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Original Contribution

RISK OF THE IGNITION OF FLUID FUELS AND SOAKED MATERIALS DURING OXYACETYLENE CUTTING OF METALS

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Abstract: *The purpose of this study is to establish the regularities of the process of firing of liquid fuels and materials, soaked with liquid fuels, during oxyacetylene cutting. By means of suitable methods and a plant, we studied the firing of petrol and diesel fuel and paper, textile and wood chips, soaked with fuel. Three basic tasks have been solved – physical modeling of dangerous event and dangerous action, determination of danger indexes and assessment of firing in the zone of distribution of waste metal spatters. Regression models of probability and time of firing depending on the distance, height and materials subject to cutting and other factors have been formulated.*

Keywords: *risk, ignition, liquid fuels, oxyacetylene cutting.*

Introduction

Fire hazard of the process of oxyacetylene cutting has not been studied enough. Some studies [4,5] are dedicated only to the problem of generation and distribution of melted and heated metal drops. They make a limited number and insufficiently substantiated experiments. Authors do not study the ignition of materials.

The above, as well as our statistical analyses of probability of fire occurrence due to fire works show that the problem is very topical. It should be analyzed for the various conditions and characteristics of cutting – parts, cutting length, gas pressure, working height, effect of reflecting surfaces, combustible materials and surface distribution.

The purpose of this study is to establish the risk and regularities of variation of the ignition of gasoline and diesel fuel and materials soaked with fuel during oxyacetylene cutting of metals.

To achieve that purpose the following tasks shall be solved:

1) Physical modeling of the process of ignition of materials;

2) Parameters of ignition are defined;

3) Multi-factor and single-factor models of the parameters of ignition of liquid fuels and materials soaked with them - paper, textile, wooden chips, located in the zone of distribution of waste metal pearls from gas cutting;

4) Assessment of risk for ignition.

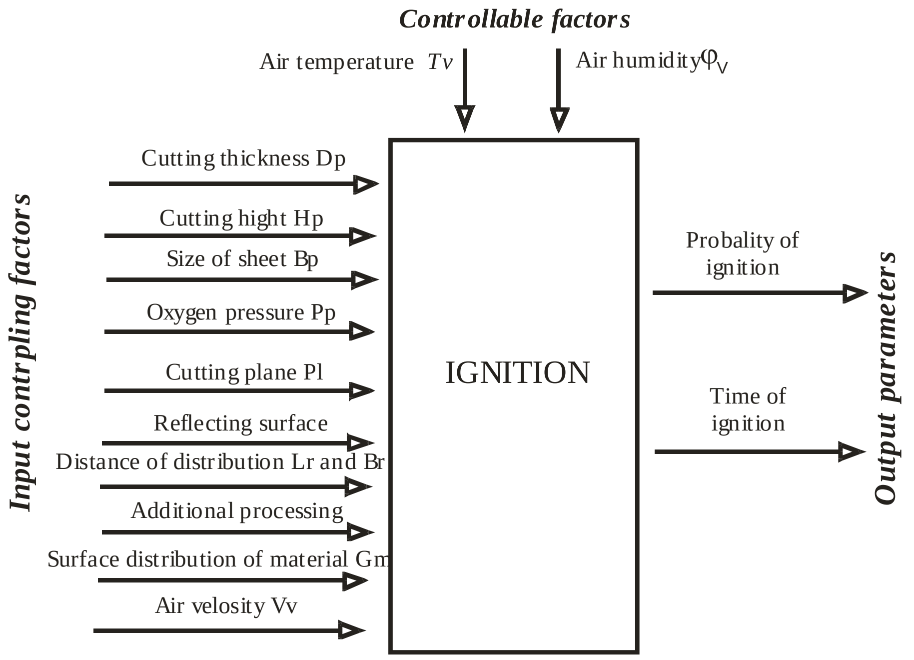

Fig. 1. Model of research

Methods of research

The objects affected by the cutting pearls are gasoline and diesel fuel, as well as the above-specified materials. They have been selected because of their availability everywhere, which makes them frequent objects, affected by cutting pearls. Once ignited they may initiate fire.

The study is carried out according to the model, presented on figure 1.

Controllable input factors are (fig.1): Cutting thickness D_P=10,15 and 20 *mm*; Cutting height H_p=2,4 and 6*m;* Size of metal sheet B_P =300x300; 400x400 and 500x500 *mm*; Oxygen pressure P_P=300, 500 and 700 *kPa*; Cutting plane P_L- vertical and horizontal; Availability of reflecting surfaces 2 and 6 (fig.2); Type of surface distribution G_{MAT} of paper, textile and wooden chips -1; 1,5 and 2 kg/m^2; Additional processing, consisting of soaking *Om* with gasoline and diesel fuel on level - 25*ml*, 75*ml*, 125*ml*/100*g*

The controlled factors are the temperature T_V and humidity φ_V of atmospheric air. Experiments have been carried out at temperature from 21,2 to 29,4^{o}C and relative air humidity 69,4-84,2%. When experiments are carried out outdoor the air velocity V_V has been subject to control. It is within the range 0,3-1,6 *m/s*.

Output parameters of the risk of ignition are the probability *Pz* and the time *Tz* of occurrence of ignition after the start of oxyacetylene cutting (fig. 1).

The method of physical modeling is used in the research.

Physical modeling is made on a plant, shown on fig. 2 – in production premises and outdoor. For simulation of the manufacturing technological process oxyacetylene cutting was carried out of hot-rolled sheet metal (according to BDS 3992-84) with the above-specified size *Bp*, from carbon steel – ordinary grade Ст0 and Ст1 with thickness 10, 15 and 20 *mm*.

Horizontal and vertical cuts were made at the specified height.

Standard oxyacetylene generator and manual cutter have been used.

Opportunity was provided to study the effect of vertical and horizontal reflecting surfaces (2 and 6 - fig.2) with different width, length and height, located in the zone of the first phase of gravitational falling of cutting pearls. For that purpose metal construction panels with standard sizes were used. The horizontal panels are installed at height 1 m from the floor.

When modeling the dangerous effect imissions of cutting pearls were monitored and analyzed in the phases of gravitational falling, flying after hitting the floor and rolling on the floor surface. These phases of movement are observed and distances of flying and rolling are approximately established. Then, based on them, were selected the distances of study of the ignition of materials. For the purpose of identifying the surface and the distance of distribution, the floor was divided into elementary sections.

Experimental research was carried out in two phases.

In the first phase the imissions of cutting pearls were analyzed.

During the second phase the dependence of the parameters of the process of ignition on the controllable

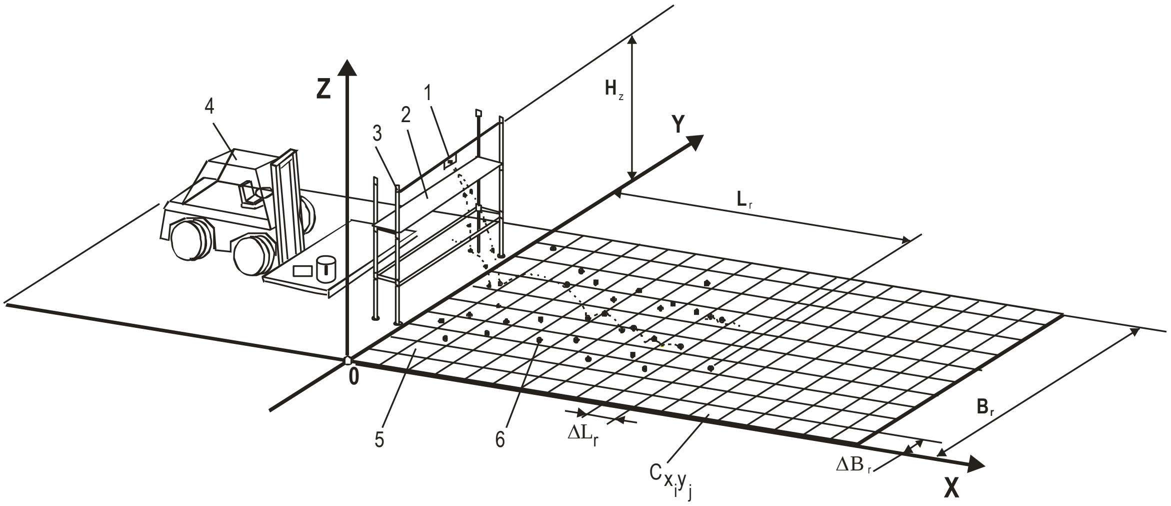

Fig. 2. Experimental system: 1-welded parts; 2- vertical reflecting panel; 3-metal scaffold; 4-work platform;5-non-combustible floor with outlined net of elementary sections $\Delta B_r x \Delta L_r$; 6-horizontal reflecting panel; 7-waste welding pearl; a, c, e, f-horizontal welds; b, d; g-vertical welds of angular profiles to the metal sheet, Of the metal sheet to the angular profiles and between metal sheets [2,3]

factors was studied.

The experiments for establishing the parameters of ignition of fuels are carried out by the method of “random location of targets". “Targets” are 5 laboratory vessels with height of the side wall 4*mm* and with diameter 100*mm*, which were placed at randomly selected points of the quadrants (fig.2) with area 1m^2. In each vessel was poured 150*ml* fuel, which was specified through preliminary experiment.

Distribution of cutting pearls in the process of oxyacetylene cutting is a probabilistic process. Therefore the interaction of pearls with the affected objects is accidental. Direct contact occurs only if pearls fall directly into the vessels. Rolling pearls do not enter into contact with the combustible liquids due to the presence of separation wall of the vessels, however they contact with fuel vapors.

Direct contact occurs during experiments with materials soaked with gasoline and diesel fuel.

Results and discussion

The main condition for ignition of materials is occurrence of imission of cutting pearls.

The imission of cutting pearls I_m is determined by their surface distribution. It is assessed by its relative share, in %, of the mass of pearls that have fallen on the elementary section $\Delta B_r x \Delta L_r$ of the floor.

The following equations of change of I_m from distances *Lr* and *Br* were established:

I. Without reflecting surfaces: *for* $0<Br<1m$: $Izp=21,2976e^{-0,52384Lr}$; *for* $1<Br<2m$: $Izp=16,2764-6,2142Lr+0,6437Lr^2$; *for* $<Br<3m$: $Izp=11,2743-6,7283Lr+0,2677Lr^2$; *for* $0<Br<-1m$: $Izp=19,6347-,3744Lr+0,2733Lr^2$; *for* $-1<Br<-2m$: $Izp=12,6347e^{-0,7281\ Lr}$; *for* $-2<Br<-3m$: $Izp=8,4348e^{-0,5477Lr}$;

II. With vertical reflecting surfaces: *for* $0<Br<1m$: $Izp=24,2633e^{-0,3255Lr}$; *for* $1<Br<2m$: $Izp=18,3677e^{-0,4437Lr}$; *for* $2<Br<3m$: $Izp=15,6277e^{-0,4738Lr}$; *for* $0<Br<-1m$: $Izp=23,4637e^{-04463Lr}$; *for* $-1<Br<-2m$: $Izp=17,2849e^{-0,5673Lr}$; *for* $-2<Br<-3m$: $Izp=14,5637e^{-0,4258Lr}$;

III. With vertical and horizontal reflecting surfaces: *for* $0<Br<1m$: $Izp=9,2453e^{-0,2864Lr}$; *for* $1<Br<2m$: $Izp=8,2764e^{-0,4563Lr}$; *for* $2<Br<3m$: $Izp=5,6237e^{-0,4766Lr}$; *for* $0<Br<-1m$: $Izp=6,7364e^{-0,3254Lr}$; *for* $1<Br<2m$: $Izp=3,2677+0,6735Lr-0,1245Lr^2$; *for* $-2<Br<-3m$: $Izp=5,6937e^{-0,2536Lr}$.

Distribution of the mass of pearls depending on their diameter is analogous to the electric-arc welding [1,2]. The range of diameters with minimum mass is wider. It is due to the bigger cavities. Furthermore scattering is much larger. Probably it results from the specificity of the cutting process during which further to melting the metal, it is blown out as a result of the effect of gas pressure.

To analyze the process of ignition were carried out experimental studies, aiming to determine the dependencies of *Tz* and *Pz* from the cutting thickness D_P; the cutting height H_P; the size of metal sheet B_P; the oxygen pressure P_P.

Data obtained from experimental study were processed by the software *Statgraph, SPSS, REG1* and *REG2*.

Regression models of time *Tz* and probability *Pz* of ignition were obtained, which in case of vertical cutting without reflecting surfaces and change of the above-specified technological factors within the established range, are from the type:

I. When cutting metal sheet 10mm:

- Gasoline:

$$Tz(Hz,Lr,Br)=23.253783+14.374834*Hz+3.283774*Lr+2.823167*Br+0.256373*Hz*Br+0.126237*Lr*Br-4.934473*Hz*Hz-0.327348*Lr*Lr-4.436844*Br*Br;$$

$$Pz(Hz,Lr,Br)=1.358637-0.209154*Hz-0.108672*Lr-0.189878*Br+0.001875*Hz*Br+0.019688*Lr*Br+0.027083*Hz*Hz+0.001886*Br*Br;$$

- Diesel fuel:

$$Tz(Hz,Lr,Br)=34.735268+14.637251 Hz+9.241826*Lr+9.226735*Br-0.192734*Hz*Lr+0.426327*Hz*Br+0.256337*Lr*Br-4.267344*Hz*Hz-0.634733*Lr*Lr-1.002636*Br*Br;$$

$$Pz(Hz,Lr,Br)= 1.338668 -0.178129*Hz -0.131741*Lr -0.224628*Br -0.000625*Hz*Lr + 0.001250*Hz*Br + 0.024375*Lr*Br + + 0.023170*Hz*Hz + 0.001372*Lr*Lr + 0.004604*Br*Br;$$

II. When cutting metal sheet 15mm:

- Gasoline:

$$Tz(Hz,Lr,Br)=27,276355+4,118201*Hz-0,211403*Lr+0,172855*Br+0.014251*Hz*Br+0,027310*Lr*Br-0,026277*Hz*Hz-1,178210*Lr*Lr-3,823764*Br*Br;$$

$$Pz(Hz,Lr,Br)=1.235366-0.018236*Hz-0.089247*Lr-0.056378*Br+0.000356*Hz*Br+0.005346*Lr*Br+0.003536*Hz*Hz+0.000342*Br*Br$$

- Diesel fuel:

$$Tz(Hz,Lr,Br)=29,276640-8,201926*Hz+1,152677*Lr+2,743601*Br-4,378422*Hz*Lr+3,934082*Hz*Br+4,726630*Lr*Br-0,067218*Hz*Hz-0,017234*Lr*Lr-0,187320*Br*Br;$$

$$Pz(Hz,Lr,Br)=1.028371-0.078230*Hz-0.045410*Lr-0.037455*Br-0.000124*Hz*Lr+0.0004352*Hz*Br+0.003546*Lr*Br+0.000253*Hz*Hz+0.000352*Lr*Lr+0.000352*Br*Br;$$

III. When cutting metal sheet 20mm:

- Gasoline:

$$Tz(Hz,Lr,Br)=22,348293+2,832010*Hz-3,278374*Lr+1,012351*Br+0.0034271*Hz*Br+0,035562*Lr*Br-0,078364*Hz*Hz-2,356277*Lr*Lr-28637745*Br*Br;$$

$$Pz(Hz,Lr,Br)=1.212457-0.17230*Hz-0.042371*Lr-0.092735*Br+0.000637*Hz*Br+0.003820*Lr*Br+0.000172*Hz*Hz+0.000201*Br*Br;$$

- Diesel fuel:

$$Tz(Hz,Lr,Br)=24,637738-4,567344*Hz+0,723562*Lr+0,046277*Br-3,621700*Hz*Lr+2,345266*Hz*Br+3,426610*Lr*Br-0,002452*Hz*Hz-0,004253*Lr*Lr-0,003455*Br*Br;$$

$$Pz(Hz,Lr,Br)=1.120102-0.245162*Hz-0.118236*Lr-0.162753*Br-0.000034*Hz*Lr+0.000431*Hz*Br+0.000531*Lr*Br$$

$$0.000645*Hz*Hz+0.000271*Lr*Lr+0.000743*Br*Br.$$

To determine the time *Tz* and the probability *Pz* of ignition, experiments were carried out individually with soaked with gasoline and fuel oil mixtures of: a) Paper – newspapers, wrapping paper, posters, cardboard, corrugated cardboard; b) Textile – cloths, threads and fabrics for working clothes; c) Wood chips – from smoothing planer, circular saw, grinder, manual work with a jointer.

The following adequate models were obtained

a) gasoline soaked paper:

$$Tz(Hz,Lr,Br,Om)=1.743774+8.614023*Hz+5.758464*Lr-5.391345*Br-0.167463*Om-0.474219*Hz*Lr+0.003688*Hz*Om+0.05546*Lr*Br+0.004594*Lr*Om+0.023813*B*Om-1.037611*Hz*Hz+0.038254*Lr*Lr+1.47176*Br*Br+0.00036*Om*Om;$$

$$Pz(Hz,Lr,Br,Om)=0.270265+0.00583*Hz-0.25752*Lr-.14167*Br+0.02250*Om-0.01000*Hz*Lr-0.006250*Hz*Br-0.015000Hz*Om+0.162500*Lr*Br+0.036250*Lr*Om-.025000*Br*Om+0.038368*Hz*Hz+0.057118*Lr*Lr-0.017882*Br*Br-0.012882*Om*Om;$$

b) diesel fuel soaked paper:

$$Tz(Hz,Lr,Br,Om)=4.723872+6.923764*Hz+9.298366*Lr-2.436273*Br-0.004325*Om-0.0345216*Hz*Lr+0.000625*Hz*Om+0.0023415*Lr*Br+0.000534*Lr*Om+0.001746*Br*Om-0.004882*Hz*Hz+0.00133*Lr*Lr+7.83462*Br*Br+0.00097*Om*Om;$$

$$Pz(Hz,Lr,Br,Om)=0.198236+0.004653*Hz-0.162726*Lr-0.115268*Br+0.017835*Om-0.000129*Hz*Lr-0.004237*Hz*Br-0.009263*Hz*Om+0.153274*Lr*Br+0.016773*Lr*Om-0.018553*Br*Om+0.093771*Hz*Hz+0.036886*Lr*Lr-0.003102*Br*Br-0.011290*Om*Om;$$

c) gasoline soaked textile:

$$Tz(Hz,Lr,Br,Om)=3.632601+9.267738*Hz+7.271182*Lr-2.662011*Br-0.112384*Om-0.213362*Hz*Lr+0.00942*Hz*Om+0.08735*Lr*Br+0.009660*Lr*Om+0.04637*Br*Om-0.099245*Hz*Hz+0.067335*Lr*Lr+1.683790*Br*Br+0.00012*Om*Om;$$

$$Pz(Hz,Lr,Br,Om)=0.342567+0.00637*Hz-0.027362*Lr-0.102466*Br+0.012536*Om-0.000621*Hz*Lr-0.002391*Hz*Br-0.009266*Hz*Om+0.103801*Lr*Br+0.087660*Lr*Om-0.012572*Br*Om+0.017239*Hz*Hz+0.018873*Lr*Lr-0.011772*Br*Br-0.020371*Om*Om;$$

d) diesel fuel soaked textile:

$$Tz(Hz,Lr,Br,Om)=9.912801+8.823655*Hz+9.356277*Lr-1.330170*Br-0.006932*Om-0.034657*Hz*Lr+0.000362*Hz*Om+0.00490*Lr*Br+0.000783*Lr*Om+0.00273*Br*Om-0.006772*Hz*Hz+0.005639*Lr*Lr+2.267366*Br*Br+0.00083*Om*Om;$$

$$Pz(Hz,Lr,Br,Om)=0.128115+0.001367*Hz-0.1008256*Lr-0.102471*Br+0.0129012*Om-0.000102*Hz*Lr-0.00237*Hz*Br-0.004627*Hz*Om+0.116249*Lr*Br+0.010723*Lr*Om-0.012473*Br*Om+0.072901*Hz*Hz+0.024516*Lr*Lr-0.002341*Br*Br-0.014839*Om*Om;$$

e) gasoline soaked wood chips:

$$Tz(Hz,Lr,Br,Om)=1.72664+12.356233*Hz+9.723627*Lr-1.732804*Br-0.936270*Om-0.145277*Hz*Lr+0.015604*Hz*Om+0.09327*Lr*Br+0.012380*Lr*Om+0.03566*Br*Om-$$

$0.0735267*Hz*Hz+0.02736*Lr*Lr+1927830*Br*Br+0.000463*Om*Om;$

$Pz\ (Hz,Lr,Br,Om)=0.42351+0.00283*Hz-0.013267*Lr-0.126735*Br+0.020063*Om-0.000237*Hz*Lr-0.001342*Hz*Br-0.003647*Hz*Om+0.13256*Lr*Br+0.093478*Lr*Om-.010471*Br*Om+0.011843*Hz*Hz+0.012770*Lr*Lr-0.010023*Br*Br-0.02738*Om*Om\ ;$

f) diesel fuel soaked wood chips:

$Tz(Hz,Lr,Br,Om)=7.273367+9.002816*Hz+8.378266*Lr-1.120345*Br-0.0035466*Om-0.012655*Hz*Lr+0.000772*Hz*Om+0.00782*Lr*Br+0.000936*Lr*Om+0.004563*Br*Om-.002138*Hz*Hz+0.002641*Lr*Lr+0.26778*Br*Br+0.000573*Om*Om;$

$Pz(Hz,Lr,Br,Om)=0.107280+0.001026*Hz-0.117346*Lr-0.193562*Br+0.0106377*Om-0.000147Hz*Lr-0.002980Hz*Br-0.001823*Hz*Om+0.148349*Lr*Br+0.018237*Lr*Om-0.010825*Br*Om+0.003315*Hz*Hz+0.006174*Lr*Lr-0.006730*Br*Br-0.018926*Om*Om.$

Conclusion

The analysis of the models shows the following trends:

- Higher risk, determined through the probability of ignition, is established for gasoline and gasoline soaked materials, which is explained with its lower ignition temperature;
- Identical effect of liquid fuels on the risk of ignition of the studied materials;
- Difficult identification of the joint influence of the controllable factors through the derived regression models;
- Completely related effect of distances and wetting with gasoline and diesel fuel on the risk of ignition;
- Complete analogy of the model components, which shows that all controllable factors have effect on the carried out experiments.

To determine the differential risk, defined in [1,2] it is necessary that the dependencies of imissions Im of cutting pearls and time Tz of ignition are established toward one argument. Most appropriate is the distance Lr from the place of cutting along axis X. Since the probability Pz of ignition depends on imissions, their dependence shall be established. This probability shall be bound with probabilistic indicator corresponding to a specified ignition time. Then calculation of differential risk may start.

To determine differential risk of ignition it is necessary that the time Tz is converted from natural to probabilistic value. For that purpose it is necessary to make a check of the hypotheses of the laws of distribution. On the basis of the obtained laws shall be specified the probability Ptz of occurrence of Tz furthermore in the interval $\pm\sigma$- the dispersion near the average value. Upon change of the controllable factors of the above-specified levels, a system of random values is formed. After their processing the models of probability Ptz by types of materials are established.

The adopted model of the research allows wide variation of controllable factors. Thus the effect of technological and spatial factors on the risk of ignition may be established.

The systems of regression models of imissions of welding pearls, of risk parameters - probability and time of ignition of studied materials. They allow calculating and establishing differential risks by types of materials. These models allow comparing the fire criticality of materials, which may be considered in forecasting and operational risk analyses.

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