Modeling and visualization of emergency situations at oil storage facilities

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Abstract

The article deals with the modeling of accidents at the storage sites of flammable and combustible liquids. The frequencies of initiating events used in the calculations, possible scenarios for the development of accidents, are given. The software for calculating the parameters of damaging factors in the case of fire of straits and ignition with the formation of a fireball in case of accidents on objects with flammable and combustible liquids using the NET Framework was developed. To visualize the accident, Unity 3D developed an application illustrating the depressurization of a tank, with a combustible substance with the formation of a hole in the side wall of the tank through which the flow occurs, followed by spreading and ignition of the combustible liquid. In this case, the individual risk is calculated and its value is indicated in the image.

1   Introduction

On the territory of the Stavropol region there are more than 300 fire and explosion hazard facilities that can be a source of danger to the population, surrounding objects, the natural environment. Therefore, the modeling of emergency situations in fire hazardous areas, both at the design stage and in emergency situations, is an urgent social and economic problem.

2   Emergency situations

The main sources of emergency situations at oil storage facilities: the destruction of reservoirs and their leakproofness for various reasons; leakage due to malfunction of fuel dispensers; overflows due to overfilling of tanks due to malfunction of the level control equipment; formation of explosive concentrations of vapors of flammable and combustible liquids due to malfunction of breathing valves, valves, etc.

The following gives the frequencies of the initiating events (Table 1).

Table 1: Table of the frequency of initiating events

Kind of initiating event	Event frequency, 1/year
Pipeline depressurization $(1\,m)$	$4,5 \cdot 10^{-6}$
Depressurization – rupture of pipeline $(1\,m)$	$5 \cdot 10^{-7}$
Depressurization of pumps	$7 \cdot 10^{-2} - 1 \cdot 10^{-3}$
Damage to pipes or valves in the pump room	$7 \cdot 10^{-7} - 3 \cdot 10^{-5}$
The destruction of the wall of the tank body	$1,161 \cdot 10^{-4}$
Destruction of thrust joints	$0,678 \cdot 10^{-4}$
Destruction of wiring connections	$0,24 \cdot 10^{-4}$
Destruction of inserts	$0,192 \cdot 10^{-4}$
Other failures	$0,342 \cdot 10^{-4}$
Leak from reservoir depressurization with $d = 0.5 - 2.5\,m$	$0,1 \cdot 10^{-4}$
Discharges of atmospheric electricity	$0,2 \cdot 10^{-4}$
Discharges of static electricity	$1 \cdot 10^{-4} - 1 \cdot 10^{-3}$
Friction Sparks	$5 \cdot 10^{-4} - 1 \cdot 10^{-3}$
Open flame and sparks	$5 \cdot 10^{-4} - 1 \cdot 10^{-3}$

Possible outcomes of emergency situations in case of depressurization of tanks with oil products are presented in the Table 2.

Table 2: Scenarios for the development of the accident

Scenarios for the development of the accident	Probability
Flare combustion	0,0574
Formation of a fireball	0,0287
Strait fire formation	0,7039
Combustion of a cloud of a fuel-air mixture by a detonation mode	0,0119
Combustion of a cloud of a fuel-air mixture in a deflagration mode	0,1689
Safe Dispersion	0,0292

From the data given in Table 2 it can be seen that scenarios related to fires in the spill of oil products and the combustion of a cloud of a fuel-air mixture in the deflagration regime have the highest frequency of realization.

As is known, modeling and supporting decision-making in emergency situations includes the following main stages [1, 2, 3, 7]:

- Collection and systematization of information on the source of emergencies;

- System study of emergencies as a control object;

- Structuring of knowledge about emergencies as an object of management;

- Constructing a conceptual model;

- Structural analysis and assessment of the adequacy of the conceptual model;

- Structural and functional decomposition of the conceptual model;

- Synthesis of methods and control algorithms;

- Modeling of control scenarios;

- Comprehensive analysis of simulation results;

- Adoption and implementation of decisions.

In the case of air defense accidents, as a rule, a complex of damaging factors operates, of which three main ones are necessary:

- Destructive impact (during explosions) – destruction of technological blocks, buildings of structures;

- Contamination of the ground layer of the atmosphere by combustion products – poisoning of people and pollution of the environment;

- Thermal effects on people – burns, overheating and on surrounding objects, damage to buildings, cars etc.

3   Modeling accidents

We have developed software that will allow us to quickly calculate the parameters of accidents involving flammable and combustible liquids.

The software consists of two parts. The first part of the software package makes it possible to calculate the amount of thermal radiation in case of a fire in the strait at different distances from the source, the amount of thermal radiation in the occurrence of the fireball and the time of its existence.

The second part allows spatial representation of the dynamics and consequences of a strait fire from a single object containing fuel.

The first part of the program is created using the NET Framework. NET Frame-work is a software platform released by Microsoft in 2002. It is actually an operating system inside the operating system. The basis of the platform is the Common Language Runtime (CLR) virtual machine, capable of performing both normal desktop applications and web applications. A distinctive feature of the NET Framework is the ability to execute programs written in different programming languages. It is believed that the platform NET Framework was the response of Microsoft to the highly ac-claimed Java platform of Sun Microsystems (now owned by Oracle), also based on a virtual machine. Although NET is a proprietary technology from Microsoft and Microsoft Windows, there are independent projects (primarily Mono and Portable NET) that allow you to run NET programs on many other operating systems.

The program for the NET Framework, written in any supported programming language, is first translated by the compiler into a single, easy-to-understand, Common Intermediate Language (CIL) for the person (formerly called Microsoft Intermediate Language, MSIL). The compiler then translates the CIL code into an object bytecode (in NET terms, assembly is obtained, English assembly), and the bytecode is either executed by the CLR virtual machine, or translated by the utility NGen.exe into executable code for the specific target processor. The use of a virtual machine is preferable, as it saves developers from having to take care of the hardware features. In the case of using a CLR virtual machine, the built-in JIT compiler on-the-fly (just in time) compiles the intermediate byte-code into the machine codes of the desired processor. Modern technology of dynamic compilation allows achieving a high level of performance. The CLR virtual machine also takes care of basic security, memory management and exception systems, saving the developer from part of the work.

Using the software platform NET Framework, we have developed a program that allows the following:

- to calculate the parameters of damaging factors in the fire of spills of flammable and combustible liquids;

- to calculate the consequences of the formation of a fireball.

After downloading the program, the user must select the scenario for the failure of the calculation of the parameters to be carried out. To do this, there are two function buttons in the upper part of the window. Two types of scenarios for the "Flammable and combustible liquids strait" and "Fire Ball" crashes are shown on the top of the window.

After selecting the alarm scenario, the user must enter the alarm parameters and set the value of the heat radiation to which the calculation will be made. In the field of the accident parameters it is necessary to set the area of the strait and the type of fuel involved in the accident.

During the selection of the necessary accident parameters, the program immediately performs all calculations and presents the results of the calculation in the form of a graph and a table.

In the upper right corner of the program window there are functional buttons for generating the report as a word processor file and printing the report. They allow you to get a printed version of the calculations made by the program.

User interface of the program for input of initial data are presented in Fig. 1.

The results of calculations for the "Fireball" scenario are shown in the Fig. 2.
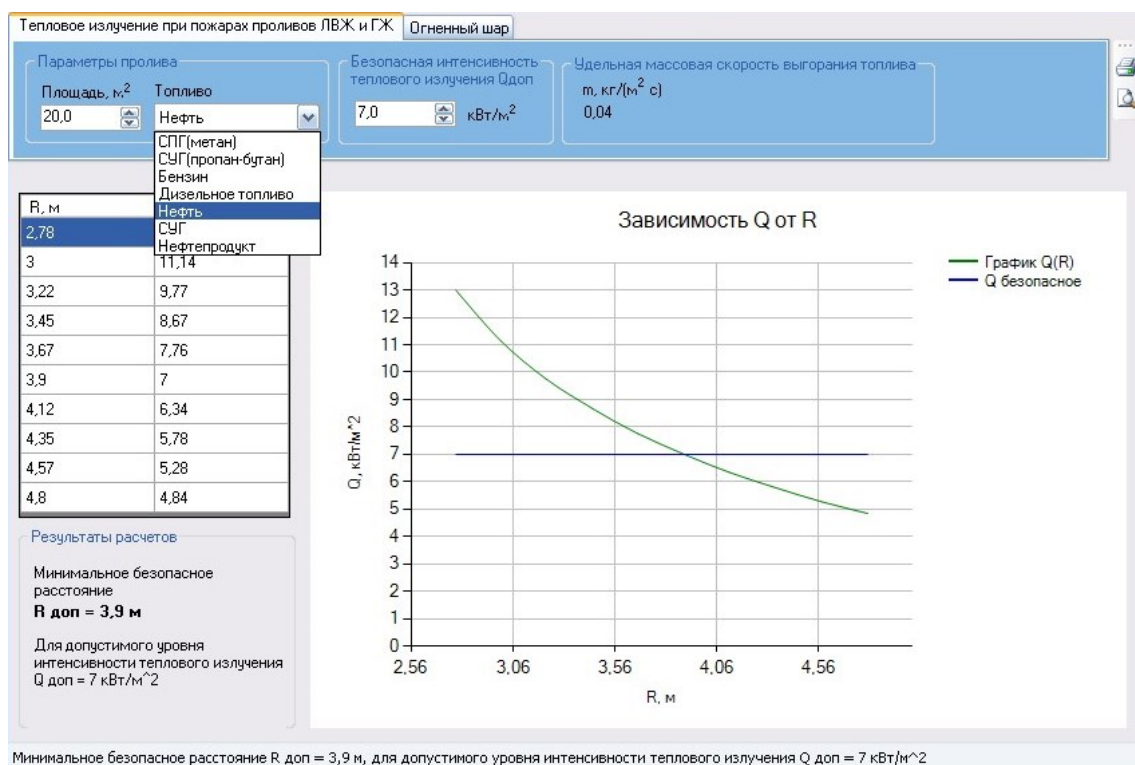
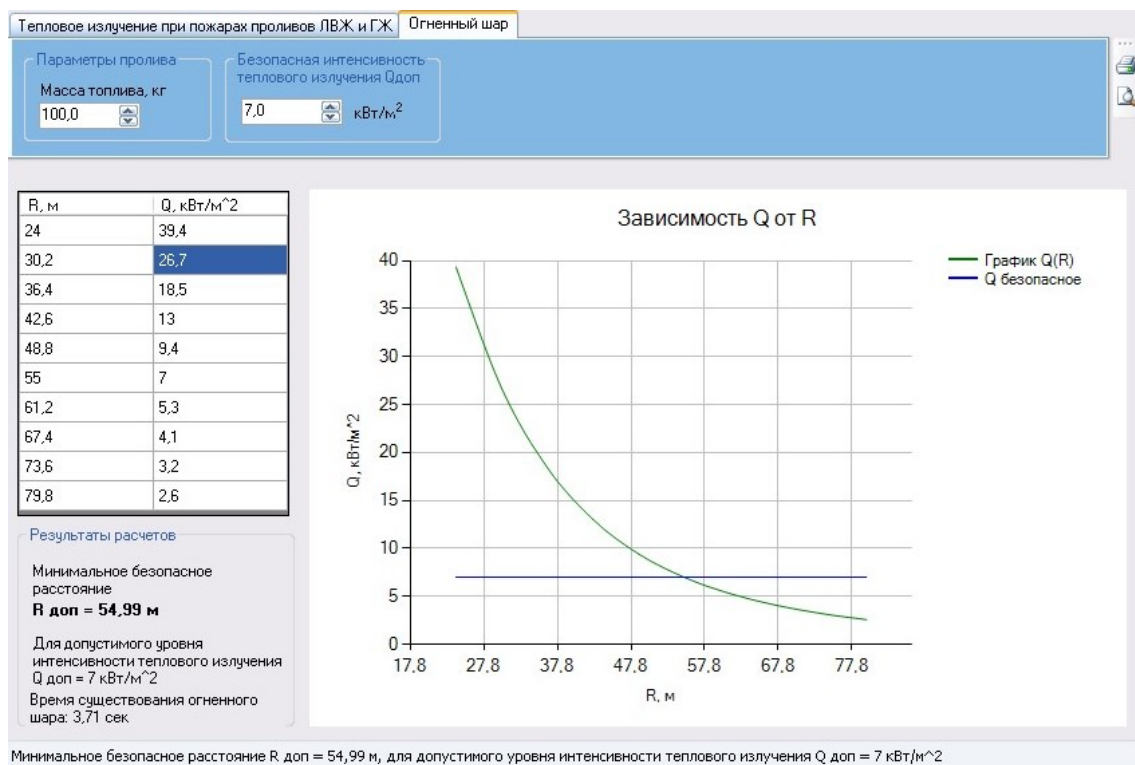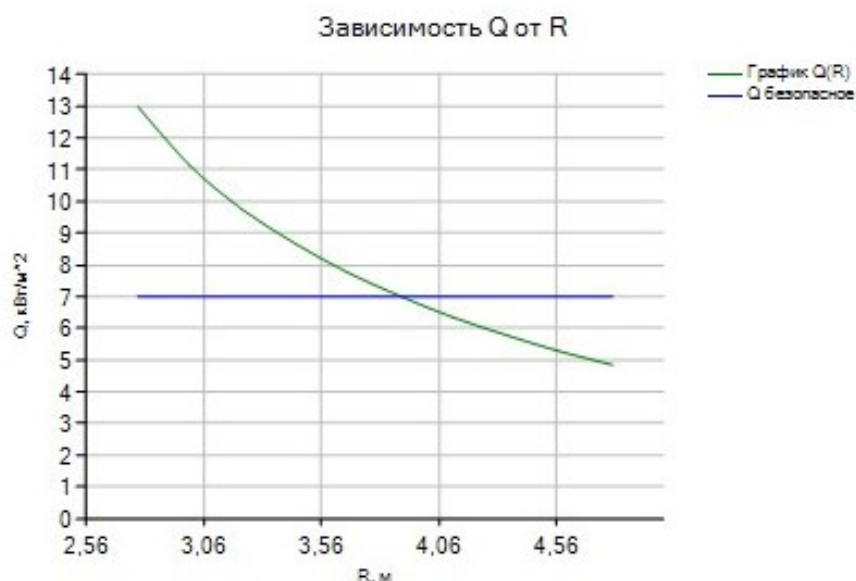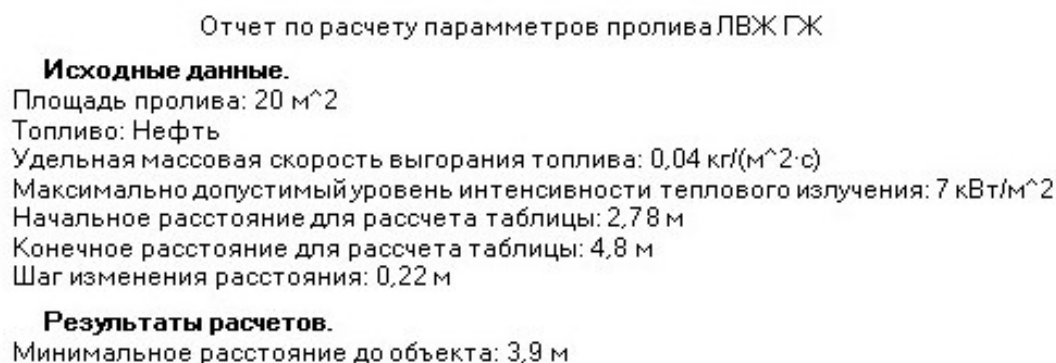Figure 1: The input data input window

Figure 2: Window of calculation results for the scenario "Fireball"

An example of printing the results of the calculation for printing is shown in the Fig. 3.

Отчет по расчету парамметров пролива ЛВЖ ГЖ

Исходные данные.
Площадь пролива: 20 м^2
Топливо: Нефть
Удельная массовая скорость выгорания топлива: 0,04 кг/(м^2·с)
Максимально допустимый уровень интенсивности теплового излучения: 7 кВт/м^2
Начальное расстояние для рассчета таблицы: 2,78 м
Конечное расстояние для рассчета таблицы: 4,8 м
Шаг изменения расстояния: 0,22 м

Результаты расчетов.
Минимальное расстояние до объекта: 3,9 м

Зависимость Q от R

R	2,78	3	3,22	3,45	3,67	3,9	4,12	4,35	4,57	4,8
Q	12,99	11,14	9,77	8,67	7,76	7	6,34	5,78	5,28	4,84

Figure 3: Results of calculation under the scenario of fire of the spill of a flammable and combustible liquid

The second part of the program includes a graphical representation of the accident at a fire and explosion hazard site. Taking into account the numerous numbers of scenarios for the development of accidents at fire and explosion hazard sites and the difficulty of creating a three-dimensional model for each of these scenarios, we chose the accident scenario that is most relevant at the time. It includes the depressurization of the tank, with combustible material, as a result of the formation of an opening in the side wall of the container through which the flow occurs, followed by spreading and ignition of the combustible liquid.

The implementation of the three-dimensional image and the execution of calculations is formed on the basis of Unity 3D - it is a multi-platform tool for developing three-dimensional applications, including a powerful engine (Unity Engine) for developing 3D applications and games, as well as an integrated development editor.

Unity Engine includes a highly optimized 3D graphics engine for both DirectX and OpenGL. It allows you to create animated 3D objects, particle systems, advanced lighting and shadows. Unity Engine supports delayed rendering technology (Rendering is a term in computer graphics that indicates the process of obtaining an image on a model using a computer program.). Unity provides a visual creation of a particle system, through which it is possible to create rain, sparks, dust poles, flames, explosions and other effects.

It is possible to combine 3D real-time graphics with streaming audio and video.

Unity supports a wide range of platforms to run the created project. 3D applications created with Unity work on Windows, MacOS, Wii, iPhone, iPod, iPad, Android, Play Station 3, XBox 360, and also through the Unity web player (connects to a browser on Windows or Mac OS as a plug-in).

Due to a large set of mathematical, trigonometric and other functions contained in the .NET libraries, the software implementation of the mathematical model of the application is greatly simplified. The rich functionality of the .NET libraries, together with the powerful 3D engine Unity, allows you to create simulation models of real processes and phenomena and visualize them in the form of three-dimensional inter-active applications. In accordance with the results of calculations performed in the software implementation of the mathematical model, a set of parameters characterizing the simulated phenomenon is obtained, with the help of which it is possible to control the visual display of three-dimensional objects.

The calculation is carried out in the same manner as the first part of the program [1, 2, 3, 4, 5, 6]. The software complex for modeling the process of development of an accident with a spill of flammable and combustible liquids is intended for:

– visual construction of the potential spill sector;
– viewing the dynamics of the development of the accident;
– construction of zones of intensity of thermal radiation at various distances from the center of the spill;
– construction of fire risk zones.

After downloading the program, the user must specify:

– type of fuel involved in the accident;
– the filling of the tank with fuel;
– hole height;
– diameter of the hole;
– the required value of the intensity of thermal radiation.

After entering the necessary parameters, the user starts the simulation process and the program performs the necessary calculations. As a result of the calculation, we obtain a three-dimensional image of the accident with the designation of safe and dangerous zones of thermal radiation and fire risk.

The data entry window is shown in the Fig. 4.

Figure 4: Window for selecting emergency settings

The visualization of the results of calculations is shown in Fig. 5.

Figure 5: Imaging Results

4 Conclusion

During the work, an analysis of the causes and scenarios for the development of emergency situations at oil product storage facilities was carried out.

Two programs have been developed. One is designed to calculate the consequences of emergency situations associated with the formation of a fire in the strait and the fireball, and the second is designed to visualize the dynamics of an emergency situation associated with the formation of a strait fire. To perform calculations, the NET Framework and the Unity Engine are used. These developments will be useful for a wide range of specialists involved in providing security.

References

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