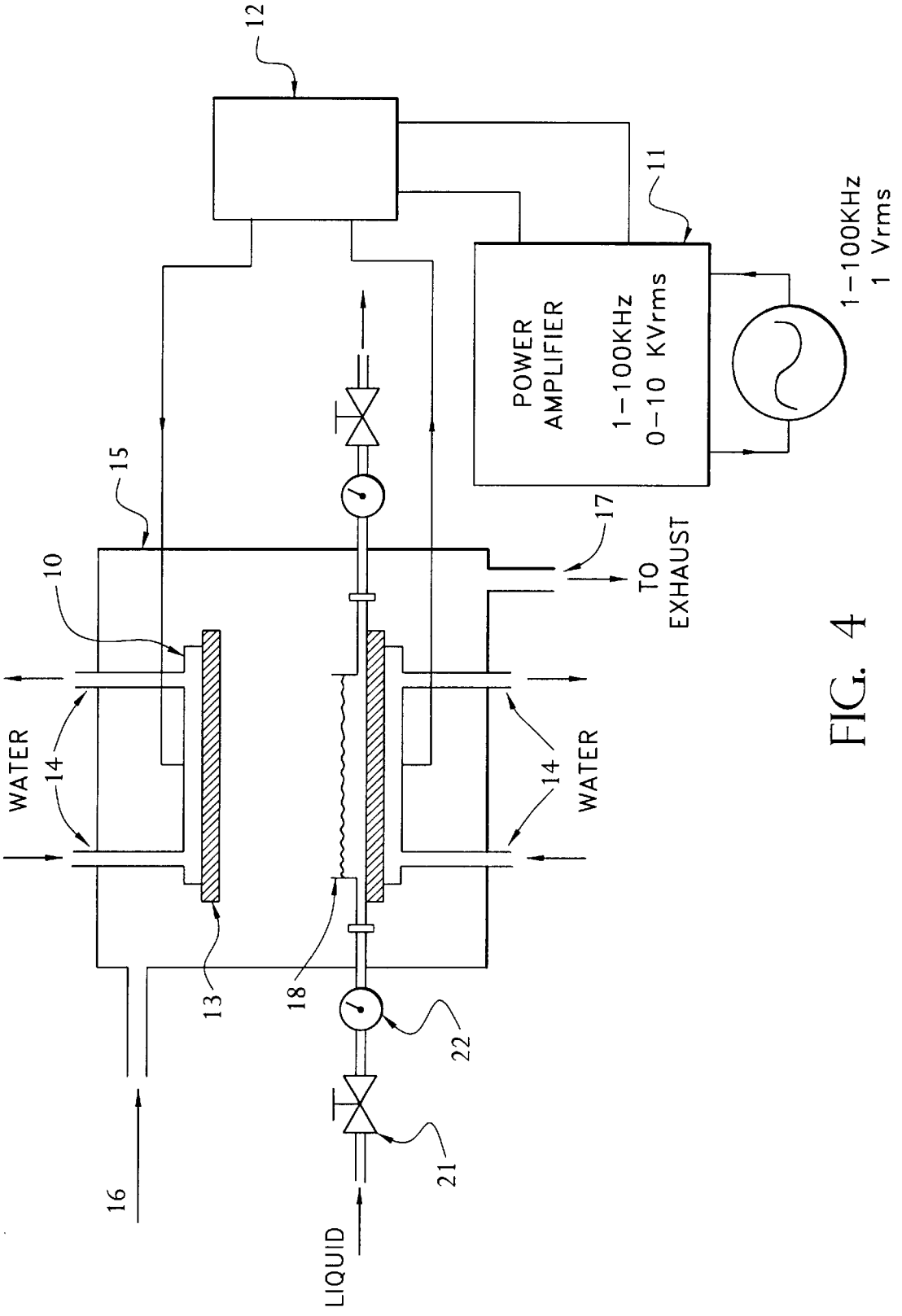
12
11
POWER AMPLIFIER
1-100KHz
0-10 KVrms
1-100KHz
1 Vrms
15
17
TO EXHAUST
10
WATER
14
14
WATER
13
18
22
21
16
LIQUID

FIG. 4

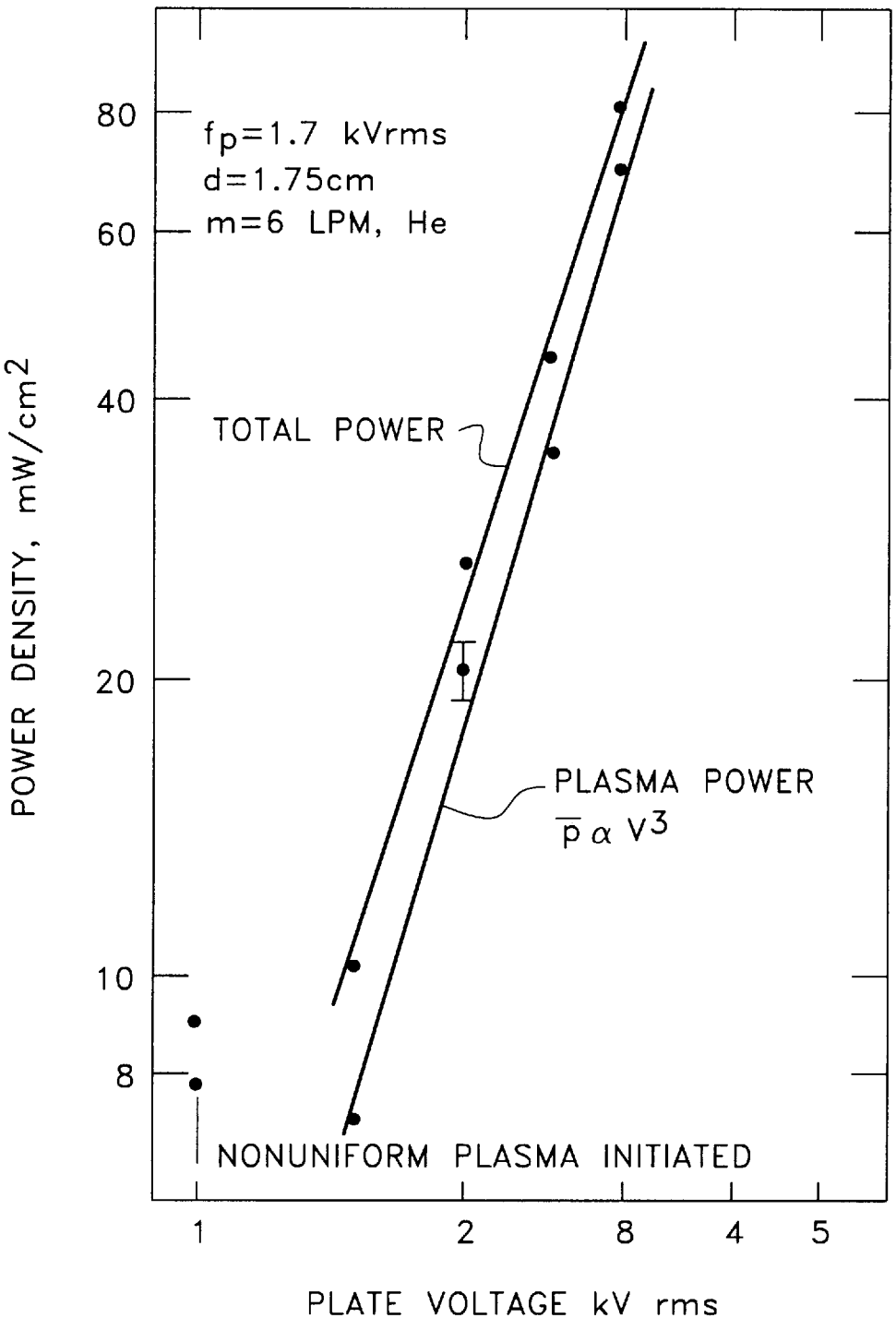
80
60
40
20
10
8
f_p=1.7 kVrms
d=1.75cm
m=6 LPM, He
TOTAL POWER
PLASMA POWER
$\overline{p} \alpha V^3$
NONUNIFORM PLASMA INITIATED
POWER DENSITY, mW/cm^2
1
2
8
4
5
PLATE VOLTAGE kV rms

FIG. 5

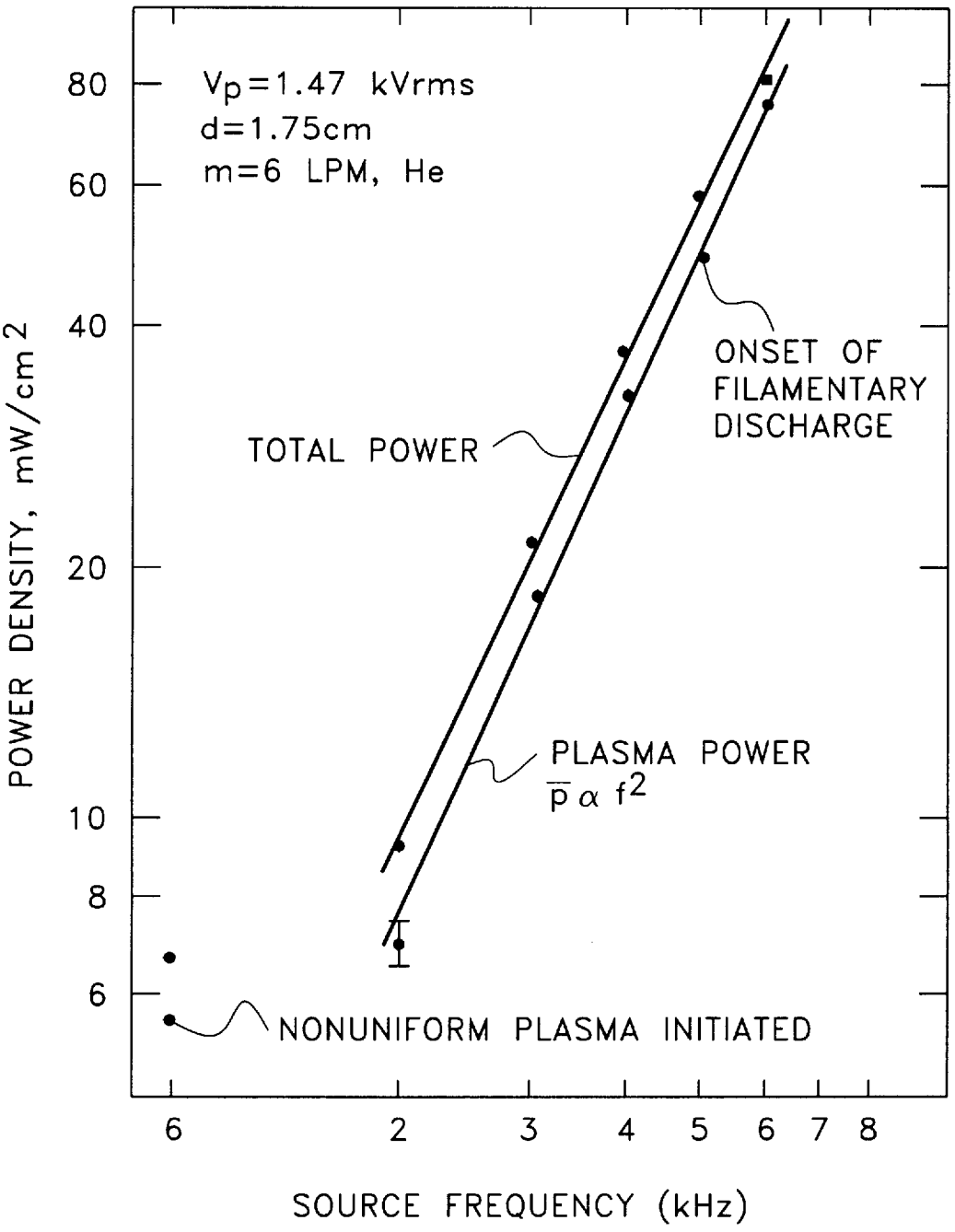
Vp=1.47 kVrms
d=1.75cm
m=6 LPM, He
80
60
40
20
10
8
6
POWER DENSITY, mW/cm 2
TOTAL POWER
ONSET OF FILAMENTARY DISCHARGE
PLASMA POWER
$\overline{p} \alpha f^2$
NONUNIFORM PLASMA INITIATED
6
2
3
4
5
6
7
8
SOURCE FREQUENCY (kHz)

FIG. 6

STERILIZATION OF LIQUIDS USING PLASMA GLOW DISCHARGE

This application claims the benefit of U.S. provisional application No. 60/006,700, filed Nov. 14, 1995.

This invention relates to the sterilization of liquids, such as infectious waste, by plasma irradiation.

BACKGROUND OF THE INVENTION

U.S. Pat. No. 5,414,324, discloses a steady-state glow discharge plasma apparatus operated at one atmosphere of pressure between a pair of spaced apart insulated metal plate electrodes, and R.F. energized with an rms potential of 1 to 5 KV at 1 to 100 KHz. Air or other gases fill the space between the electrodes. The electrodes are charged by an impedance matching network adjusted to produce the most stable uniform glow discharge. That patent is incorporated herein by reference.

Other patents that relate to steady-state glow discharge plasma at one atmosphere are U.S. Pat. Nos. 5,387,842, 5,456,972 and for the treatment of polymer material 5,456, 972. These patents are incorporated herein by reference.

SUMMARY OF THE INVENTION

In one embodiment the invention is a method for sterilizing a liquid, that is for killing the microorganisms present in a liquid, which method comprises exposing the liquid to a steady state glow plasma discharge for a period of time sufficient to kill or render inviable all microorganisms present in the liquid. Preferably, the glow plasma discharge is at a pressure of about one atmosphere.

In another embodiment, the invention is an apparatus for sterilizing a liquid, which apparatus comprises a pair of metal plate electrodes mounted in approximately face-to-face parallel alignment, a radio frequency (RF) power amplifier connected to both plates energized with an rms potential of 1 to 5 or more KV at 1 to 100 KHz, an enclosure for maintaining a controlled gas atmosphere in the space between the plates, and a container positioned within the enclosure and between the plates for holding the liquid to be sterilized, which liquid may be stationary within the container or may flow through the container.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic of the apparatus for practicing the method of the invention.

FIG. **2** shows a schematic of the apparatus for sterilizing a static liquid within a container.

FIG. **3** shows a schematic of the apparatus for sterilizing a liquid in which one of the electrodes is perforated.

FIG. **4** shows a schematic of the apparatus for sterilizing a flowing liquid.

FIG. **5** is a log-log graph of total and plasma power density in milliwatts per cubic centimeter as a function of RMS voltage applied to the electrodes.

FIG. **6** is a log-log graph of total and plasma power density in milliwatts per cubic centimeter, as a function of R.F. frequency.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In accordance with the invention, the apparatus described is used to irradiate, by a steady-state glow discharge plasma, infectious waste for sterilization. Liquids, like water, can be exposed to the plasma and treated in accordance with the method of the invention. Thus, health threatening organisms living in liquids for human or animal consumption can be exterminated by exposure of the liquid to the one atmosphere pressure plasma. In effect, this brings about the elimination or sterilization of unsafe organisms from the liquids, like from water supplies.

In such manner, water treatment systems of municipalities and other locations can be treated and sterilized. The method of the invention is more attractive, both economically and environmentally, than the present methods of incineration. Excellent commercial applicability is expected.

The apparatus for production of the plasma discharge comprises an enclosure, such as a plexiglass enclosure, which contains two electrodes, either both insulated or one of the two, preferably the lower electrode, uninsulated, which are separated by a variable distance d. The plasma is generated by applying an RF voltage between the two electrodes. When the frequency of the RF voltage falls within a range around a critical frequence f_o a uniform glow discharge fills the entire space between the electrodes. The critical frequency f_o is determined by the equation: $f_o=eVrms/\pi mv_c d^2$, where Vrms is the rms value of the voltage between the two electrodes, v_c is the collision frequency (dominated by electron-neutral collisions and is about 10^{12} Hz for electrons and 10^{10} HZ for ions), and d is the distance between the electrodes. The rms voltage necessary to start the discharge depends on the type of gas between the electrodes and the distance d. For an inert gas like helium and a 1 to 5 cm gap between the electrodes, f_o is about 1 to about 10 KHz. In the expression of f_o shown above, "e" is the electronic charge, (1.6×10^{-19} C) and "m" is the atomic mass of the gas.

Virtually any liquid can be sterilized by the method of the invention. The liquid to be sterilized may be of low viscosity, such as water, or of high viscosity, such as a gel. Generally, any liquid which can be maintained at a depth of 1 cm or less may be sterilized by the method of the invention. The method of the invention is particularly well suited for the sterilization of liquids such as water, milk, juice, beer, pharmaceutical solutions and suspensions, blood and blood products, microbiological culture media, and sewage.

The method of the invention can be used to sterilze a liquid containing one or more microorganisms. The method is effective to kill virtually any microorganism, at any stage of growth of the microorganism. Examples of microorganisms which may be destroyed in accordance with the method of the invention include viruses, gram negative bacteria such as Pseudomonas spp. and *Escherichia coli*, gram positive bacteria such as *Staphylococcus aureus*, and Bacillus spp., including bacillus endospores, and eukaryotic microorganisms, such as protozoa, yeasts, and fungi, including endospores thereof.

Generally, in accordance with the method of the invention, a liquid to be sterilized is placed within a container, and the container is immersed in a steady state plasma glow discharge for a period of time sufficient to kill the microorganisms in the liquid. Typically an exposure time between 10 seconds and 10 minutes is sufficient to sterilize a liquid. The depth of liquid within the container should be less than about 1 cm, such as about 0.1 or 0.2 to 0.7 cm, and preferably between about 0.3 to 0.5 cm. The container may be any container which is of a size to fit within the gap between the two electrodes which produce the plasma glow discharge and which is made of a dielectric material which