THE RADIATION ENERGY LOSSES AND STRUCTURE OF OXIDE CONDENSATION ZONE DURING A Mg PARTICLE COMBUSTION

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Abstract

The work is devoted to the experimental study of radiation losses during combustion of a single Mg particle. For the first time the total radiation energy is measured directly. It is shown that radiation energy consists nearly constant part (~40%) of total heat release during combustion for all the particles studied.

Introduction

Burning metal particles and metal particle clouds are strong radiators and radiative heat transfer supposed to play essential role in combustion of metals. The main part of radiation energy is emitted by burning particles or by ultrafine oxide particles forming during combustion [1]. In case of burning magnesium particle the ultrafine oxide particles emit the main part of radiation energy [2]. When theoretical modeling of Mg particle combustion the radiative heat transfer is described using Stefan-Boltzmann law in assumption that the emissivity of condensation zone not depends on the initial particle size [3]. But for the present moment there are no reliable data on the emissivities of the ultrafine oxide particle clouds at high temperatures. In the present work the integral radiative loses during total time of Mg particle combustion was measured. The spatial distribution of the extinction caused by the ultrafine oxide particles near the burning particle was studied by scanning of the focused He-Ne laser beam.

Experimental approach

Experiments were carried out with spherical 1-2.5 mm diameter Mg particles. Vertical 120 μm boron wire having tungsten core supported the particles. Ignition was via small propane-air diffusion flame that was removed immediately after the beginning of induction period of particle combustion. The ignition was identified with transition to vapor phase combustion occurred by further particle self-heating due to the magnesium oxidation.

Fig.1 shows the schematic of the focused laser beam scanning. The oscillating mirror deflects the He-Ne laser beam. After the deflection the laser beam passes through the first lens that provides round-trip parallel motion of the focused laser beam in the flame region. A linear slide moved burning particle downward to provide 2D scanning. The second lens focuses beam on the photodiode connected with the oscilloscope. The connection scheme provides the proportionality of the registered signal to the logarithm of the intensity of signal coming onto photodiode. The laser beam thickness in the flame region was less than 40μm. Radial distribution of extinction coefficient near the burning particle was restored by the inverse Abel transform.

The integral radiation energy loses during total Mg particle combustion was measured by calorimetric photo-detector IMO-2N. This device was carefully calibrated using the tube model of absolute radiator built specially. Fig.2 shows the schematic of radiation losses measurements. Photo-detector measured integral radiation energy emitted by the flame into known small spatial angle in the horizontal direction. For the correct calculation of the total energy emitted in all directions it was necessary to control radiation indicatrix. Indicatrix of Mg particle flame radiation was measured simultaneously with the measurement of the radiation energy by the photodiode rapidly moving around the particle. Steel rods were installed on a round between the burning particle and photodiode trajectory to define current photodiode position. Indicatrix registration time was less than 0.1s.

The main energy during Mg combustion released when MgO vapor condensing. To control total energy release the degree of conversion Mg to condensed oxide was measured by weighting of initial Mg particles and total amount of condensed oxide (smoke + ash) after combustion. Fig.3 shows the schematic of the oxide smoke collection.

Results and discussions

Weighting of initial Mg particles and of total oxide after combustion has shown that all initial magnesium was converted to condensed oxide, i.e. maximal possible energy was released. The total energy release (it is proportional to initial particle mass) was calculated by known thermal effect.

Fig.4 shows experimentally measured integral radiative heat loss during Mg particle combustion via the initial particle mass. One can see from Fig.4 that radiation heat loss is nearly proportional to the initial particle mass, so the ratio of energy loss to initial particle mass is approximately constant. As total energy release during combustion linearly depends on initial Mg particle mass we can conclude that the ratio of total radiation loss to total heat release is constant also. The slope of approximating line in Fig.4 gives the value ~40 % for the part of total released energy which loosed by the radiation

The radial distribution of the extinction coefficient near the burning particle was restored by the results of the laser beam scanning. It was revealed that the extinction takes place within narrow spherical layer with diameter twice larger than the initial particle diameter. The thickness of this layer was less than 100 μm for all the particles studied. The absolute values of optical thickness of condensation zone for Mg particles of different initial diameters are also obtained by laser beam scanning (Fig5).

The effective emissivity of the condensation zone was calculated by the results of the radiation energy measurements and by the obtained dimension of the condensation zone using the laser beam scanning. Fig. 6 shows the dependence of the emissivity on the initial particle size. For the effective emissivity calculation we used the experimentally measured temperature of the condensation zone $T=2600\ K$ [2]. Decrease of the effective emissivity with the initial Mg particle size increase does not correspond to the theoretically accepted invariance of the condensation zone emissivity [3].

The measured absolute values of optical thickness of condensation zone showed that condensation zone more reasonable to consider as a transparent than as a solid. For transparent zone the total radiation energy can be regarded as the sum of energies emitted by each condensing oxide particle. In this case emissivity of condensation zone must depends on the ultrafine oxide particles concentration in this zone. As the gas convection removes oxide particles out of condensation zone, this concentration depends on the mean gas convection velocity near the burning particle. So, the part of total heat release lost by the radiation also must depend on the convection velocity in this case.

Supposing that ultrafine oxide particles concentration is proportional the optical thickness of condensation zone, Fig.5 reflects tendency of decrease of this concentration and, consequently, of the emissivity of the condensation zone with increase of initial Mg particle diameter. So, the revealed changing of Mg particle flame emissivity dependently of initial Mg particle diameter can be caused by changing of oxide particles concentration in the condensation zone. It should be noted that last conclusion was made on the base of the traditional idea that radiation of condensing oxide particles is thermally equilibrium. Recently the hypothesis is given [4] that this radiation can be essentially nonequilibrium. This hypothesis predicts constancy of ratio of radiation loss to total heat release during Mg particle combustion independently of oxide particles concentration in the flame. This constancy is also formally equivalent to experimentally observed changing of condensation zone emissivity with changing of initial Mg particle diameter.

To reveal the nature of condensing oxide radiation (equilibrium or not equilibrium) future experiments on Mg particle flame radiation with regulated oxide particles concentration in the condensation zone are needed. Artificial reducing or increase of gas convection velocity in the flame region might realize such a regulation.

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References

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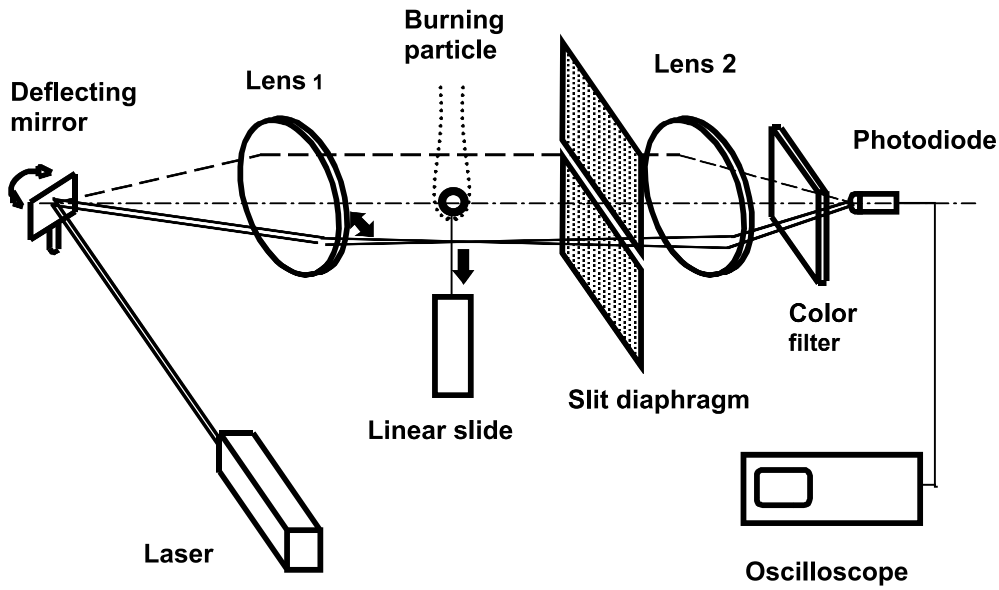

Fig.1. Schematic of focused laser beam scanning of Mg particle flame

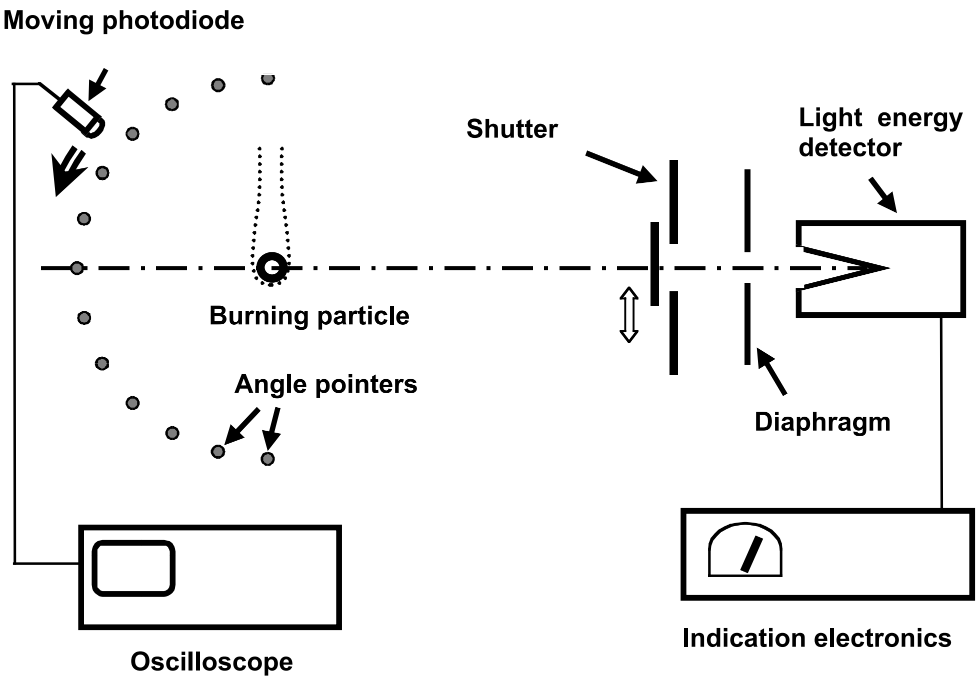

Fig.2. Schematic of measurement of radiation energy and radiation indicatrix of burning Mg particle.

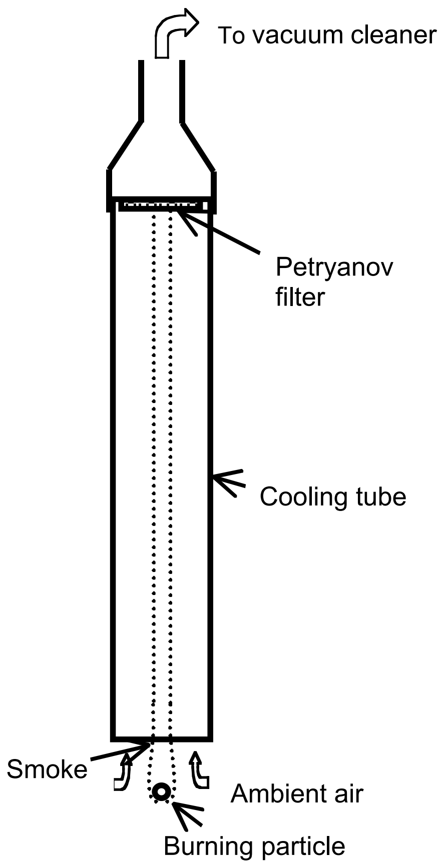

Fig.3. Schematic of ultrafine oxide smoke collection.

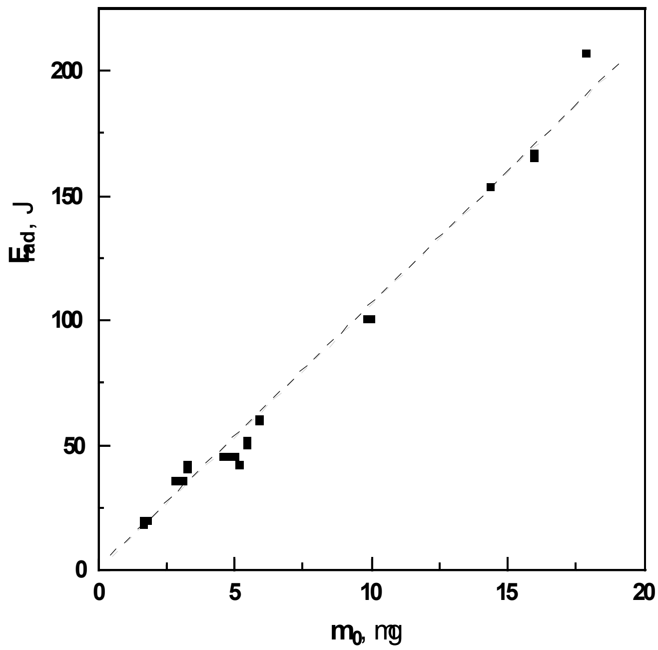

Fig.4. Measured integral radiation losses vs. initial Mg particle mass.

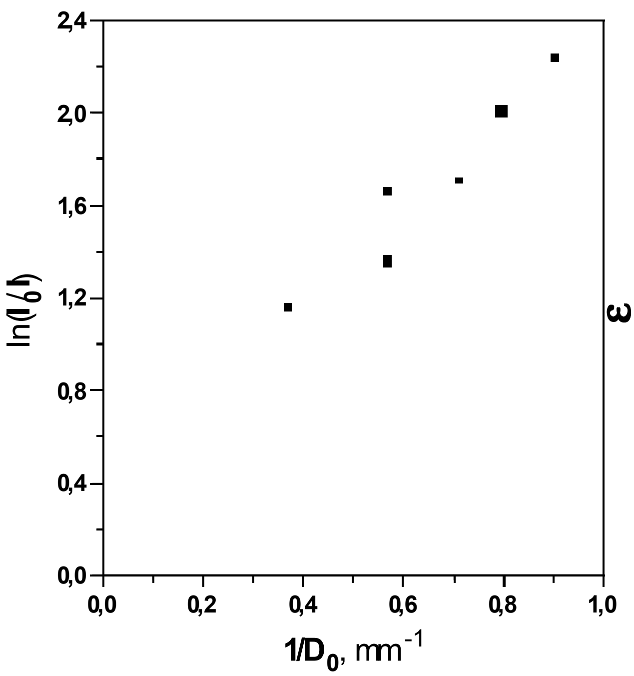

Fig.5. Measured full light extinction by condensation zone vs. inverse initial Mg particle diameter.

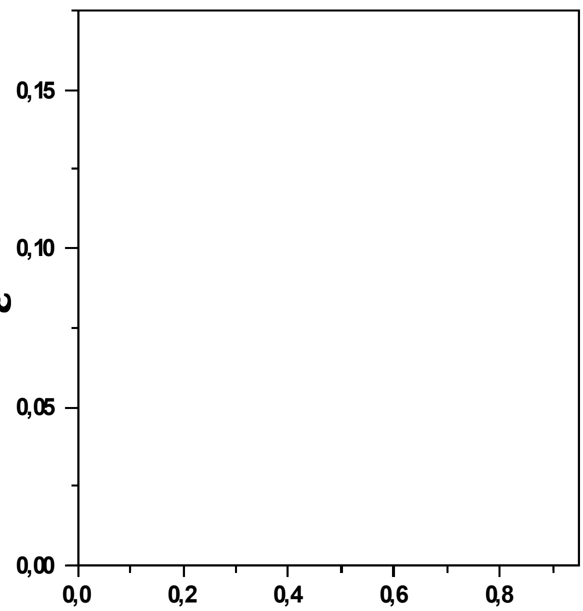

Fig.6. Calculated by experimental data condensation zone emissivity vs. inverse initial Mg particle diameter.