Flammability Limits of Mixtures of Combustible Gas-Air-Gas-Aerosol Compositions

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ABSTRACT

An experimental investigation of conditions of inertization of combustible gaseous mixtures by gas-aerosol compositions has been executed at room temperature and atmospheric pressure. Methane and petrol vapour were used as a combustible, composition E1 produced by organization "Granit-Salamandra" was used as inhibitor. A comparison of obtained results with published data for gaseous diluents has been made. It has been found, that minimum mass inertization concentrations of the E1 composition are remarkably lower, than for known gaseous diluents. This effect is caused by an effective inhibition of combustion processes by fine particles of inorganic salts, which are the main part of the gas-aerosol composition. A qualitative interpretation of the possible mechanism of inhibition is presented.

INTRODUCTION

Gas-aerosol fire extinguishing compositions producing by burning of solid fuels are now widely used [1-8]. Despite of differences in these fuels they contain as a rule inorganic oxidisers and salts (KNO_3, $KClO_4$, KCl) and organic or inorganic combustibles (Mg, epoxycombinations) [7]. As a result of such complex fuel burning a gas-aerosol composition is generated. A gaseous phase of this composition consists mainly from N_2 and CO_2, and a solid phase contains K_2CO_3, $KHCO_3$, KCl [2]. The solid phase acts on a flame similarly to fire extinguishing powders, but it has sufficiently high efficiency due to a high dispersibility of particles (mean diameter of particles less than 5 µm [1]). Such fine particles hardly can be generated by mechanical dispergation.

Despite of the fact, that a mechanism of fire extinguishing by gas-aerosol composition is not elucidated in detail, in scientific literature there are many experimental data

concerning fire extinguishing concentrations for combustibles of various chemical nature [1-8]. But inertization conditions for these compositions are investigated rather poor. According to [5] for inertization of stoichiometric hydrocarbon-air mixtures the gas-aerosol composition concentration of 40-80 g/m^3 is needed, and for hydrogen-air mixtures with $[H_2]=20$ % (vol.) this concentration is equal to 230 g/m^3. Therefore this work is aimed on an experimental investigation of the conditions of inertization of gaseous mixtures by gas-aerosol compositions in order to explore this phenomenon more detail.

EXPERIMENTAL

Experiments have been carried out on a set-up, which scheme is presented in fig. 1. The set-up contains reaction vessel, system for supplying of gases and vapours, ignition source. The reaction vessel is made from stainless steel and cylinder with volume 53 dm^3 (diameter is equal to 300 mm, height is equal to 800 mm) with a lower bottom, which can be opened. The reaction vessel has a vertical window for a visual detection of a flame propagation.

Experiments have been carried out on a following manner. A required mass of the gas-aerosol producing composition was placed into the reaction vessel. The reaction vessel was evacuated in order to remove combustion products from a previous experiment, and then air was introduced in it to pressure of 50 kPa. Burning of the gas-aerosol producing composition was made by supplying of an electrical voltage of 15 V on a nichrom wire of diameter 0.2 and length 60 ± 1 mm. Later 45 sec after the solid fuel burning a required quantity of combustible gas or vapour which was detected by partial pressure was introduced into the reaction vessel. Then air was introduced into the reaction vessel to atmospheric pressure, and convective mixing of gaseous mixture was produced by a short-time heating of a special element placed in the lower part of the reaction vessel. After the mixing the lower bottom of the reaction vessel was opened in order to avoid a destruction of the reaction vessel during combustion of the gaseous mixture, and ignition of the mixture was produced by a supplying of an electrical voltage of 220 V on nichrom wire of diameter 0.2 and length 5 ± 1 mm. A flame propagation in the reaction vessel was detected visually. Methane and petrol vapour were used as a combustible, gas-aerosol producing fuel was E-1 composition from organization "Granit-Salamandra". Experimental data were processed according to standard GOST 12.1.044-89. A relative error of a flammability limits determination did not exceed 10 %.

RESULTS AND DISCUSSION

Results of a determination of flammability limits of mixtures combustible gas-air-gas-aerosol composition are presented in Figs. 2 and 3. Experimental data for other diluents (N_2, C_2F_5H, $C_2F_3Cl_3$) are presented for comparison too. It follows from the presented data, that minimum inertization mass concentrations of gas-aerosol composition is sufficiently lower, than for other diluents including halons. It means, that the investigated gas-aerosol composition has strong inhibition properties in relation to

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remixed flames of mixtures of organic substances with air. But minimum inertization oncentrations of the gas-aerosol composition are much higher, that its minimum ireextinguishing concentration, which is equal for the most part of organic substances
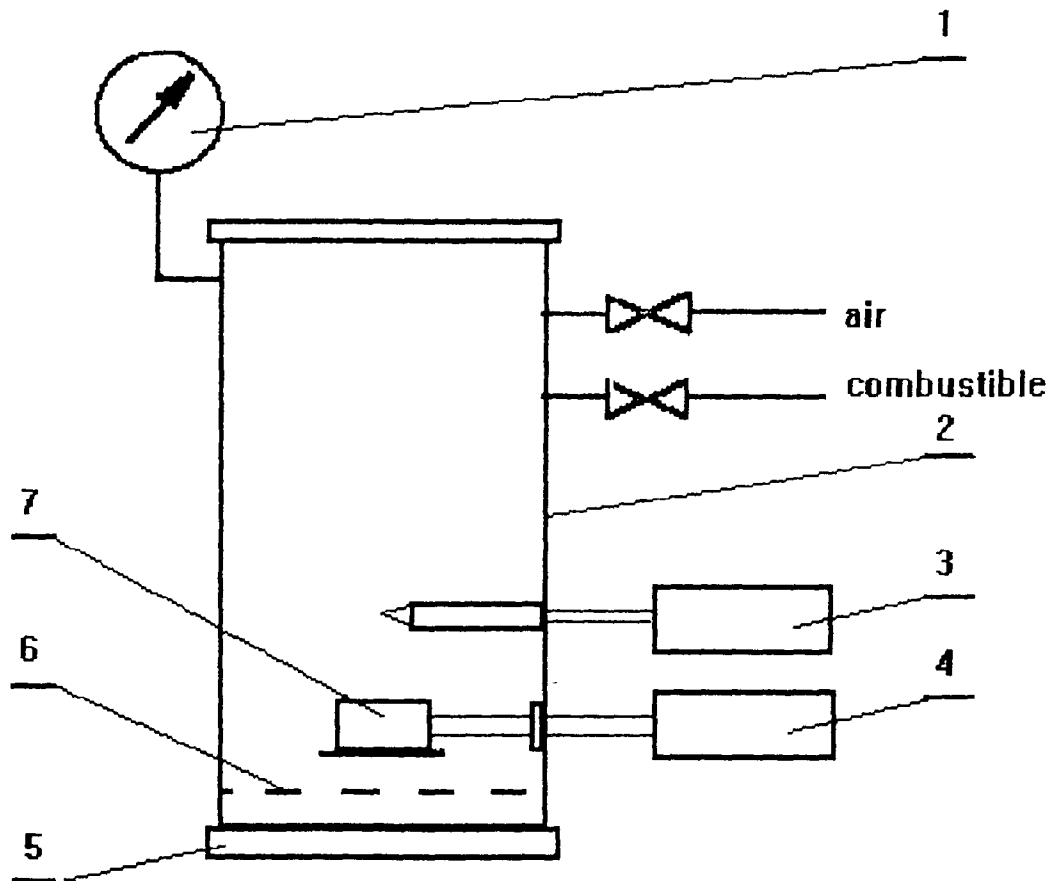

FIGURE 1. Scheme of the experimental set-up.

-manometer; 2-reaction vessel; 3-device for ignition of gaseous mixtures; 4-device for gnition of solid fuel producing gas-aerosol composition; 5-lower bottom which can be >pened; 6-flame arresting net; 6-solid fuel producing gas-aerosol composition.

iear 50 g/m³ [13]. The nature of this difference is not clear. Probably this effect is aused by a nonuniformity of concentration of the gas-aerosol composition in the eaction vessel. It has been noted [14,15], that gaseous mixtures combustible-air-diluent it inertization points are reach (stoichiometric in relation to combustion to CO and I₂O). In the case of combustible mixtures dilution by the gas-aerosol composition these nixtures are lean. This conclusion has been obtained by as with an account, that at a :ombustion of the fuel El near 50 % of the fuel nass is converted into gas, and the rest mass is converted into solid aerosol particles. Γhe mentioned above difference in compositions of combustible mixtures at nertization points does not have any satisfactory explanation.
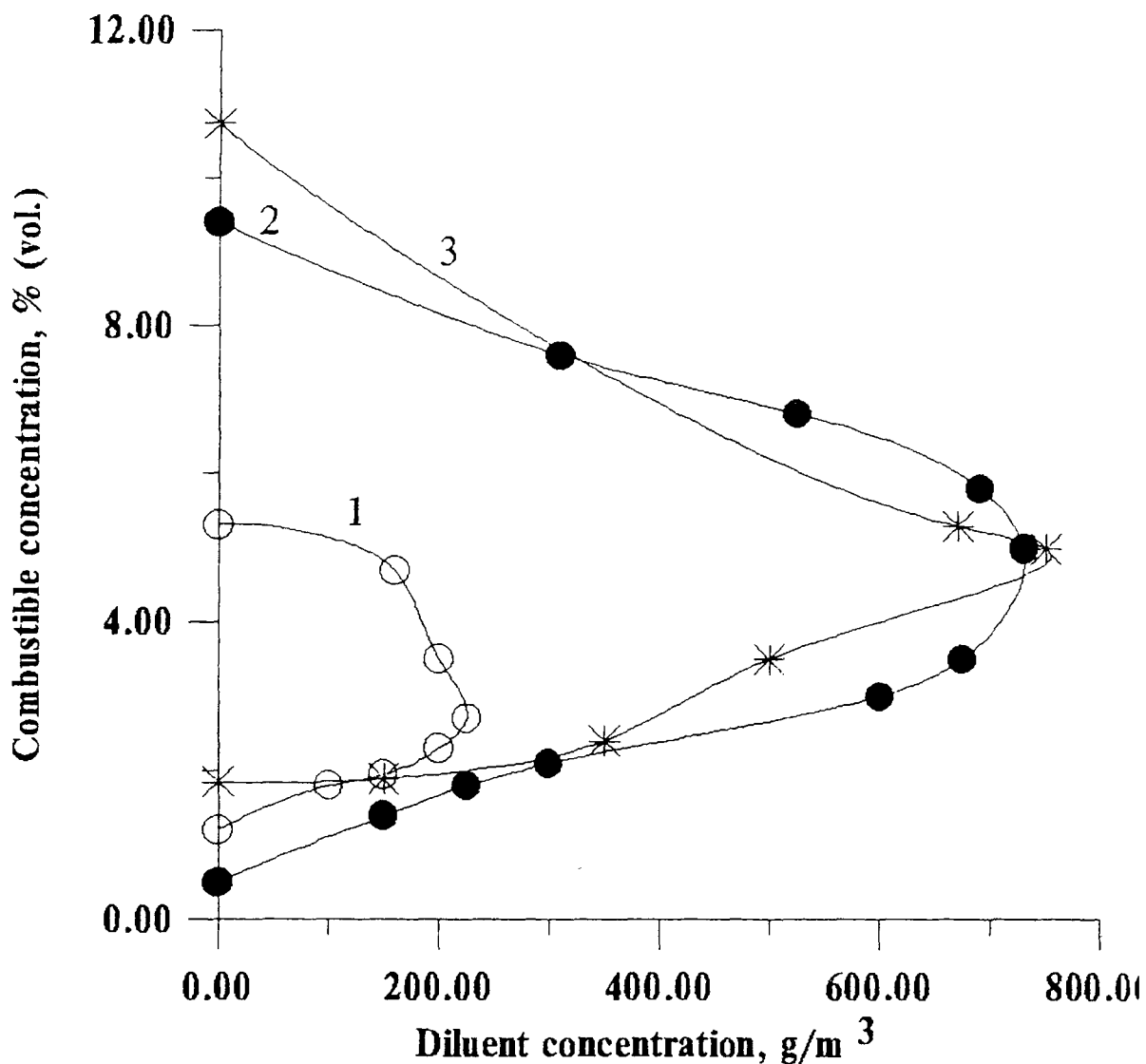
FIGURE 2. Flammability limits in mixtures CH_4 - air - gas-aerosol composition (1) CH_4 - air - N_2 (2) and CH_4 - air - C_2F_5H (3).

A mechanism of inhibition by gas-aerosol compositions is probably analogous to fir extinguishing powders and can be described by a following manner. As it has bee noted, one of the main components of fine aerosol are KCl particles. An evaporation o these particles in a flame front gives an origin of the following chemical reactions [9]:

$$KOH+H \leftrightarrow K+H_2O, \tag{I}$$

$$K+OH+M \leftrightarrow KOH+M, \tag{II}$$

$$K+Cl+M \leftrightarrow KCl+M, \tag{III}$$

$$HCl+OH \leftrightarrow H_2O+Cl, \tag{IV}$$

$$Cl+HO_2 \leftrightarrow HCl+O_2, \qquad\qquad\qquad (V)$$

$$K+HCl \leftrightarrow KCl+H, \qquad\qquad\qquad (VI)$$

$$Cl+RH \leftrightarrow HCl+R, \qquad\qquad\qquad (VII)$$

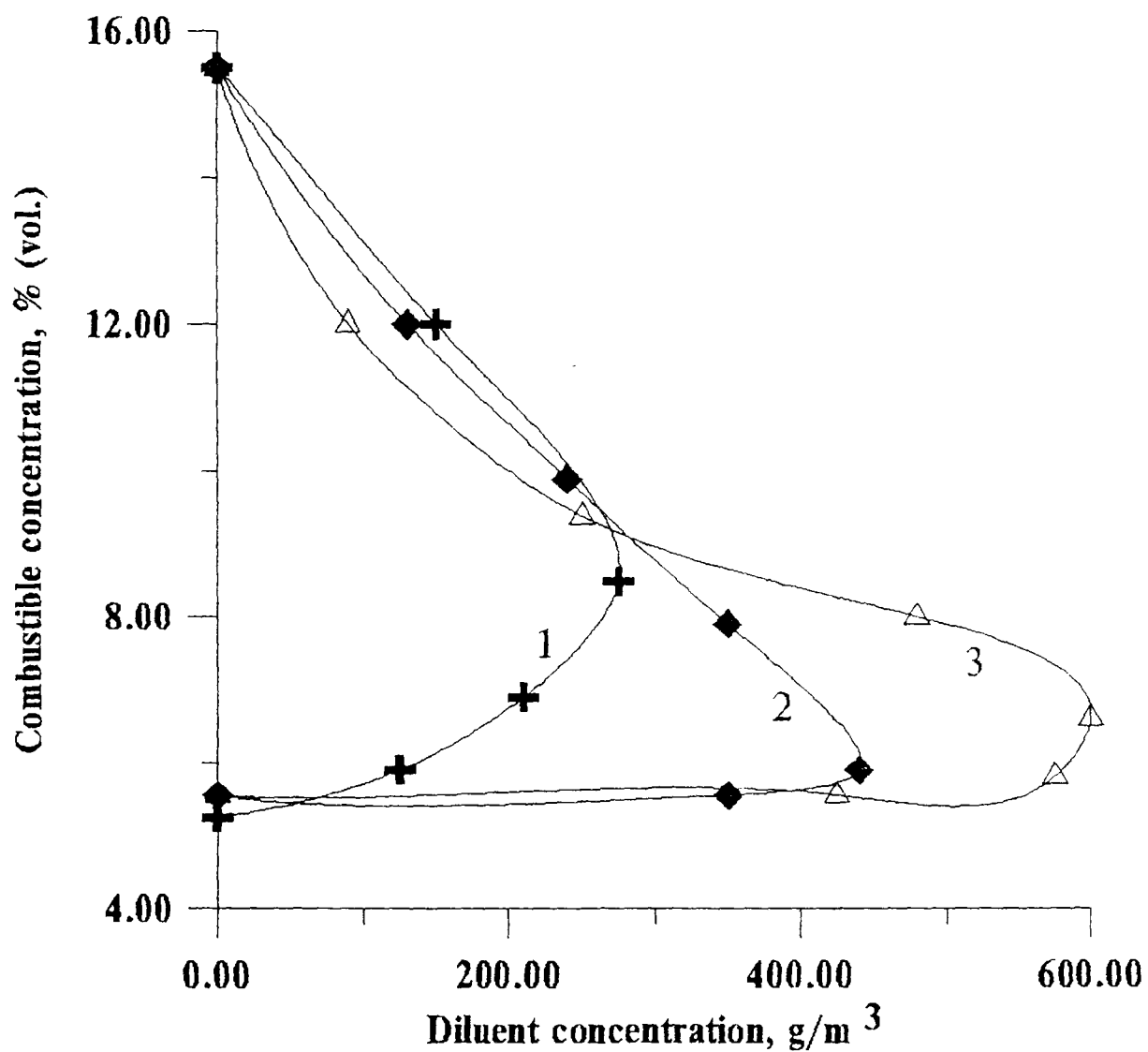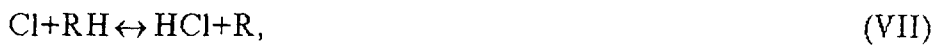$$KCl+HO_2 \leftrightarrow KO_2+HCl, \qquad\qquad\qquad (VIII)$$

FIGURE 3. Flammability limits in mixtures petrol - air - gas-aerosol composition (1), complex combustible (petrol (50 % (vol.)) - acetone (50 % (vol.))) - air - $C_2F_3Cl_3$ (2), complex combustible (petrol (50 % (vol.)) - ethanol (50 % (vol.))) - air - $C_2F_3Cl_3$ (3).

$$KO_2+Cl \leftrightarrow KCl+O_2, \qquad (IX)$$

$$KOH+Cl \leftrightarrow KCl+OH, \qquad (X)$$

$$K+O_2+M \leftrightarrow KO_2+M, \qquad (XI)$$

$$KO_2+H_2 \leftrightarrow KOH+O_2, \qquad (XII)$$

$$KO_2+OH \leftrightarrow KOH+O_2, \qquad (XIII)$$

$$K+HO_2 \leftrightarrow KO_2+H, \qquad (XIV)$$

$$K+HO_2 \leftrightarrow KOH+O, \qquad (XV)$$

$$KO_2+H \leftrightarrow KOH+O, \qquad (XVI)$$

$$KOH+HO_2 \leftrightarrow KO_2+H_2O, \qquad (XVII)$$

$$H+Cl+M \leftrightarrow HCl+M, \qquad (XVIII)$$

$$H_2+Cl \leftrightarrow HCl+M, \qquad (XIX)$$

$$HCl+O \leftrightarrow OH+Cl. \qquad (XX)$$

An analysis of this scheme of inhibition was made in [16,17]. Numerical analysis, which was carried out in these works, has shown, that this homogeneous mechanism explains qualitatively observed in experiments changes of laminar burning velocity of methane-air mixture under the action of fine fire extinguishing powders, but some quantitative discrepancies between theory and experiment exist. It has been noted, than the most important for inhibition reactions are processes (I) and (II). In the first of these processes loss of an active radical H occurs, and in the second one regeneration of inhibitors takes place. In [16,18] an evaluation of the role of heterogeneous mechanism in inhibition of methane-air flame by KCl has been carried out. It has been revealed, that even in approximation of instantaneous recombination of active centres on a solid surface and absence of competing processes of H_2O, O_2 and N_2 adsorption only a minor change of laminar burning velocity takes place, that is the heterogeneous mechanism is unimportant in this case.

CONCLUSIONS

inertization conditions for methane-air and petrol vapour-air mixtures by the gas-aerosol composition E1 have been experimentally investigated. It has been shown, that minimum inertization mass concentrations of this composition are much lower, than for other gaseous diluents. It is stipulated by an effective inhibition of a flame by fine aerosol particles. A qualitative interpretation of a possible mechanism of inhibition is presented.

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