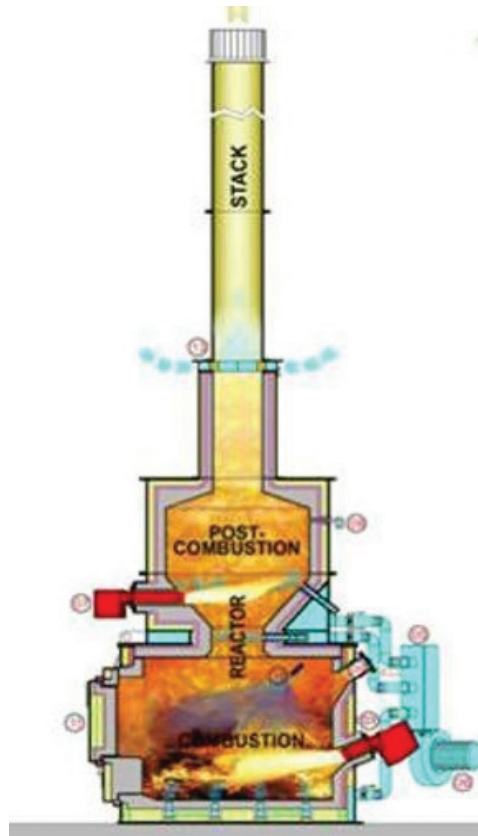
Health and environmental aspects

Incinerators release a wide variety of pollutants, including dioxins and furans, into the atmosphere. Pollutants vary according to the composition of the waste. Bottom ash residues are also generally contaminated with dioxins, leachable organic compounds, and heavy metals and have to be treated as hazardous waste. The ash should be disposed in sites designed for hazardous wastes, e.g. designated cells at engineered landfills, encapsulated and placed in specialized monofill sites, or disposed in the ground in ash pits.

Installation requirements

- Electricity: 220/230/240 Volt
- Fuel type: diesel, gas

Figure 12. Dual chamber incinerator



Capacities and consumptions

Dual chamber incinerators are available from 5 to 500 kg per hour with fuel consumption of 3 to 65 litres per hour. Some examples are outlined below in Table 4. The cycle time includes the time needed for adding in waste, treatment and waste removal. The table below provides some examples of capacities and consumption. The consumption is based on a full load:

Capacity (kg/batch)	15	20
Cycle time (minutes)	60	60
Diesel consumption (l/cycle)	3	3

Data provided by: TTM e.V., Germany.

5.2.2 Single chamber incineration without flue gas treatment

Small scale incinerators like single-chamber, drum and brick incinerators are designed to meet an immediate need for public health protection where there are no resources to implement and maintain more sophisticated technologies. However, they can emit 400 times more dioxins and furans than the 0.1 ng/m³ recommended by the Stockholm Convention (Batterman 2004). Using such technologies involves a compromise between the environmental and human health impacts from combustion with an overriding need to protect public health where the only alternative is indiscriminate dumping.

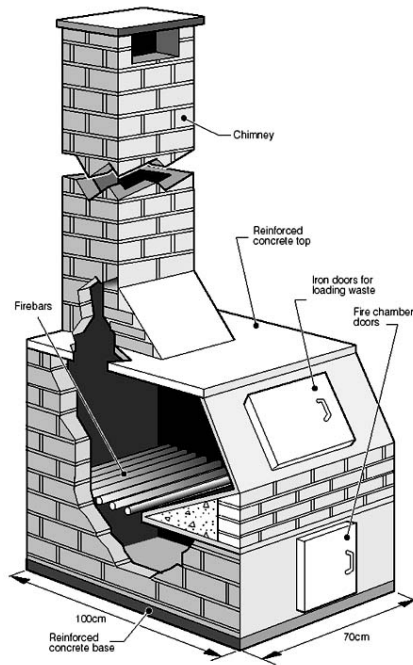
The use of single chamber incinerators without flue gas treatment includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none">✓ Residue is unrecognizable✓ Reduction of waste volume	<ul style="list-style-type: none">✗ Very high negative environmental and health impact (high air emissions)✗ Pathogens can survive the process✗ Bottom and fly ash is potentially hazardous✗ Not in accordance with the Stockholm Convention

Health and environmental aspects

Health care waste incinerators release a wide variety of pollutants into the atmosphere, according to the composition of waste including dioxins and furans. Pathogens can also be found in solid residues and the exhaust of poorly designed and operated incinerators. In addition, the bottom ash residues are generally contaminated with dioxins, leachable organic compounds, and heavy metals and need to be treated as hazardous waste.

Figure 13. Single chamber incinerator



WEDC, Emergency Sanitation - Assessment and Program Design, Figure 8.4 Permanent Incinerator, Loughborough University, 2002

Installation and construction requirements

- Construction material:
 - Heat resistant refractory bricks and mortar
 - High grade stainless steel metal parts
- Fuel type: Biomass (wood, coconut shells, etc.)

Capacities and consumptions

Most single chamber incinerators are low cost but also last less than 5 years. Capacities vary from 5 to 50 kg per hour and the costs of biomass depends on the local market.

Frequently experienced problems:

- Operation:
 - Incinerator is not preheated by biomass (low temperatures – high emissions).
 - Incinerator is overfilled.
- Firebox access doors and frames that warp, hinges that seize and break, and assemblies that break free of mortar.
- Grates that distort, break, or become clogged.
- Chimneys (stacks) that are badly corroded, and chimney supports (guy wires) that are not adequately attached, broken, loose or missing.
- Masonry, bricks and particularly mortar joints that crack.
- Grills that are damaged or missing.

5.2.3 Open burning

Open burning covers a wide range of different uncontrolled waste combustion practices, including dump fires, pit burning and fires on plain soil/open ground. In emergencies, open burning is the easiest, most sanitary means of reducing waste volume and disposing of combustible materials. This is especially true for situations with no access to organized waste handling.

This document provides no guidance for open burning practices due to the human and environmental harm resulting from open burning. The process should be minimized and eliminated as soon as possible and wherever feasible. Open burning should be considered a last resort where there are no alternative disposal or recovery methods due to inadequate infrastructure, where sanitary disposal is required to control disease or pests, or in the case of a disaster or other emergency (UNEP 2007, Section VI).

Open burning of infectious and sharp waste includes the following advantages and disadvantages:

Advantages	Disadvantages
<ul style="list-style-type: none">✓ No specific infrastructure or energy/water resources needed✓ Residue is mainly unrecognizable✓ Reduction of waste volume	<ul style="list-style-type: none">✗ Very high negative environmental and health impact (very high air emissions)✗ Ash and emissions may contain viable pathogens.✗ Remaining ash is potentially hazardous✗ Not in accordance with the Stockholm Convention

Health and environmental aspects

The low temperature burning and smouldering typical of open burning promote the formation of a range of toxic and potentially harmful chemicals, including dioxins and furans. These compounds form during open burning regardless of the composition of the material being burnt. The compounds produced from sources of open burning can travel long distances and be deposited on soil, plants, and in water. The remaining ash in the burn pile also contains pollutants, which can spread into soil and water. Additionally, smoke and particulates from open burning sources can trigger respiratory health problems (UNEP 2007, Section VI). Pathogens may not be killed by the comparatively low temperatures of open burning and can be dispersed in the air via ash and other particulates.

Installation Requirements

- Available space on the health care facility compound
- Deep ground water table to reduce the risk that hazardous effluents contaminates the ground water

Capacities and consumptions

Not applicable.

Annex 1

Technology options

Low-heat thermal processes

Steam-based treatment technologies are widely used to destroy pathogens contained in infectious and sharp wastes by using heat (thermal energy) for a defined period of time, depending on the size of the load and the content. In general, low-heat thermal technologies for waste treatment operate between 100 °C and 180 °C and the processes take place in either moist or dry heat environments. Moist (or wet) thermal treatment involves the use of steam to disinfect waste and is commonly performed in an autoclave or steam-based treatment system (WHO 2014). Microwave treatment and frictional heat treatment is essentially a moist thermal process since disinfection occurs through the action of moist heat generated by the microwave energy or by friction.

To guarantee full decontamination of infectious material, the process needs to be validated. The validation process consists of verifying in a certified and clearly documented manner that a process meets the requirements for which it was designed (WHO 2016). Part of this is regular testing using biological, chemical and physical test parameters. This is determined by the ability of the heat to penetrate the waste load. Inactivation of vegetative bacteria, fungi, lipophilic/ hydrophilic viruses, parasites and mycobacteria at a 6 Log₁₀ reduction (i.e. reduction of an initial population of one million organisms to close to zero) or greater, and inactivation of *Geobacillus stearothermophilus* spores or *Bacillus atrophaeus* spores at a 4 Log₁₀ reduction or greater must be guaranteed (WHO 2014). Confirmation of the inactivation of bacteria can be carried out, using self-contained biological indicators (UNDP 2010). Besides validation of the process, for every treatment cycle chemical indicators should be used. Chemical indicators show exposure by means of physical and/or chemical changes and are designed to react to one or more parameters of the decontamination process such as time of exposure, temperature and presence of moisture. This proves the waste decontamination efficiency of each cycle and should be documented.

Low-heat treatment can be combined with mechanical methods like shredding, grinding, mixing, and compaction to reduce waste volume, but such treatments do not destroy pathogens. Shredders and mixers before treatment can improve the rate of heat transfer and increase the surface area of waste for treatment. Mechanical methods should not be used for infectious and sharp waste before the waste is decontaminated, except if the mechanical process is part of a closed system that decontaminates the chamber of the mechanical process and air before it is released to the surrounding environment. Mechanical methods have the advantage that the waste volume is reduced, is made unrecognizable and it cannot be reused. However, the use of mechanical treatment increases the investment, operational and maintenance costs.

Chemical-based processes

Infectious waste can also be decontaminated with the use of chemicals. Chemical treatment of solid infectious waste is potentially problematic due to the variability of chemical efficacy based upon load characteristics and the generation of toxic liquid waste. The speed and efficiency of chemical decontamination depends on operational conditions, including the type of chemical disinfectant used, its concentration, the contact time between the disinfectant and the waste, the extent of contact, the organic load of the waste, operating temperature, and factors that may affect the efficacy of the disinfectant such as humidity and pH. Manual systems using chemical disinfection are not regarded as a reliable method for the treatment of waste (WHO 2014). Chemicals used should be neutralised before release from the system. The soaking of infectious and sharp waste in chlorine solutions have become less used due to concerns of environmental and occupational safety (UNEP 2012a). This document only includes fully automated chemical disinfection methods which considers safety for workers and the environment and which monitor the chemical concentration continuously.

Burning of waste

Incineration is a dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a significant reduction of waste volume and weight. Burning health care waste without flue gas treatment releases a wide variety of pollutants into the atmosphere, according to the composition of the waste. These pollutants may include particulate matter such as fly ash, heavy metals (arsenic, cadmium, chromium, copper, mercury,

manganese, nickel, and lead), acid gases (hydrogen chloride, hydrogen fluoride, sulphur dioxides, nitrogen oxides), carbon monoxide, and organic compounds (including dioxins and furans, benzene, carbon tetrachloride, chlorophenols, trichloroethylene, toluene, xylenes, trichloro-trifluoroethane, polycyclic aromatic hydrocarbons, vinyl chloride). If medical waste is incinerated in conditions that do not constitute best available techniques or best environmental practices, there is potential for the release of dioxins and furans in relatively high concentrations. Dioxins and furans are bio-accumulative and toxic.

Pathogens can also be found in solid residues and in the exhaust gases and particulates of poorly designed and badly operated incinerators. In addition, the bottom ash residues can be contaminated with dioxins, leachable organic compounds, and heavy metals and should be treated as hazardous waste (UNEP 2012a). To prevent hazardous emissions and the generation of hazardous bottom and fly ash, infectious and sharp waste should be treated and decontaminated by alternative non-burn technologies (UNEP 2003).

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Further information and resources

The **International Solid Waste Association (ISWA)** is a non-governmental, independent and non-profit association by statutes and follows the mission statement to promote and develop professional waste management worldwide as a contribution to sustainable development. The Working Group on Health care Waste works on promoting the integrated provision of the infrastructure for the safe management of health care waste world-wide, within the framework of the objectives, activities and means of implementation established by Agenda 21 of the United Nations Conference of the Environment and Development:

https://www.iswa.org/iswa/iswa-groups/working-groups/working-groups/wg/show_details/working-group-on-health-care-waste/

A database on alternative **non-incineration health care waste technologies and manufacturers** can be found at: <http://www.medwastetech.info>.

Details on waste treatment technologies, including capacities and capital costs can be found here: <https://www.health-care-waste.org/resources/technologies/>.

Additionally, the **WHO UNICEF knowledge portal** on WASH in health care facilities (www.washinhcf.org) provides further information on approaches and tools for improving the safe management of health care waste.

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ISBN 978 92 4 151622 8

