Theoretical Investigation of Gas-phase Ignition of Liquid Condensed Substances by Heating Sources with Limited Energy Store

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Abstract

The theoretical investigation of ignition processes of typical liquid condensed substances (benzene, kerosene, diesel oil) by heated till high temperature metallic (steel, aluminum) and no metallic (carbon) small sizes particles within the limits of gas-phase ignition model considering processes of heat conductivity, liquid evaporation, diffusion and convection of fuel vapors at the oxidizer environment, forming of vapor gap between particle and liquid, partial submergence of heating source in liquid is executed. The determinant factors influencing on the characteristic of this processes are established.

Introduction

The results of theoretical and experimental investigations of liquid condensed substances ignition processes, in particular, hydrocarbon fuel and its drops, by massive heated solid [1–5] are well-known. Analogous processes for heating sources with limited energy store, for example, heated till high temperatures metallic and no metallic small sizes particles are less studied.

Ignition processes at the system "particle with small sizes – liquid condensed substance – oxidizer" are very interested for investigation for some reasons. Firstly, in contrast to solid condensed substances for liquids the common ignition theory similar to [1] is not developed. Secondly, the results of investigation of this phenomenon's can be used at the development of new methods of flame initialization at particularized plants. Thirdly, ignition processes by metallic particles, resulting, for example, at the welding building structure, and no metallic particles, formed at the result uncontrolled man-caused factors, of liquid fuels are quite often reasons of many conflagration at the industrial plants and in private life [6].

The aim of given work – theoretical investigation of regularities of liquid condensed substances gas-phase ignition by heated till high temperature particles within the limits of model considering complex of interrelated physical-chemical processes at the system "particle – liquid – oxidizer".

Task statement

The task of gas-phase ignition of typical liquid fuels (benzene, kerosene, diesel oil) by heated till high temperatures particles of different nature (carbon, steel, aluminum) is considered. Following stages of ignition process are considered at the modeling: heating and evaporation of liquid, forming

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of vapor gap between particle and liquid, partial submergence of heating source in liquid, particles material crystallization (for metallic particle), fuel vapors transfer over liquid surface due to diffusion and convection, its mixture and intensive response with air oxidizer.

Single heated till high temperatures (T_{ch}>850 K) particles at the form of parallelepipeds, disks and hemisphere (example, for parallelepiped H_{ch}=L_{ch}=1÷5 mm) are assumed as ignition sources.

The geometry of delivered task solution area is illustrated on Fig. 1.

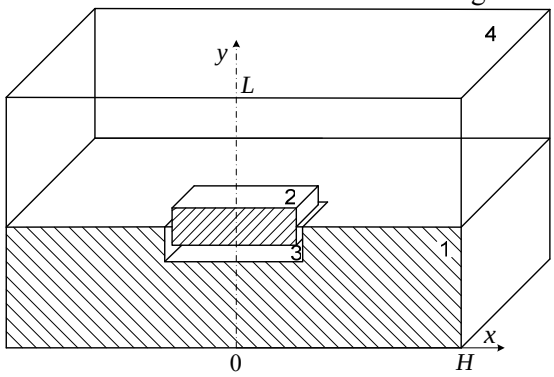

Figure 1. Task solution area scheme (1 – liquid, 2 – particle, 3 – fuel vapors, 4 – fuel vapors and air mixture).

Here H, L – lengthwise and transverse sizes of task solution area (H=10 mm, L=20 mm).

Numerical analysis of investigated process is executed at the following assumptions:

1. One substance with known characteristics forms at the result of liquid evaporation.
2. Particle is not fully submerged in liquid. In case of carbon particle this assumption carries out at the wide turndown of ignition conditions. These particles have relatively low density and sufficiently high porosity. For metallic particles it is necessary considered the probability of partial submergence. However, for light metals (for example, aluminium) this probability is very little.

The following ignition conditions are passed [1]:

1. The heat formed at the result of chemical reaction of fuel vapors and oxidizer exceeds the heat passed from particle to liquid and air.
2. Temperature of fuel vapors and air mixture exceeds initial temperature of particle.

Method of solution

Modeling of investigated process led to solution of transitional heat conduction equations for solid (particle) and liquid (condensed substance) phases, equations of balance, motion, continuity and diffusion for fuel vapors and air mixture [7–9].

Task solved at the dimensionless variables and axial-symmetric statement (Fig. 1). The system of nonlinear transient differential equations with corresponding initial and boundary conditions solved by finite difference method. The difference analogues of differential equations solved by sweep method using implicit four-point finite scheme. Method of iterations used for solution of nonlinear equations. The verification of finite scheme conservatism [7] is carried out for estimation of numerical investigations results reliability.

Results and discussion

The values of determinant parameters of ignition process at the concerned system (Fig. 1), thermo physical characteristics of condensed substances, their vapors, particles, air from temperature are presented in [7].

At the result of theoretical investigation of ignition process of liquid combustible substances it is established that the ignition zone at the system (Fig. 1) can be situated nearby of particle side edge or over particle (Fig. 2, 3).

All liquids burns at the gas phase [6]. However, ignition zones can be situated on different distances from its surfaces depending on ignition source type, thermo physical and thermo chemical properties of liquid and environment conditions. In concerned system fuel vapors due to diffusion and convection move along of side edges of particle. At the same time particle cools and fuel vapors heat. Over particle nearby symmetric axis heated till sufficiently high temperatures vapor and gas mixture is formed (Fig. 2, 3). Local temperature gradients of vapor and gas mixture over upper edge of particle nearby symmetric axis exceed gradients in other areas.

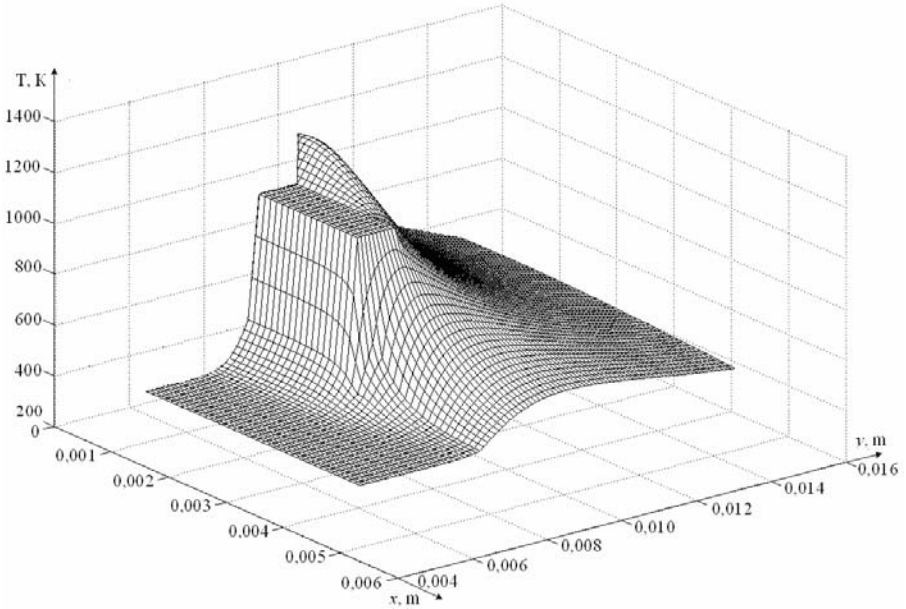

Figure 2. Temperature field of the system "steel particle – benzene – air" at the ignition moment (t_z=1,545 c) at T_{ch}=1000 K, H_{ch}=4 mm, L_{ch}=1 mm.

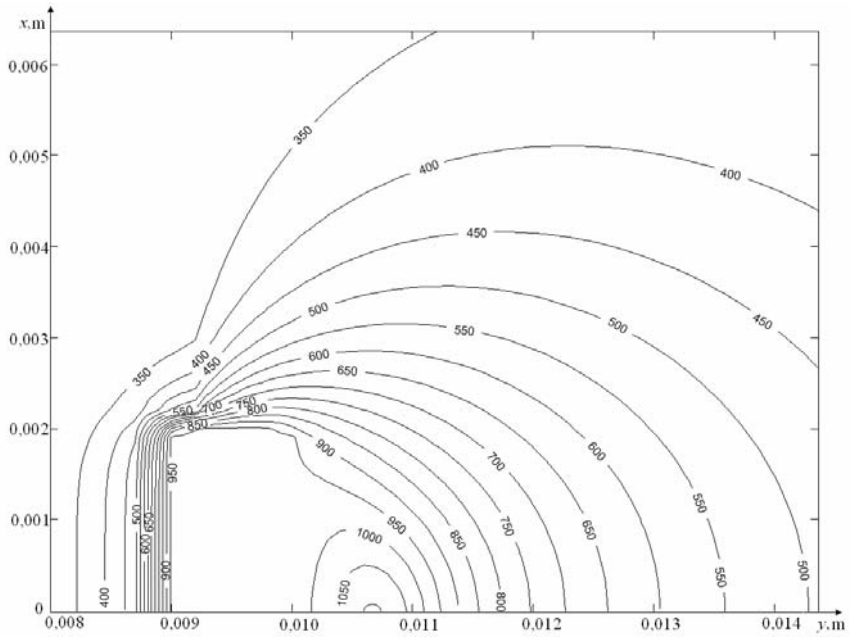

Figure 3. Isotherms of the system "steel particle – benzene – air" at the ignition moment (t_z=1,545 c) at T_{ch}=1000 K, H_{ch}=4 mm, L_{ch}=1 mm.

On Fig. 2, 3 can see decrease of particle temperature at the boundaries with air and liquid due to heat sink from all edges. Intensive absorption of phase transfer energy and forming of vapor gap between liquid and particle occur at the liquid evaporation. Furthermore, particle submergence in liquid influences material effect. At the result this processes the particle temperature lowering on boundaries with liquid is maximum. On contact boundary with air the heat transfer process from particle to air is less intensive and particle temperature decreases insignificantly.

In [7–9] results of theoretical investigations of influence scales on the ignition process characteristics (in particular, ignition time delay t_z) at the system "particle – liquid condensed substance – oxidizer" of ignition source parameters (initial temperature, sizes, form, thermo physical properties, thermal effects of particle material crystallization), thermo physical properties of liquids, and outside parameters (air temperature and humidity) are presented.

It is established that ignition time delay substantially depends on particle immersion depth in liquid and sizes of vapor gap between particle and liquid. At the same time the best conditions realize at location of energy source on liquid surface.

It is determined that the basic parameter which substantially influences on ignition process characteristics is heat content of ignition source (finite energy stock). By the example of massive heated solids this appropriateness is difficult determined.

Conclusion

Results of interaction process investigations of single hot particles with combustible liquids can be used for development of general ignition models of liquid condensed substances at the its interaction with heating source which have small sizes and finite energy stock.

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