Physical characteristics of the thermal impact of an emergency fire

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Abstract. The article is devoted to the identification and analysis of the physical characteristics and thermal effects of a fire in an emergency situation. The main purpose of the work is to study the influence of physical damaging factors on the degree of danger of a potentially hazardous object. The article considers a deterministic method for assessing the effects of the action of a physical damaging factor (intensity of thermal radiation). The study is an effort to analyze the physical damaging factors of the fire, because it is the physical basis for an objective assessment of the danger and risk of an accident at the researched object.

1. Introduction
Fires in Russia and around the world cause great damage to buildings and structures, and take thousands of lives of the population and employees of enterprises. The forest industry occupies an important place in the Russian economy, so it is especially important to protect timber warehouse on a wood processing plant from the impact of various damaging factors of a man-made accident.

Fire statistics in Russia show that the number of fires is gradually decreasing, but in absolute terms remains at a high level in 2017, the number of fires was 132844 cases, and the forecast for 2018 is 126468 cases.

Direct material damage from fires consistently amounts to about 13 billion rubles annually. Thus, fire protection is an urgent and demand task.

The main purpose of the work is to study the influence of physical damaging factors on the degree of danger of a potentially dangerous object.

The main task is to analyze the physical damaging factors of the fire at the studied object, because it is the physical basis for an objective assessment of the danger and risk of an accident at the studied object.

The article considers a deterministic method for evaluating the effects of a physical damaging factor in the intensity of thermal radiation, because this is the physical basis for an objective assessment of the hazard measure and the risk of an accident at the researched object. The analysis of statistics and existing methods for assessing physical impacts in the fire was carried out in accordance with the [1-10].

Since the company is at the stage of the "operation" life cycle, tasks that need to be performed to achieve the stated goals:
• updating of data on the main hazards of accidents, technical data of the object and information about the condition
• fire hazard analysis of an object
• determining the frequency of fire hazard situations
• building fields of fire hazards for various scenarios of its development
• assessment of the impact of fire hazards on people for various scenarios of its development.
• develop safety recommendations and, if necessary, adjust measures to reduce the risk of accidents.
• improvement of operating and maintenance instructions, action plans for localization and elimination of the consequences of accidents at the potentially hazardous object.

The subject of the research is methods for assessing the danger of emergency situations in case of fire.

2. Materials and Methods
The most likely events and immediate causes of fire situations:

Mechanical damage to the equipment as a result of employee errors or falling objects—logs on the fuel tank of the loader, depressurization of equipment, formation of a flammable vapor-air mixture.

The output of process parameters beyond critical values, which is caused by a violation of the technological regulations, for example, the appearance of ignition sources in the places where flammable vapor-air mixtures are formed.

Figure 1 shows the options for finding an employee on the site.

Information about frequencies implementations fire-prone areas situations (including number of occurrences as a result employee errors), necessary for evaluation risk, maybe to be received directly from data about functioning the subject object or from data about functioning other similar ones objects.

The method of logical event trees [14] is used to determine possible scenarios for the occurrence and development of fires. In accordance with the above 2 scenarios were formed:

• the explosion flammable vapor-air mixture and ignition stacks in the result incorrect the actions of the employee.
• fire of stacks as a result of violation of safety regulations by personnel.

According to [14] we calculate value individual risk and magnitude potential customer risk factors.

Value potential customer risk assessment $P(a)$ year$^{-1}$ in particular how to site object, and celebrity the area near the object is defined according to the formula:

$$ P_r = \sum_{j=1}^{l} Q_{dj} \times Q(j) \tag{1} $$

where $J$ – number of scenarios development fire-prone areas situations
Qdj (a) - conditional probability defeats the person in charge specific point of the territory (a) as a result implementations j-th development scenarios fire-prone areas situations that respond a specific one initiator crash an event

Qj – implementation frequency during the year j-th scenario development fire-prone areas current year -1

Value individual risk assessment Rm year -1 for workers m of the object when its location on site the object is defined by the formula:

\[ R_m = \sum_{i=1}^{l} q_{im} \times P(i) \tag{2} \]

where \( P(i) \) - value potential risk assessment in i-regions territories of object, year -1

\( q_{im} \) - probability presence employee m in i-regions territories

The main one a characteristic thermal management impacts it is intensity heat pump the flow. Intensity heat pump flow on the irradiated surface the object is defined an expression:

\[ J = \frac{E_T F_i}{2 \pi R^2} \tag{3} \]

Secure radius for location a person calculated according to the formula [4]:

\[ R = \left( \frac{E_T F_i}{2 \pi J} \right)^{1/2} \tag{4} \]

Calculation (4) shows that according to the source data is secure distance for a person equal to 28.2 meter.

In the second accident scenario, diesel fuel spilled out of the loader's fuel tank and caught fire. It is necessary to assess the radius of heat damage to people and the possibility of fire in the lumber warehouse located 5 meters from the accident site.

We have the following initial data:

\( \rho = 950 \text{ kg/m}^3 \) – density of diesel fuel; \( Q = 44 \times 10^3 \text{ kJ/kg} \) – heat of combustion of diesel fuel; \( V_m = 0.04 \text{ kg/(m}^2 \cdot \text{s}) \) – mass rate of combustion of diesel fuel; \( E_T = 40 \text{ kW/m}^2 \) average surface density of thermal radiation of the flame for petroleum products; \( J_{\text{human}} = 4.2 \text{ kW/m}^2 \) – threshold radiation intensity for a human; \( m \) – mass of fuel in the fuel tank of the loader; \( J_{\text{timber}} = 13.9 \text{ --18.8 kW/m}^2 \) – radiation intensity for wood fire (irradiation time, respectively, 15...3 min.). We believe that the thickness of the diesel fuel spot on the earth’s surface is \( h = 5 \text{ cm} \), the weather is windless. Figure 2 shows the relative location of the fire source and the timber stacks.

![Figure 2](image)

**Figure 2.** The relative location of the fire source and the timber stacks.

1. Determining the diameter of the spot of spilled diesel fuel:

\[ R_d = \left( \frac{4m}{\pi \rho h} \right)^{1/2}, \quad d = \left( \frac{4 \cdot 500}{3.14 \cdot 950 \cdot 0.05} \right)^{1/2} \approx 3.66 \text{ m} \tag{5} \]

2. Calculating the duration of combustion diesel fuel:
\[ t = \frac{\rho h}{V_m}, \quad t = 950 \cdot 0.05/0.035 \approx 1188 \text{ c} = 19.8 \text{ min} \quad (6) \]

3. Determining the height of the flame:

\[ H \approx 2.5d^{0.7}, \quad H = 2.5 \cdot 3.66^{0.7} \approx 6.20 \text{ m} \quad (7) \]

4. Determining of the radius of heat damage to people and fire of timber stacks:

\[
R_{\text{human}} = \left( \frac{E_r F_1}{2 \pi J_{\text{human}}} \right)^{1/2}, \quad R_\alpha = \left( \frac{40 \cdot 10^3 \cdot 3.66 \cdot 6.2}{6.28 \cdot 4200} \right)^{1/2} \approx 5.86 \text{ m} \quad (8)
\]

\[
R_{\text{timber}} = \sqrt{\frac{E_r F_1}{2 \pi J_{\text{timber}}}}, \quad R_\beta = \sqrt{\frac{40 \cdot 10^3 \cdot 3.66 \cdot 6.2}{6.28 \cdot 13900}} \approx 3.22 \text{ m} \quad (9)
\]

3. Results

Table 1 shows features thermal management defeats personnel and buildings.

| Distances to the object, m | Destroyed item | Intensity heat pump stream, \(J_i\), kW | Conditional probability of defeats |
|---------------------------|----------------|-----------------------------------------|----------------------------------|
| 2.5                       | Human          | 5276                                    | 1                                |
| 5                         | Human          | 133                                     | 1                                |
| 60                        | Building       | 0.93                                    | 0                                |

It is proved that the main damage factor of a fire is thermal radiation, since this is the most long – range factor. Predicting the result of its action is carried out by deterministic methods.

Deterministic method. It provides for the calculation of a critical parameter of exposure – the intensity of thermal radiation. Comparison of the effective radiation intensity \(J\) with its threshold value \(J_{\text{por}}\), which causes a burn in a person or a material fire, allows us to assess the consequences of the type "burned – not burned": at \(J_i \geq J_{\text{m}}\) – the object burned, at \(J_i < J_{\text{min}}\) – not burned. Figure 3 shows the dependence of the intensity of thermal radiation on the distance to the source of the fire. Knowing the threshold values it is possible to predict the radii of heat damage to people and fire of timber stacks.

\[ q(t) \]

\[ q(t) \]

**Figure 3.** Dependence of the heat radiation intensity on the distance to the fire source for the second scenario.

Analysis received results it shows that staff (loader operator, hamburner operator machine tools, riggers) located in the danger zone. Required events by reducing the number of users risk of failure personnel management timber warehouse heat transfer the impact.

In during operation offered a number of preventive measures events technical support and organizational character. More information about the events is available in the works [15-17].
Technical measure:

1. Device automatic alarm systems in the premises enterprises for timely delivery notifications workers and employees about an accident or explosion gas contamination territories and so on.
2. Placement warehouses potentially dangerous substances taking into account the direction the dominant ones winds.
3. Reducing to the minimum possible value occurrences fires by: installations water curtains, devices fire fighters gaps. Software fire Department maneuvers forces and means during the extinguishing period or localizations fires, construction special features fire fighters reservoirs with water, artificial reservoirs, application fire-resistant structures.
4. Digging in power supply lines and installation automatic ones disabling them devices for prevention ignition points materials when short short circuit.
5. Organizational measure:
6. Advance payment preparation guidelines employees and presenters specialists to interchangeability.
7. Preparation 2-3 management groups (by the number of shifts), which should be prepared take the lead production and organize emergency services and other urgent cases works with the occurrence emergency situations.

4. Discussion

The main results of the research were reported at the scientific and practical conference "Science Week" Peter the Great St.Petersburg Polytechnic University in 2019 and awarded a diploma for best report.

5. Conclusion

In this article we study the influence of physical damaging factors on the degree of danger of a potentially hazardous object and analyze the physical damaging factors of the fire at the studied object. The calculations determined the safe distance on the territory of the plant. The purpose of the work is to develop measures to prevent man-made emergencies at the forest processing plant for early warning of threats, causing harm to the life and health of staff, and damage to the property of the timber plant. The results of the research can be widely applied in practice at the plants of the russian timber industry.

Reference

[1] Kuter N, Yenilmez F, Kuter S 2011 Forest fire risk mapping by kernel density estimation Croatian Journal of Forest Engineering Vol 32, pp 599–610
[2] Yang W, Gardelin M, Olsson J, Bosshard T 2015, Multi-variable bias correction: Application of forest fire risk in present and future climate in Sweden Natural Hazards and Earth System Sciences Vol 15, pp 2037–2057
[3] Kirchmeier-Young M C, Gillett N P, Zwiers F W, Cannon A J, Anslow F S 2019 Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season. Earth’s Future 7, pp 2–10
[4] Pandey K, Ghosh S K 2018 in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives (International Society for Photogrammetry and Remote Sensing), vol 42, pp 299–304
[5] Larjavaara M, Kuuluvainen T, Tanskanen H, Venäläinen A 2004 Variation in forest fire ignition probability in Finland. Silva Fennica Vol 38, pp 253–266
[6] Fire Risk Potential Checking in Forests using Fire Risk Model. International Journal of Constructive Research in Civil Engineering. 3 (2017), doi:10.20431/2454-8693.0304006.
[7] Guettouche M S 2011 A Fire Risk Modelling and Spatialization by GIS. Journal of Geographic Information System Vol 03, pp 254–265
[8] Fraser J S, Wang W J, He H S, Thompson F R 2019 Modeling post-fire tree mortality using a logistic regression method within a forest landscape model Forests Vol 10, doi:10.3390/f10010025

[9] Michael Y 2018 Economic assessment of fire damage to urban forest in the wildland-urban interface using planet satellites constellation images. Remote Sensing Vol 10 doi:10.3390/rs10091479

[10] Pandey K, Ghosh S K 2018 in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives (International Society for Photogrammetry and Remote Sensing), vol 42, pp 299–304

[11] Tumanov A, Gumenyuk V, Tumanov V 2017 Development of advanced mathematical predictive models for assessing damage avoided accidents on potentially-dangerous sea-based energy facility. IOP Conference Series: Earth and Environmental Science 19 C 012027

[12] Tumanov A 2019 Risk Assessment of Accidents During the Transportation of Liquid Radioactive Waste in Multimodal Transport IOP Conference Series: Earth and Environmental Science 272 № 032078

[13] Kulinkovich A V, Sakova N V and Tumanov A Yu 2019 Development of the Express Method for Controlling Uranium Compounds in Natural Waters in Emergency Situations on Floating Nuclear Thermal Power Plants IOP Conf. Ser.: Earth Environ. Sci. 272 № 022016

[14] Tumanov A Yu 2018 Scientific and methodological foundations of risk assessment IOP Conf. Series: Earth and Environmental Science 459 (2020) 032042 IOP Publishing doi:10.1088/1755-1315/459/3/032042

[15] Tumanov A Autonomous safety system for MSW landfills E3S Web of Conferences (2020) 161 DOI: 10.1051/e3sconf/202016101043

[16] Tumanov A, Solovyov A, Kulinkovich A, Tumanov V Development of the Theoretical-Practical Model of Protection of the Means of Transport of Radioactive Materials et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 459 032042

[17] Tumanov A Y, Ryabinina E P, Avdeeva M O and Tumanov V A Methodology for Evaluating a Prevented Damage in Accidents at Energy Saturated Objects IOP Conference Series: Earth and Environmental Science, Vol 459, Chapter 3