Interaction of a microwave beam with a liquid: energy conversion, possible applications

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An investigation is made of the boiling of liquids (water, petroleum) in a powerful microwave beam for converting the microwave power into mechanical work (microwave steam engine), for self-pumping, for fractionation of liquids (separation of volatile fractions, rectification, desalination), for accelerating diffusion, for facilitating fluid penetration through porous media, etc. The possibility is noted of cracking fuel in a microwave discharge or microwave heating.

The development of present day microwave power technology is associated not only with high efficiencies of generation, but also with high powers of sources.[1,2] Lately, in particular, variants of microwave transport of energy from space power stations are being discussed.[3]

Already at flux densities of $I \approx 10^2$–10^3 W/cm^2 the rate of heating of surfaces of media is quite great: $T \approx \alpha I / C\rho\delta \sim 10^2$ deg/s in the case of fraction of absorption $\alpha \approx 0.5$, heat capacity of the absorbing layer $C\rho\delta \approx$ J/cm^2 and depth of absorption $\delta \approx 0.5$ cm; in a liquid process of evaporation and boiling should quickly begin which may be utilized for conversion of microwave energy. The present note is devoted to a demonstration of possibilities of application of such action of a microwave beam.

Experiments have been carried out using the apparatus of Fig. 1 with the generator of radiation in the centimeter range producing in the regime of periodic pulses of 50 μs duration and 10 J energy with a repetition frequency of up to 100 Hz an average power of $P \approx 1$ kW with a pulse density of 100 kW/cm^2. Such an apparatus was utilized earlier for a plasma torch conversion of microwave energy into the energy of a current (cf. Ref. 4, where an efficiency of 20% was obtained). The microwave beam was focused by a lens and a vessel containing a liquid was placed at the focal spot (with heating from the side), or the beam was directed by a mirror onto the surface of a liquid in the vessel (with heating from the top). From the vessel there emerged a pipe leading the steam outside the "barrel" which served to screen the microwave radiation.

The particular features of boiling of the liquid in such a beam were manifested, in particular, in a special regime of heating and boiling in the case of heating from above (boiling from the surface without bubbles throughout the volume) and in the production of superheating in the case of heating from the side. The rapid input of energy led to superheating—the violent boiling produced a large bubble in the liquid and an explosive liberation of steam (Fig. 2).

1. MICROWAVE STEAM ENGINES

A turbine was tested operating on the jet of the emerging steam. A turbine with a moment of inertia of 10^4 g·cm^2 and with a damping time for the rotation of 2 s and a blade length of 8 cm was speeded up to rotation frequencies of 10 s^{-1}. In terms of the power of work against friction forces $W_{fr} \approx J\Omega^2_{turb}/T_{damp}$ an estimate was made of the conversion efficiency (efficiency $= W_{fr}/P$) which amounted to 1% without taking into account the return of the heat upon condensation of steam, and this is not bad for such an imperfect construction. Much more efficient would be engines of piston type in which the steam presses on a working surface within a closed volume (cf. engines using a microwave torch[5]).

2. SELF-PUMPING OF LIQUID

A test was made of self-pumping of a liquid under the action of steam pressing on the surface. A tube was inserted into the liquid being heated (cf. Fig. 1b) and as the tempera-

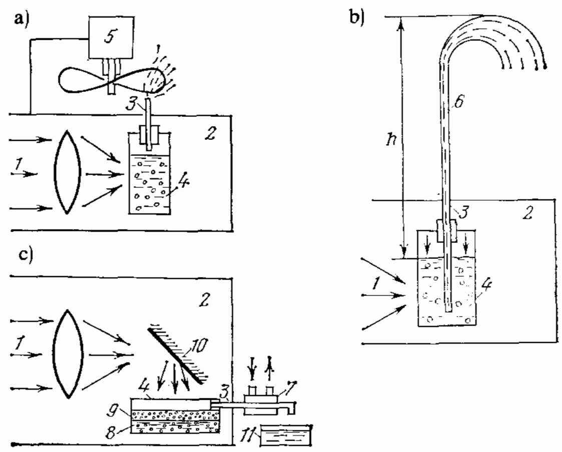

FIG. 1. Diagram of experiments. a) Conversion of microwave energy into mechanical energy (microwave steam engine); b) Self-pumping of liquid boiling under the action of microwaves; c) Passage of a liquid through porous media (rectification and fractionation of petroleum). 1—microwave beam, 2—metallic barrel for screening, 3—exit pipe, 4—glass vessel with liquid, 5—turbine, 6—jet of a liquid fountain ejected to a height of 1–2 m, 7—cooler of the exit pipe, 8—layer of petroleum in the layer 9 of quartz sand used in investigating breakthrough upon heating, 10—mirror for turning the beam to heat the liquid from above, 11—receptacle for the light fraction of petroleum evaporated upon heating (rectification was carried out both in heating from above or from the side).

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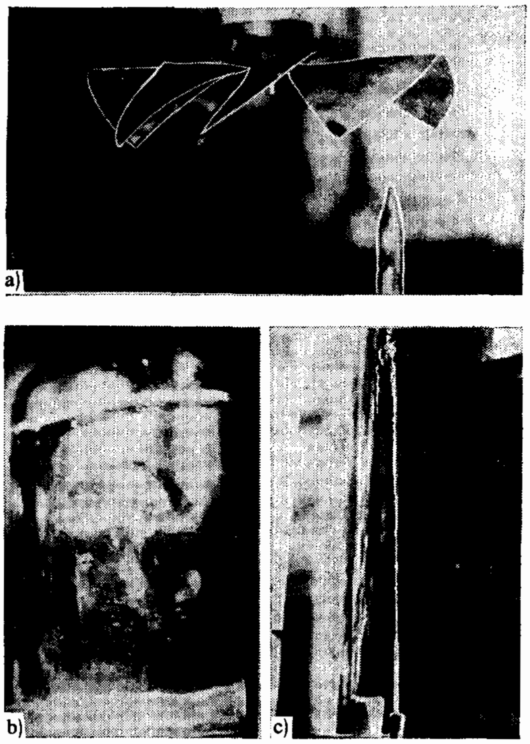

FIG. 2. Photographs of the boiling of a liquid in a microwave beam and of the resultant work. a) Photograph of a microwave steam turbine; b) photograph of water boiling with superheating (a bubble being formed violently can be seen; explosive boiling improved the conversion of the energy into mechanical energy); c) photograph of the fountain jet of the liquid.

ture of the liquid was raised a fountain spurted upwards to a height of $h \approx 1$–2 m (with liquid being ejected at the rate of $\dot{M} \approx 20$ g/s at a velocity of ejection of $v = \sqrt{2gh} \approx \sqrt{4 \cdot 10^5} \approx 10^3$ this corresponds to a power of $W = \dot{M}gh \approx$ W). This experiment demonstrates the possibility of self-pumping of liquids (water, petroleum) using microwave heating.

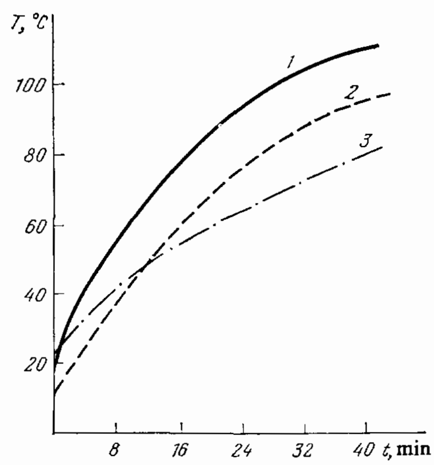

FIG. 3. The relative rate of microwave heating of different liquids in a vessel with plane walls (in a vessel with a conical end in order to decrease reflection the rate of heating is several-fold higher). 1—sea water, 2—plain water, 3—petroleum.

Accelerated diffusion and breakthrough of petroleum and petroleum vapors through quartz sand was observed with microwave heating.

Measurements were made of the rate of heating of water, sea water, and petroleum taking into account possible changes in reflection and absorption with the temperature in the range of 10–100 °C (Fig. 3).

3. FRACTIONATION OF LIQUIDS USING MICROWAVE HEATING

An investigation was made of the effect of microwaves on mixtures of liquids (natural petroleum) and solutions (sea water). The measured rate of heating with incidence from the side shows good coefficients of absorption even when the beam falls on a plane boundary (with better matching and a decrease of reflection when the beam was incident on a vessel with a conical indentation the rate of heating was almost doubled). When petroleum was heated and boiling occurred (cf. Fig. 1c) a light fraction was separated which indicated the possibility of using microwaves for fractionation of petroleum.

When sea water was boiled the salinity of the remaining portion increased, and this demonstrates the possibility of microwave desalination.

At high temperatures and pressures destructive processing of fuel is possible both in a gaseous medium and in a liquid (a microwave discharge in gases and vapors can be utilized for the breaking up of heavy hydrocarbons and the production of high quality fuels).

Even this incomplete list of possibilities shows the great promise of practical utilization of microwaves.

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