FIRE DANGER OF INTERACTION PROCESSES OF LOCAL SOURCES WITH A LIMITED ENERGY CAPACITY AND CONDENSED SUBSTANCES

Dmitrii O. Glushkov[1,a], Pavel A. Strizhak[1], Ksenia Yu. Vershinina[1]

[1]*Institute of Power Engineering, National Research Tomsk Polytechnic University, Lenina Avenue, 30, 634050, Tomsk, Russia*

Abstract. Numerical investigation of flammable interaction processes of local energy sources with liquid condensed substances has been carried out. Basic integrated characteristic values of process have been defined – ignition delay time at different energy sources parameters. Recommendations have been formulated to ensure fire safety of technological processes, characterized by possible local heat sources formation (cutting, welding, friction, metal grinding etc.) in the vicinity of storage areas, transportation, transfer and processing of flammable liquids (gasoline, kerosene, diesel fuel).

1. INTRODUCTION

The aim of this paper is the experimental study of the ignition of coal dust from the Talovsky deposit during its moving in a stream of heated air.

Flammable and combustible liquids are the most flammable and highly explosive substances. The absence of recommendations or a security breach during storage, transportation, transfer and processing of these condensed substances explains the large number of ignitions, fires and explosions in chemical, petrochemical and petroleum refining industrial enterprises. It is quite difficult to establish causes of accidents in each case. Among many possible ignition sources a large group of local energy sources with a limited energy capacity can be distinguished. These sources include single heated to high temperatures metal and nonmetal particles. These particles are formed as a result of technological processes in various industries. In particular, in metallurgical industry, solid and liquid metal particles of small size with a temperature more than several hundred degrees are formed during procurement materials processing. Cutting and welding of metal constructions, uncontrolled technological and natural processes may also lead to hot particles formation.

---

[a] Corresponding author: dmitriyog@tpu.ru

The purpose of the work is numerical investigation of ignition processes integral characteristics in systems "hot particle – liquid substance – oxidizer", "hot particle – liquid substance membrane – oxidizer", "hot wire –liquid substance vapor and an oxidizer mixture", "moving hot particle – liquid substance vapor and an oxidizer mixture".

2. PROBLEM STATEMENT

The most common four patterns (Fig. 1) have been considered at numerical investigation of liquid condensed substances ignition processes by local energy sources with a limited energy capacity.

(a)   (b)

(c)   (d)
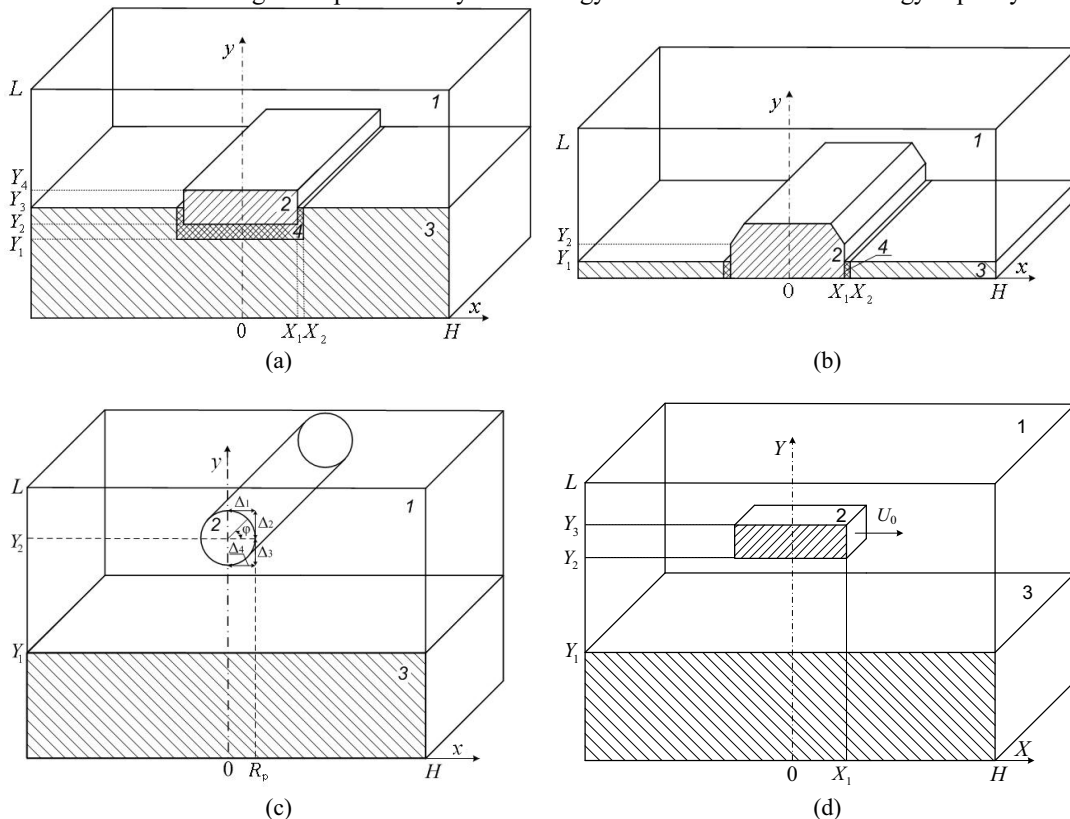
Figure 1. A scheme of the solution domain area of ignition problem at $t = 0$ in the system: a – "hot particle – liquid substance – oxidizer"; b – "hot particle – liquid substance membrane – oxidizer"; c – "hot wire – liquid substance vapor and an oxidizer mixture"; d – "moving hot particle – liquid substance vapor and an oxidizer mixture": 1 – air (gas mixture at $0 < t \leq t_d$), 2 – local energy source, 3 – liquid condensed substance, 4 – vapor layer

Complete physical settings and mathematical models of investigated processes are presented in works [1–4]. The principal difference is the conditions of ideal contact and the lack of direct contact between energy source and liquid condensed substance. All of the cases are characterized by mutual interconnected physical and chemical processes. As a result of heating of liquid condensed substance near-surface layer by hot particle energy, fuel evaporation occurs. Fuel vapor is mixed with an oxidizer (air) in the external environment due to diffusion-convective mass transfer. The gas mixture is warmed up while moving in the vicinity of energy source. Gas-phase ignition in the system (Fig. 1) occurs at critical values of fuel component concentration and gas mixture temperature.

Ignition conditions [5]:
1. Energy, released as a result of a gas mixture oxidation reaction, is more than heat consumed by hot particle to heat liquid condensed substance and gas mixture.
2. Gas mixture temperature in exothermic reaction area is higher than energy source initial temperature.

3. Results and discussion

As a result of large-scale numerical investigations of liquid condensed substances ignition processes, it has been defined, that the ignition delay time depends mainly on heat content of energy source – a hot particle. Its value is determined by thermal characteristics, dimensions and initial temperature of the particle. The last factor exert the greatest influence on energy source heat content, therefore, hot particle initial temperature has been varied for a qualitative comparison of liquid condensed substances ignition delay time.

Tables 1–4 show the dependences of the ignition delay time t_d of typical solid condensed substances at different values of energy sources initial temperature T_p for the most typical cases (Fig. 1). In the tables 1–4 left boundary of the range of energy source initial temperature variation characterizes the minimum value at which ignition occurs in each of the considered cases.

Table 1. Dependence of kerosene ignition delay time from energy source temperature at L_p=3 mm, H_p=3 mm, T_a=300 K, C_{w0}=0

T_p, [K]	850	875	900	925	950	975	1000
t_d, [s]	2.105	1.671	0.724	0.501	0.392	0.297	0.253

Table 2. Dependence of kerosene membrane ignition delay time from energy source temperature at L_p=3 mm, H_p=3 mm, T_a=300 K, C_{w0}=0

T_p, [K]	1000	1100	1200	1300	1400	1500	1600
t_d, [s]	1.607	1.196	0.725	0.251	0.183	0.107	0.094

Table 3. Dependence of gasoline vapor and an oxidizer mixture ignition delay time by stationary steel core from energy source temperature at R_p=3 mm, L_{pl}=15 mm, T_a=300 K, C_{w0}=0

T_p, [K]	1300	1400	1500	1600	1700	1800	1900	2000	1300
t_d, [s]	0.447	0.214	0.118	0.073	0.051	0.036	0.029	0.025	0.023

Table 4. Dependence of ignition delay time of gasoline vapor and an oxidizer mixture of a steel particle moving along a curved path from energy source temperature at L_p=2 mm, H_p=4 mm, U_0=0.5 m/s, a=1 m/s^2, L_{pl}=20 mm, T_a=308 K, C_{w0}=0

T_p, [K]	1300	1400	1500	1600	1700	1800	1900	2000
t_d, [s]	0.078	0.041	0.024	0.015	0.011	0.008	0.006	0.005

In tables 1–4 there are used following symbols: L_p is energy source width in the shape of a parallelepiped, H_p is energy source height in the shape of a parallelepiped, R_p is energy source radius in the form of a rod, L_{pl} is the distance between energy source and liquid condensed substance surface, T_a is air temperature, C_{w0} is fuel vapor initial concentration in the air, U_0 is energy source initial velocity along the axis Ox, a is convective heat transfer coefficient.
Analyzing dependencies $t_d=f(T_p)$, it can be concluded, that the minimum ignition delay times are characterized for the case (Fig. 1a) of energy source direct contact with a liquid condensed substance.

Its ignition is possible at relatively low hot particle initial temperature (T_p = 850 K). For other systems: "hot particle – liquid substance membrane – oxidizer" (Fig. 1b), "hot particle – liquid substance membrane – oxidizer" (Fig. 1c), "moving hot particle – liquid substance vapor and an oxidizer mixture" (Fig. 1d), the possibility of ignition is also high, but energy source temperature must significantly exceed 850 K.

4. Conclusion

As a result of numerical investigations, dependencies of the main integrated characteristic of the process have been defined – the ignition delay time at the interaction of a single source with limited energy capacity and liquid condensed substance. Analysis of the results allowed to formulate recommendations for ensuring the fire safety of holding different technological processes with the possible local heat sources formation (cutting, welding, friction, metal grinding, etc.) in the vicinity of storage areas, transportation, transfer and processing of flammable and combustible liquids:

1. Carry out hot works at the minimum possible temperatures of welders functioning.
2. Use closed containers for the storage of liquid combustible and flammable substances. This allow preventing the possibilities of liquid evaporation under ambient conditions and the formation of flammable and highly explosive gas-vapor mixtures.
3. Set the minimum air temperature and the maximum humidity in a room at which combustible and flammable liquid storage is possible.
4. Organize forced ventilation in a room (air speed no less than 2 m/s) before the commencement of works.
5. Ensure sufficient distance of welding electrodes and other devices from tanks and fluid transfer areas (the minimum distance, while being passed, formed energy sources – metal particles, wires or rods cool down to "safe" temperatures).
6. Remove foreign objects (e.g., fabrics, impregnated with lubricants, combustible and flammable substances) from work areas.

References

1. D.O. Glushkov, G.V. Kuznetsov, P.A. Strizhak, Adv. Mech. Eng. **2014**, article number 764537 (2014).
2. P.A. Strizhak, J. Eng. Thermophys. **20**, 459 (2011).
3. G.V. Kuznetsov, P.A. Strizhak, J. Eng. Phys. Thermophys. **82**, 1059 (2009).
4. G.V. Kuznetsov, P.A. Strizhak, Int. J. Heat Mass Transfer. **53**, 923 (2010).
5. V.N. Vilyunov, V.E. Zarko, *Ignition of Solids* (Elsevier, Amsterdam, 1989).