NON-INCINERATION MICROWAVE ASSISTED STERILIZATION OF MEDICAL WASTE

Paolo Veronesi[1], Cristina Leonelli[1], Umberto Moscato[2], Angelo Cappi[3], Ornella Figurelli[3]

[1]Department of Materials and Environmental Engineering, University of Modena and Reggio Emilia, Italy
[2]Institute of Hygiene - Catholic University of Sacred Hearth, Rome, Italy
[3]CMS, Marano s.P., Italy

A non-incineration method for sterilizing hospital infectious wastes has been studied and realized. A small apparatus operating at 2.45 GHz and at a power of 3 kW was designed to optimize power transfer from the electromagnetic field to the infectious materials, which have been previously shredded and moisture-corrected. The high pressure reached in the reactor, 7 atm, was enough to ensure complete sterilization in just a few minutes for a batch of several hundred grams of waste. Sterilization efficacy during microwave irradiation was also optimized with a new procedure using thermal, microbiological and water vapour sensors in a single test.

Submission Date: 11 November 2006
Acceptance Date: 4 March 2007
Publication Date: 30 May 2007

INTRODUCTION

All wastes that are susceptible to containing pathogens (or their toxins) in sufficient concentration to cause disease to a potential host are considered hazardous medical wastes, or infectious wastes.

In hospitals, wastes are partially infective, about 15% or less of the overall waste stream [Emmanuel, 2004], with a daily production on an Italian basis [Melino, 2001], between 1 and 5 kg per in-patient, but sometimes it can reach 13 kg. Usually, infectious waste is periodically collected in small containers (40-80 litres volume), which can be recyclable or disposable. Typically, the collected waste is transported as it is to the final disposal site or to the incinerator, which is an enormous responsibility for the sanitary director of the structure where the waste was originally produced. To avoid the risk of contamination of people or materials, the hospital can proceed with in-situ waste sterilization, if not at the division where it is produced, at least in a designated site within the hospital in accordance with Italian laws [D. Lgs. 22/97, art.45] and the UNI ISO technical standards [UNI 10384/94].

Presently, non-incineration technology is preferred over incineration because it reduces high temperature evolution of tetrachlorodibenzo-p-

Keywords:

Table 1: Commercial non-incineration sterilization processes available for hospital waste.

Technology	Systems	Operations	Advantages	Disadvantages
Steam Disinfection (93°C-177°C)	Autoclaves, Retorts	Vacuuming, Continuous Feeding, Shredding, Mixing, Fragmenting, Drying, Chemical treatment, Compaction	No pyrolysis, no combustion, no gasification	Long treatment time (hours)
Microwave Technology: Steam-based low-heat thermal process but sometimes can be dry heat process	Autoclaves, sometimes with radiant heaters	Same as above, plus forced convection and/or circulating heated air	Same as above	Treatments are in the range of tens of minutes
Chemical Technologies	Chemical resistant systems	Disinfecting agents, shredding, mixing, grinding, removal and recycling the disinfectant, possible capsulation process	Fast	Emission of toxic vapours, particular care in chemicals manipulation
Irradiative Processes	Bombardment with ionising radiation cobalt-60, UV-C light	Grinding, shredding	Fast	Costly, safety issue with UV light is a problem

dioxin (TCDD) and related compounds, such as Persistent Organic pollutants (POPs) and Total Volatile Organic Compunds (TVOC). These non-incineration methods can be roughly divided into low-thermal, chemical, biological and irradiation technologies. As listed in Table 1, they all present advantages or disadvantages.

Thermal processing (autoclave) is one of the preferred means to achieving sterilization before transportation because it is a technology well known for instrument sterilization as well.

Commercial microwave equipment [Edlich, 2006, for a complete review in Europe see Emmanuel, 2004; Drake, 1993; Brent, 1992] is essentially steam-based low-heat thermal processes where disinfection occurs through the action of moist heat and steam. The types of waste commonly treated in microwave systems are identical to those treated in autoclaves and retorts: cultures and stocks, sharps (Microwave units routinely treat sharps waste such as needles and wastes containing pieces of metal. It is a misconception that metals cannot be treated in the microwave disinfection system.), materials contaminated with blood and body fluids, isolation and surgery wastes, laboratory wastes (excluding chemical waste) and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care.

Some equipment handles unshredded materials [Drake, 1993; Brent, 1992], while others prefer shredding to allow better vapour/ waste contacts [Edlich, 2006 ; Emmanuel, 2004; Blenkharn 1995].

State of the art sterilization equipment installed on Italian territory was investigated to determine the costs connected to the set-up and maintenance of the plants [Moscato, 2005]. Electron beams seem to provide the lowest costs, followed by microwaves, attrition and vapour processing. Moreover, high running costs and inefficiencies are connected to the practice of centrally collecting the waste containers before sterilization can take place in the existing large equipment. Thus, a local, effective and rapid way of sterilizing hospital waste would be welcome by hospitals because it would lead to cost savings and lower contamination risks during transportation. The aim of the present work is to present the study of a prototype design and realization of a rapid microwave assisted waste-sterilization equipment able to fit into less than 3 m^3 of space, thus allowing for the efficient treatment of waste produced in a hospital corridor and optimizing the hospital's staff acceptance. Different from other commercial equipment, the reduced size and load of the proposed machinery make it suitable for indoor use. Some comments on the microbial inactivation efficacy are also presented following a recently tested sterilization procedure.

EXPERIMENTAL

Materials composing typical hospital waste were characterised and the mixture's dielectric properties were evaluated, varying the particle size and the starting water content. Modeling of a multi-mode microwave applicator, comprehensive of pressure windows and measurement ports was conducted using the commercial software Concerto 3.5 (Vector Fields, U.K.). The software optimization procedure allowed for the determination of the best applicator geometry and loading conditions in terms of the minimum reflected power and uniform microwave heating.

Laboratory prototype design

The parameterised model used for optimizing the applicator's dimensions consisted of a cylindrical container with a conical protrusion on the bottom, loaded with the material up to a certain height, connected to a circular to rectangular waveguide (WR340) mode transformer, constituting the high pressure part of the applicator. Two different twin pressure window systems were designed in order to separate the microwave generation environment from the treatment zone, and to minimise energy reflection. An impedance matching iris was modeled too, and the cylinder-pressure window distance could be varied. The optimization, on the basis of $|S11|$ minimisation and SAR homogeneity in axial and radial direction, consisted of the cylinder dimensions, the distance of the twin windows and the mode transformer geometry. Different loads were simulated in order to account for the composition variability of the waste to be treated.

Laboratory system

A laboratory prototype connected to an Alter SM1150 switching power supply feeding a TM030 microwave head (up to 3 kW power, water cooled) operating at 2.45 GHz, was built and tested. The microwave applicator's outer dimensions were approximately 0.2 m diameter, 0.9 m height (variable), including pressure windows, impedance matching devices and waveguide junctions. The reflected power was monitored by a directional coupler, and the temperature of the materials was measured by a Neoptix fibre optic system at 4 different levels during the microwave heating tests. The pressure in the applicator was monitored, too, in order to detect unwanted reactions, for instance combustion, which could create gaseous products. Non-reversible temperature indicators were also added at different heights in the load.

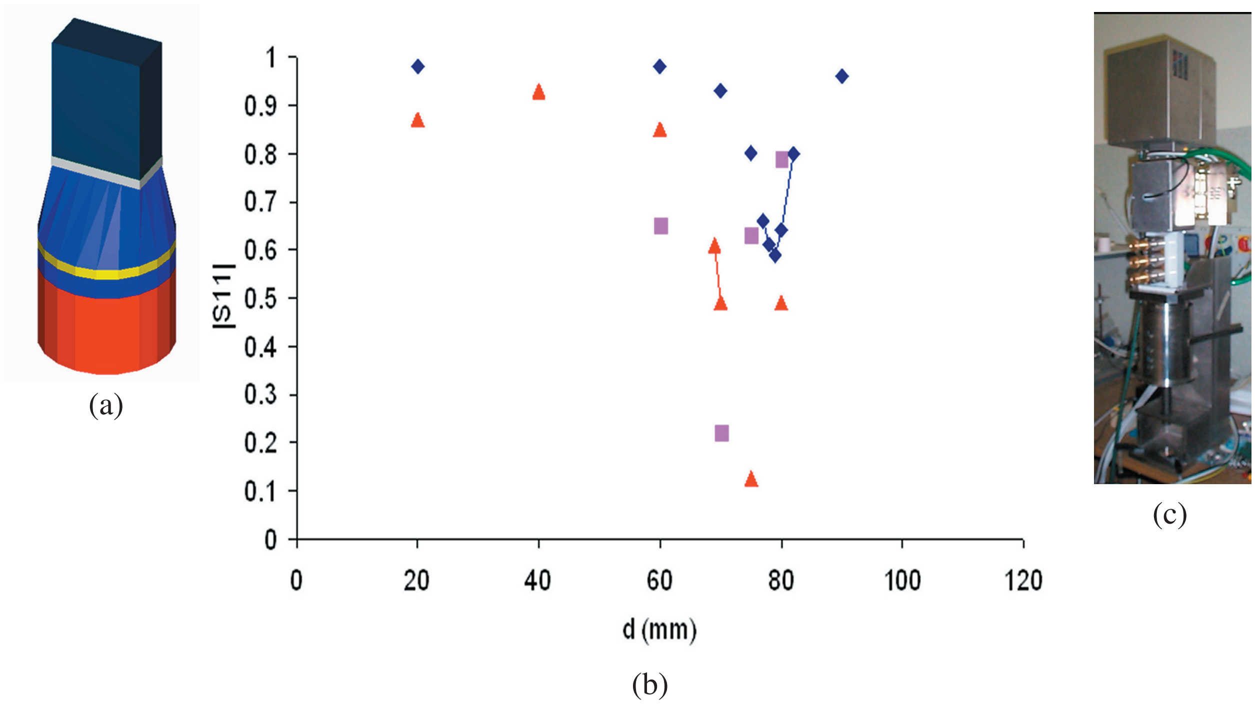

FIGURE 1. From the model to the prototype: a) 3-D visualization of the model; b) variation of |S11| as a function of the pressure window to load surface distance (d), in three different loading conditions; c) photograph of the prototype.

All devices were connected to a PLC in order to operate in temperature control, pressure control or in power control.

A mixture of materials reproducing the contaminated waste was used, and a designated toothed crusher was developed in order to achieve the required particle size, as well as to provide homogenisation. Sterilization tests on the treated materials were performed in accordance to the test methods of the UNI ISO 10384/94, opportunely set up for microwave autoclaves in collaboration with International PBI [Moscato, 2006], using Bacillus atrophaeus (ATCC 9372) and Geobacillus stearothermophilus (ATCC 7953) strip indicators, under the terms of the ISO 11138 and of the EN866 [ISO, 2006]. Nevertheless, previous studies already proved the lethal action of 2450MHz microwave irradiation on different bacteria and spores [Fujikawa, 1992; Najdovski, 1991; Jeng, 1987; Furia, 1986; Goldblith, 1967; Lechowich, 1969; Vela, 1969], but a standard procedure was not optimized under irradiation.

Afterwards, a larger prototype was implemented with an internal shredder, a rotating conveyor screw and a holding section with the microwave heated autoclave studied for the laboratory prototype. No hot air heater or hot air circulating blower was used to help homogenise the temperature as in previously designed machinery [Takashi, 1993].

RESULTS AND DISCUSSION

Laboratory prototype testing

An optimized geometry was attained according to the criteria mentioned in the previous section and a first 900 mm high prototype was built and subjected to intensive testing in order to verify the results obtained by the computer simulation, and to further optimize the model and the prototype. Figure 1

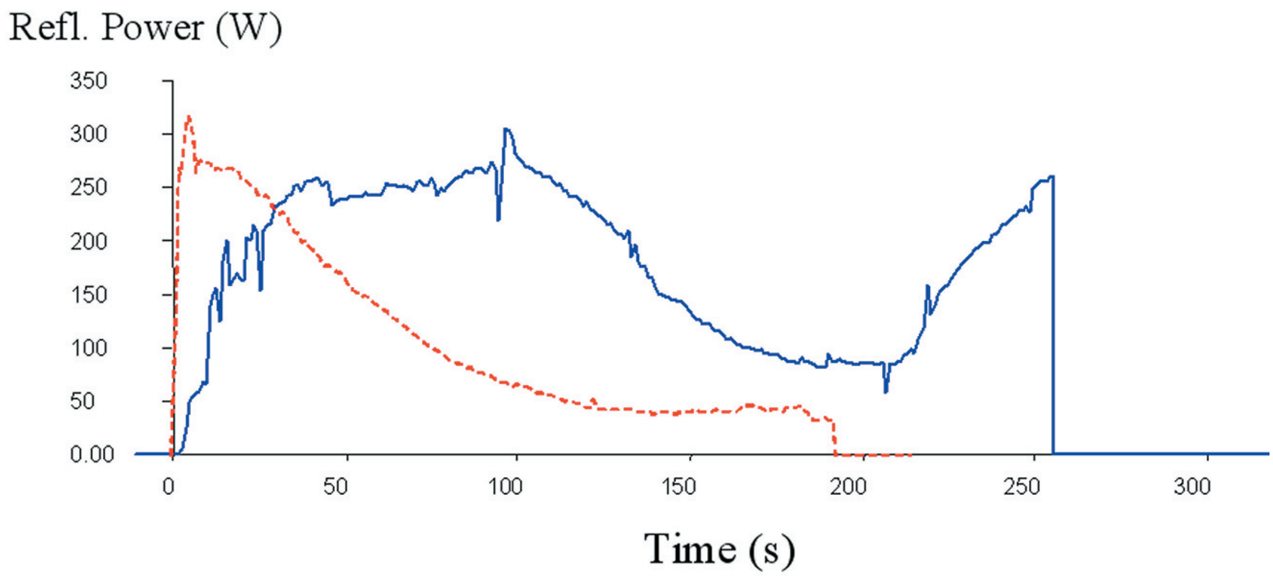

FIGURE 2. *Reflected power for a typical 3kW input power vs. time curve for 2 different fixed impedance matching conditions: at low pressure (continuous line, blue) and at high pressure (hatched line, red).*

schematically shows the path leading from the model to the prototype.

A more precise model of the microwave system was obtained on the basis of the experimental values (temperature stratification, moisture distribution), and a modified applicator was designed and implemented in order to maximise the treatment's efficiency. The best impedance matching conditions were determined in order to provide the lowest overall reflections, considering the variability of the load properties during time and pressure. In particular, due to the extreme variability of a system operating in the 0-10 bars pressure range, impedance matching was conducted on the prototype according to the criterion of the minimum overall power consumption, i.e. the minimum integral of the curve reflected power vs. time (Figure 2).

Commercial equipment

The system provided a good reproductibility of the microwave treatments, despite the high quantities of metal or the disproportion of a single component of the waste. Sterilization was achieved in all the tests performed on the optimized applicator (no microbiological growth was assessed from the 256 samples), and further developments involved the thermal insulation, the loading procedure and the on-board control systems.

In particular, in case of non-uniform heating in the axial direction due to the microwave attenuation caused by the high loss load or by the presence of a high density of metallic particles, the system guarantees the sterilization of the whole load by varying the microwave power emission level and the residence time of the waste. Figure 3 presents an optimized heating cycle with a homogenous temperature inside the microwave autoclave.

The temperature and pressure are monitored during each sterilization cycle and automatically recorded separately for each single batch treated.

The complete system has been fully implemented with a "block" design procedure, which is able to separately maintain the microwave generation sub-system, the mechanical parts, the auxiliaries and the

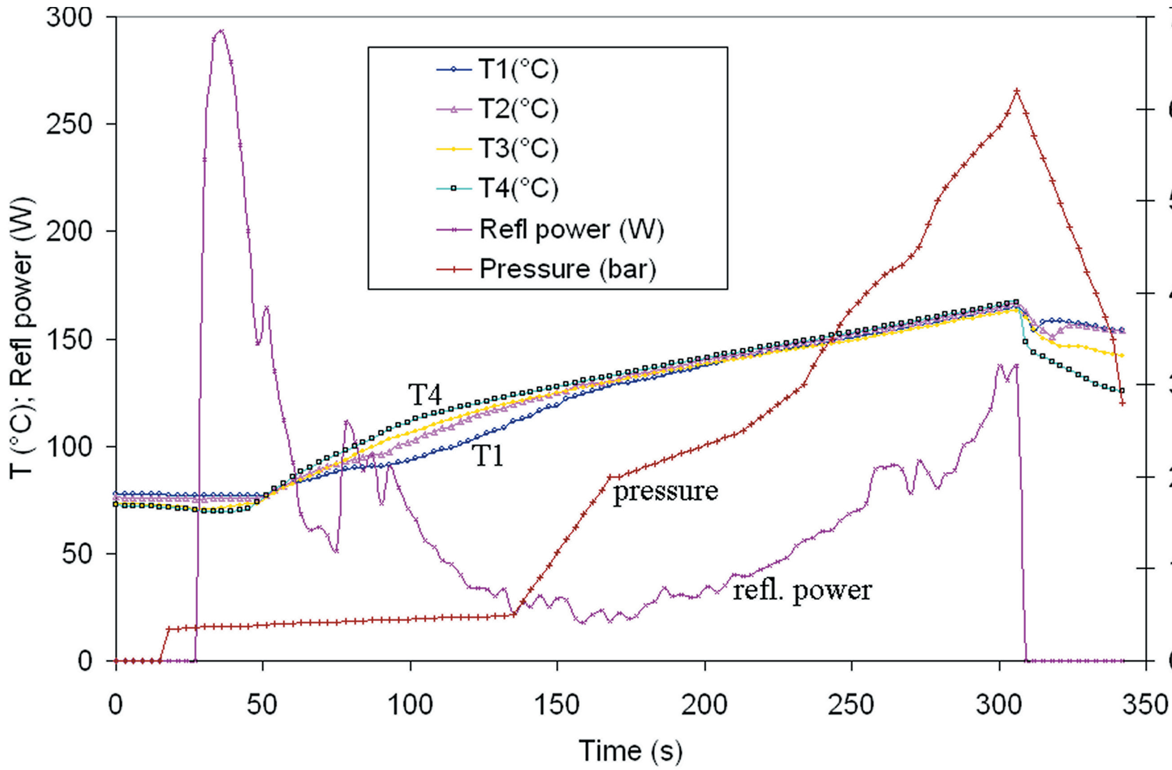

FIGURE 3. *Temperature profiles in the axial direction of the loaded applicator (T1, T2, T3, T4) as a function of time. Internal pressure values and reflected power are also reported for the very same run.*

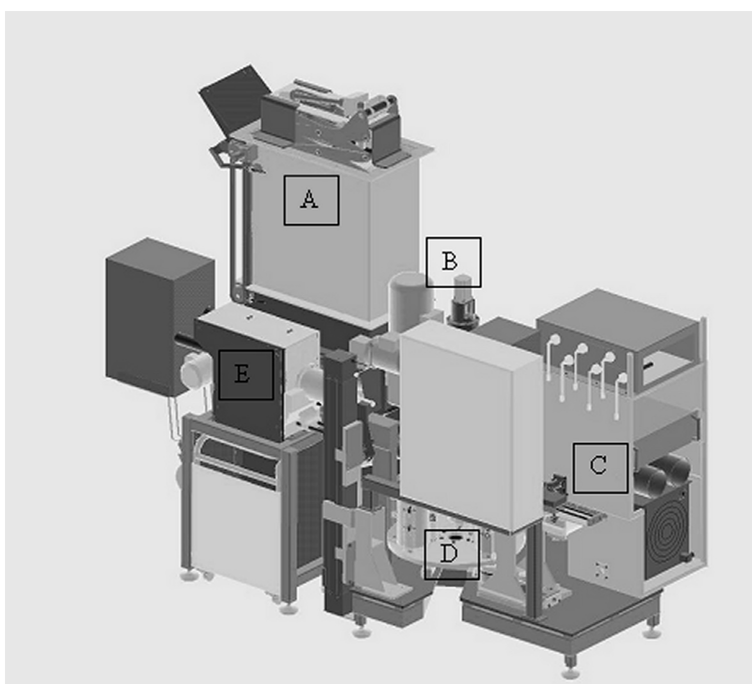

FIGURE 4. *Schematic 3-D view of the equipment indicating the main blocks: A) loading station; B) shredding and moisture correction; C) Process control + power supply; D) Treatment zone; E) Unloading.*

potentially contaminated region [CMS, 2006]. Fast installation procedures allow the rapid and complete maintenance or substitution of a damaged or malfunctioning part, without the risk of contamination for the operator. As a matter of fact, the contaminated region of the equipment can be sealed and transported to a centralised maintenance site where it can be conventionally sterilized before inspection or maintenance.
Figure 4 shows a schematic view of the commercial equipment. A full economic assessment of the achievable economical and safety benefits is in progress, based on the on-field results of long-term continuous-use experiments.

CONCLUSION

A non-incineration compact system using microwaves for sterilizing hospital infectious wastes has been realized on both laboratory and commercial scales, and thoroughly tested. The process is essentially a steam-based one in which sterilization occurs through the action of moist heat and pressurised steam. Numerical simulation allows the maximization of the applicator efficiency, as well as radial and longitudinal heating homogeneity. A block design approach was taken in order to be able, every time, to inspect and service the non-infected parts and component and, in case, to safely perform the on-site maintenance of the equipment.

A microwave generator operating at 2.45 GHz and up to 3 kW allows for the rapid and efficient heating of a shredded and pre-treated load, which may contain up to 10% wt of metal parts. The microwave applicator has been tested and used up to a pressure level of 7 atm, and it is equipped with a multi-point temperature controller, which is able to detect and correct load heating unhomogeneities that could result in potential mistreatment of the waste. Sterilization efficacy during microwave irradiation was tested and optimized using a newly developed procedure, which implements thermal, microbiological and water vapour sensors in a single test. The commercial scale system is completely closed; emissions, in terms of odours and noise, are maintained below the minimum of standard regulation by HEPA (high efficiency particulate air filter) and suitable insonorization (<45 dBA).

ACKNOWLEDGMENTS

The authors are grateful to CMS for providing continuous support and consultancy to the project and for building both prototypes. Gratitude goes also to the University of Modena and Reggio Emilia for financial support under Contract no.32, Progetti di ricerca Industriale 2005-2007 “Implementazione, ottimizzazione ed ingegnerizzazione di un sistema a microonde per la sterilizzazione di rifiuti ospedalieri” (Implementation, optimization and final design for a microwave system capable of sterilizing hospital waste).

REFERENCES

Blenkharn, J. I. (1995). “The Disposal of Clinical Wastes.” *Journal Hospital Infection*. 30, pp.544-520.

Brent, David A. (1992). “Method for Processing Infectious Waste Using Microwaves.” United States Patent, 5124125.

CMS-Costruzioni Meccaniche Salda S.p.A., Marano sul Panaro (MO), Italy, Prototipe of STR10.

Edlich, R.F. , Borel, L., Jensen, H. G., Winters, K. L., Long III, W. B., Gubler, K. D., Buschbacher, R. M ,Becker, D. G., Chang, D. E., Korngold, J., Chitwood, Jr., W. R., Lin, K.Y., Nichter, L. S., Berenson, S., Britt, L. D., Tafel, J.A. (2006). “Revolutionary Advances in Medical Waste Management. The Sanitec® System.” *Journal of Long-Term Effects of Medical Implants*. 16(1), pp.1–10.

Emmanuel, J., Hrdinka, C., Gluszynski, P., Ryder, R., McKeon, M., Berkemaier, P., Gauthier, A. (2004). “Non-incineration Medical Waste Treatment Technologies in Europe.” *Health Care Without Harm*

Europe. www.noharm.com.
Drake, R. C. (1993). "Apparatus for Sterilizing Medical Waste by Microwave Autoclaving." United States Patent 5223231.
Fujikava, H., Ushioda, H., Kudo, Y. (1992). "Kinetics of Escherichia Coli Destruction by Microwave Irradiation." *Appl. Environ. Microbiol*. 58, pp.920.924.
Furia, L. Hill, D.W., Gandhi, O.P. (1986). "Effect of Millimetre-Wave Irradiation on Growth of Saccharomyces Cerevisiae." *IEEE Trans Biomed Engineer*. 33, pp.993-9999.
Goldblith, S.A., Wang, D.I.C. (1967). "Effect of Microwave on Escherichia Coli and Bacillus Subtilis." *Appl. Microbiol*. 15, pp.183-184.
ISO International Organization for Standardization. 11138-1:2006.(2006). Ed. 2 Sterilization of health care products -- Biological indicators -- Part 1: General requirements, Genève, Switzerland.
Jeng, D.K., H., Kaczmarek, K.A., Woodworth, A.G., Balasky, G. (1987). "Mechanism of microwave sterilization in the dry state." *Appl. Environ. Microbiol*. 53, pp.2133-2137.
Lechowich, R.V., Beuchat, L. R., Fox, K.I., Webster, F. H., (1969). "Procedure for Evaluating the Effect of 2,450 Megahertz Microwave Upon Straesptocuccus Faecalis and Saccharomycs Cerevisiae." *Appl. Microbiol*. 17, pp.106-110.
Melino, C. Messineo, A. Rubino, S. Allocca, A. (2001). L'Ospedale: Igiene, Prevenzione e Sicurezza. S.E.U. Third Edition, Roma, Italia.
Attuazione delle direttive 91/156/CEE sui rifiuti, 91/689/CEE sui rifiuti pericolosi e 94/62/CE sugli imballaggi e sui rifiuti di imballaggio (Enforcement of the European directives91/156/CEEon waste, 91/689/CEE on dangerous waste, and 94/62/CE on packaging and used packaging). GU n. 38 del 15-2-1997 - Suppl. Ordinario n.33.
Moscato, U, Veronesi, P, Laurenti, P, Cappi, A, Ricciardi, G, Leonelli, C. (2005). "Rapid Microwave Assisted Sterilisation of Hospital Wastes." Proceedings 2nd Annual HTAi Meeting "Bringing HTA into practice." Rome, June 20 th-22nd 2005, Italy.
Moscato, U, Dalla Torre, F, Figurelli, O, Leonelli, C, Veronesi, P, Ricciardi, G. (2006). "International PBI: Application note-Biological indicators for sterilization of health care products." Milan, Italy [in printing].
Najdovski, L., Dragas, A.Z., Kotnik, V., (1987). "The Killing Activity of Microwaves on Some Non-Sporogenic and Sporogenic Medically Important Bacterial Strains." *J. Hosp. Infect*. 19, pp.239-247.
Takashi, K., Shigenori, K., Koichi, N. (1993). " Method of an Apparatus for Treating Infectious Medical Wastes." US Patent 5213758.
UNI 10384-1:1994 Ente Nazionale Italiano di Unificazione. (1994). Impianti e processi di sterilizzazione dei rifiuti ospedalieri. Requisiti generali. (Machinery and processes for the sterilization of hospital wastes-General procedure) Milan, Italy.
Vela, G.R., Wu, J.F. (1969). "Mechanism of Lethal Action of 2450 MHz Radiation on Microorganisms." *Appl. Environ. Microbiol*. 37, pp.550-553.