

Miniature microwave powered steam sterilization chamber

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A small device for the rapid ultrahigh temperature sterilization of surfaces is described. Microwave power generated by a 2.45 GHz magnetron is delivered via coaxial cable to a silicon carbide block housed within the chamber. Small quantities of water or aqueous hydrogen peroxide are introduced into the chamber. Upon application of power, the liquid flashes to vapor and superheats producing temperatures to 300 °C. The hot vapor permeates the enclosed space and contacts all exposed surfaces. Complete microbial kill of $>10^6$ colony forming units of the spore forming thermophile, *Bacillus stearothermophilus*, has been demonstrated using a variety of temperatures and exposure times in both steady state and thermal pulse modes of operation. © 1997 American Institute of Physics. [S0034-6748(97)03910-5]

A miniature sterilization chamber was developed as a primary component of the microwave sterilizable access port, a sterile interface for the transfer of nutrients, and specimens between biologically sensitive systems and the external environment.¹ Biological systems which are particularly prone to contamination include tissue cultures and eukaryotic cell bioreactors, such as those for the propagation of hybridomas.² While potentially applicable under a broad range of circumstances, the microwave sterilizable access port was intended specifically for use with the Mammalian Cell Bioreactor currently under development by NASA for growth of human tissue under microgravity conditions.

The fundamental operational advantage conveyed by the use of microwave power to drive the thermal sterilization of all exposed surfaces within the miniature sterilization chamber is the direct absorption of electromagnetic energy by materials with appropriate dielectric loss characteristics.^{3,4} In contrast to resistive heating which relies on conduction and convection, microwave heating is much more rapid, and also more selective, in that only materials with the requisite properties absorb energy directly. This allows the overall thermal impact to the system to be minimized, while, at the same time, a rapid and efficient thermal sterilization is achieved.

The small sterilization chamber, illustrated in Fig. 1, consists of an aluminum housing which surrounds a 14 cm³ cylindrical silicon carbide (SiC) monolith. Inside the SiC block, a small chamber with an internal volume of approximately 1 cm³ is formed in which test specimens may be placed. Within the chamber an antenna emits radiation directly into the SiC heating block. SiC was selected based upon its heat capacity, thermal conductivity, thermal and mechanical stability, and excellent dielectric loss characteristics. An insulating layer of silicone impregnated glass mat between the aluminum housing and the SiC block provides thermal isolation of the chamber interior. The chamber is fitted with both pressure and temperature monitoring ports.

Access to the sterilization chamber is gained through the cover which is clamped into position during use. O rings ensure an adequate seal between the cover and the sterilization chamber body.

Microwave power originates from an 800 W magnetron emitting at 2.45 GHz into a WR 430 waveguide launcher section. Microwave power is transmitted sequentially through a WR 430 to WR 284 transition, a WR 284 to coaxial adapter, and a shielded coaxial cable to the panel mount SC connector attached to the sterilization chamber and which conducts directly to the antenna buried in the SiC heating block. The use of coaxial cable transmission lines which can be easily connected or detached makes practical the application of a single microwave power source with a multiplicity of sterilization chambers. Microwave power output is regulated using a temperature controller in the time proportional mode to regulate ac input to the magnetron power supply. Temperature and pressure readouts are provided by a digital thermometer and pressure transducer, respectively.

Exposed surfaces within the chamber are sterilized using a small quantity of water ($\approx 500 \mu\text{L}$) or an aqueous hydrogen peroxide solution. Both of these substances readily absorb microwave energy at 2.45 GHz. The liquid is rapidly vaporized and then superheated within the pressure tight chamber by absorption of microwaves and by thermal conduction from the SiC block. This also pressurizes the system. The superheated vapors contact all surfaces internal to the miniature sterilization chamber. While routine autoclave procedures at 2 atmospheres and 121 °C require 16 min at operating temperature and pressure to ensure sterilization, the exponential relationship between temperature and exposure time allows much more rapid destruction of micro-organisms at higher temperatures.^{5,6} For example, an equivalent lethality, i.e., $F_0 = 16$, can be achieved at 135 °C in 42 s. Because temperature is monitored by a thermocouple mounted in the SiC block near the microwave antenna, until steady-state conditions are reached, the indicated temperatures do not re-

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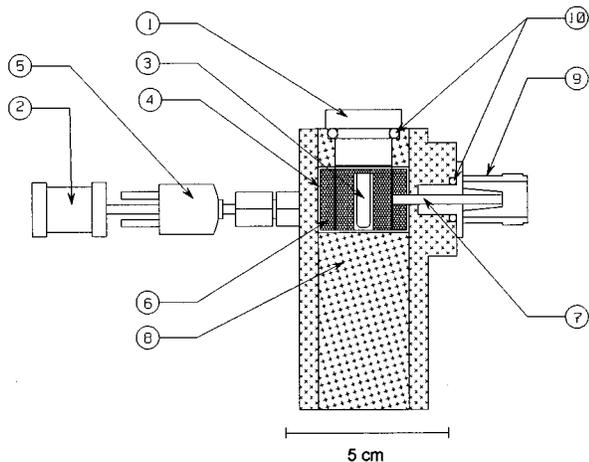


FIG. 1. Prototype sterilization chamber: 1—cover, 2—pressure port, 3—specimen, 4—PTFE insulation, 5—temperature ports, 6—silicon carbide heating block, 7—antenna, 8—aluminum housing, 9—coaxial connection, 10—O-ring seals.

fect the actual temperatures of the superheated vapor, but rather more localized values within the heating block.

An important operational constraint was to minimize the amount of liquid required to achieve sterilization. A series of tests were performed using polytetrafluoroethylene (PTFE) coupons housed within the microwave powered sterilization chamber. The coupons were contaminated with $\approx 10^6$ colony forming units (CFU) of either *Bacillus stearothermophilus* or *Enterococcus faecalis*. Variable volumes of deionized (DI) water were introduced into the system. Steady state indicated chamber temperatures and exposure times were varied. Initial tests indicated a reduction in population of *E. faecalis* by a factor of 10^6 at 140°C with $600\ \mu\text{L}$ of water introduced into the chamber and an exposure time of 3 min. Subsequent tests were conducted exclusively with *B. stearothermophilus*, a more thermally resistant organism. Constant temperatures of 150°C for an exposure of 5 min were found adequate for complete destruction of the microbe using $500\ \mu\text{L}$ of 1% H_2O_2 .

A second operational strategy was explored for the miniature microwave powered sterilization chamber. Rather than maintaining a constant temperature, a thermal pulse was applied to the SiC block. The temperature controller was programmed to deactivate magnetron power once a preset temperature was reached. This allowed the transient use of much higher indicated temperatures. Pressure profiles suggested that system temperatures were in general substantially below the maximum indicated temperatures. Initially, sterilization

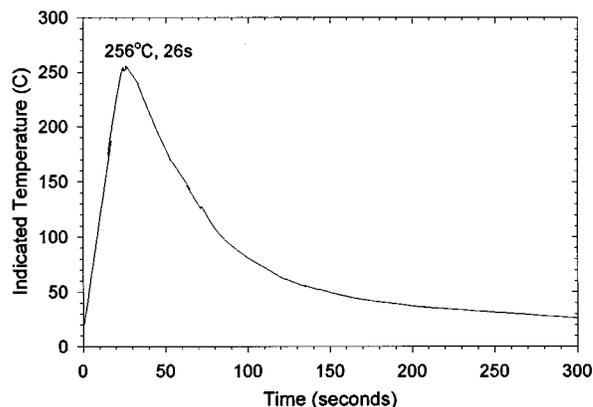


FIG. 2. Sterilization chamber indicated temperature profile.

chamber heat up was too rapid to provide the required exposure time following discontinuation of power. This problem was alleviated by slightly detuning the launcher waveguide section using a variable position end plate, resulting in a reduced efficiency of microwave transmission via the coaxial cable. Under these conditions, $500\ \mu\text{L}$ of water and a set-point temperature of 250°C were found to result in a complete bacterial kill. A typical indicated temperature profile for a thermal pulse sterilization event with a set point of 250°C is shown in Fig. 2. In this example, the set-point temperature is reached in 26 s. A maximum pressure of 3.3 atmospheres was achieved within the chamber for this event after 30 s. The need for cool down and depressurization resulted in an approximate 5 min period between subsequent sterilizations. Significantly higher heating rates are achievable, but in the thermal pulse mode of operation, higher heating rates result in exposure times at elevated temperatures which are not sufficient to ensure a complete microbial kill.

ACKNOWLEDGMENT

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