Tamara SAVCHUK[1], Andriy KOZACHUK[1], Konrad GROMASZEK[2], Laura SUGUROVA[3]

Vinnitsa National Technical University (1), Lublin University of Technology (2), Kazakh National Technical University after K. I. Satpaev (3)

Forecasting the state of technogenic emergency situation on the railway transport using data mining technologies

Streszczenie. *W pracy przedstawiono wyniki badań odnośnie zapobiegania sytuacjom awaryjnym w transporcie kolejowym. Autorzy wykorzystali model matematyczny do prognozowania stanu składu kolejowego ze zbiornikiem cieczy przegrzanej oraz użyli wybranych technik data mining.*

Abstract*. The paper presents the results of research railway transport emergency prevention. Authors used mathematical model for the prediction of the state of the train tank cargo with superheated liquid and considered some data mining techniques (****Prognozowanie technogennych sytuacji awaryjnych w transporcie kolejowym z wykorzystaniem technik data mining****).*

Słowa kluczowe: transport kolejowy, zbiorniki przegrzanej cieczy, prognozowanie sytuacji wyjątkowych, techniki data mining.
Keywords: railway transport, superheated liquid tanks, emergency forecasting, data mining.

doi:10.12915/pe.2014.01.12

Introduction

The development of the railway transport, the increase in its role in people's life is accompanied not only by the positive effects, but also by the negative consequences, such as high levels of transport facilities accidents.

Prevention of emergency situations on the railway transport implies the preparation and implementation of the complex of legal, social and economic, political, organizational, technical, sanitary and other activities aimed at regulation of the safety, risk levels evaluation, timely response to the threat of an emergency based on the monitoring (observation) data, expertise, research and forecasts of the possible development of the events in order to prevent them from escalating into an emergency situation or minimize their possible consequences.

Rapid detection of the dangerous situation on the railway transport is very important: the earlier the risk is identified, the more time will the manager have for the decision making and implementation of protective actions, which increases the possibility of advance warning the possible development of a dangerous situation that will lead to better preparation for its possible consequences or even avoid it. It should be noted that today the problem of predicting the dangerous situations on the railways and prediction of their development is unresolved in Ukraine. In other countries, such as Russia, the existing system of forecasting are only focused on the local railways, which is their disadvantage, since the technologies, which are on the base of these systems, stipulate for the connection of the emergency to the place of its origin, since it is difficult to establish the dependence between the rapid technogenic emergency situation on the railway transport and their place of origin. There are the systems of emergency forecasting in Ukraine, but they are focused on the solution of the problem of natural emergencies forecasting (eg floods in the Carpathians), and although they target the rapid situation, it is not possible to apply them to the emergency situations of technogenic origin. In addition, the current order of Ukrainian Ministry of Emergency Situation "About the approval of the methodology for predicting the consequences of influence (discharge) of hazardous chemicals on the industrial objects and transport" refers to the prediction of the consequences of the possible emergency situation, rather than predicting its development. Thus, the conventional technologies for forecasting the deciduous technological emergencies on the railway transport has not been developed. Their development will allow to improve the safety operation of railway transport.

Goals and objectives of the research

The goal of the research is to improve the accuracy in the determination of the safety degree of the emergency situation on the railway transport by improving the methods for forecasting, based on a multidimensional approach to presenting the data on emergency situation on the railway transport and use of methods and algorithms of Data Mining during their intellectual processing.

To achieve this goal it is necessary to solve the following problems:

- to analyze the existing systems for forecasting the emergency situations on the railway transport;
- to develop a mathematical model for the process of forecasting the development of emergency situations on the railway transport;

The object of the research is the process of prediction of the state of emergency situation on the railway The subject of the research – the technologies for the forecasting of rapid technogenic emergency situation on the railway transport.

Development of the model for the process of prediction of the development of emergency situation on the railway transport

To predict the state of the emergency situation on railway transport, it is necessary to know the most accurate information on the physical condition of the cargo carried by the train. Let's consider a mathematical model for the prediction of the state of the train tank cargo.

The basis of the mathematical model of temperature distribution in the railroad tank, we accept the tank as set of the elementary cells [1]. The main feature of the cell is the same value of all physical parameters for all the points belonging to the cell. Cells interact with each other by the process of heat-mass transfer, resulting in changing of their physical parameters such as pressure and temperature [2, 3]. The outer layer of cells represents the surrounding environment. Physical parameters of this layer does not depend on the parameters of the inner layers (however, affect them).

The hard shell is heated by the external heat source, the intensity of which is distributed by three-dimensional normal distribution law, which can be presented in the following form:

$$f(x,y,z)=\frac{1}{(2\pi)^{\frac{3}{2}}\delta_x\delta_y\delta_z}$$

$$\exp\left(-\frac{1}{2}\left(\frac{(x-mx)^2}{\delta_x^2}+\frac{(y-my)^2}{\delta_y^2}+\frac{(z-mz)^2}{\delta_z^2}\right)\right),$$

where $f(x,y,z)$ is a value of external heat source intensity, x,y,z – geometrical coordinates, mx,my,mz – distribution parameters.

Heat exchange between cells occurs under the law of heat transfer (1).

(1) $$\frac{\partial t}{\partial\tau}=a\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2}\right),$$

where a – coefficient of thermal transfer, τ – time, t – temperature. Let's change function's derivative to their discrete form:

$$\frac{\Delta t}{\Delta\tau}=a\left(\frac{\Delta^2 t}{\Delta x^2}+\frac{\Delta^2 t}{\Delta y^2}+\frac{\Delta^2 t}{\Delta z^2}\right).$$

In this statement $\Delta\tau$ is time step, Δt – temperature growth, $\Delta x,\Delta y,\Delta z$ – coordinates steps (size of elementary cell).

(2) $$\Delta t=a\Delta\tau\left(\frac{\Delta^2 t}{\Delta x^2}+\frac{\Delta^2 t}{\Delta y^2}+\frac{\Delta^2 t}{\Delta z^2}\right).$$

Statement (2) includes discrete operators, which values could be found using statements (3 – 5).

(3) $$\frac{\Delta^2 t}{\Delta x^2}=\frac{1}{\Delta x^2}\left(t_{x+1,k}+t_{x-1,k}-2t_{x,k}\right);$$

(4) $$\frac{\Delta^2 t}{\Delta y^2}=\frac{1}{\Delta y^2}\left(t_{y+1,k}+t_{y-1,k}-2t_{y,k}\right);$$

(5) $$\frac{\Delta^2 t}{\Delta z^2}=\frac{1}{\Delta z^2}\left(t_{z+1,k}+t_{z-1,k}-2t_{z,k}\right);$$

And then Eq.(2) becomes:

$$\Delta t=\frac{a\Delta\tau}{\Delta x^2}\left(t_{x+1,k}+t_{x-1,k}-2t_{x,k}\right)+\frac{a\Delta\tau}{\Delta y^2}\left(t_{y+1,k}+t_{y-1,k}-2t_{y,k}\right)+\frac{a\Delta\tau}{\Delta z^2}\left(t_{z+1,k}+t_{z-1,k}-2t_{z,k}\right).$$

Last correlation allows to solve system of equations (2) for the (n+1)th step of discretization, having value of u for the nth step. u_{xyz}^{n} – temperature of iteration number n. Here and bellow indexes assumed to have values x,y,z if they are not set explicitly.

(6) $$u_{x,y,z}^{n+1}=u_{x,y,z}^{n}+\Delta t.$$

So, solving the system explicitly allows to make a conclusion that, value of temperature can be obtained for any point at any time moment, but this method for the solution of the system of equations is unstable [1].

Direct solution of the equation system (6) is unstable and eventually leads to the accumulation of distortions, which significantly reduce the simulation accuracy [4, 5]. To achieve the satisfactory accuracy it is necessary to reduce the simulation time step, which leads to a significant increase in simulation time (up to several days).

This problem was solved by using an implicit Douglas-Hann method for the solution of the 3-dimensional system of differential equations. According to this method, the execution of each iteration is divided into three iterative steps [4, 6].

The temperature of each elementary cell is determined by statement

(7) $$u^{*}-u^{n}=\frac{r_x}{2}\delta_x^2(u^{*}+u^{n})+r_y\delta_y^2u^{n}+r_z\delta_z^2u^{n};$$

(8) $$u^{**}-u^{n}=\frac{r_x}{2}\delta_x^2(u^{*}+u^{n})+\frac{r_y}{2}\delta_y^2(u^{**}+u^{n})+r_z\delta_z^2u^{n};$$

(9) $$u^{n+1}-u^{n}=\frac{r_x}{2}\delta_x^2(u^{*}+u^{n})+\frac{r_y}{2}\delta_y^2(u^{**}+u^{n})+\frac{r_z}{2}\delta_z^2(u^{n+1}+u^{n});$$

$$r_x=\frac{a*\Delta t}{\Delta x^2},\ r_y=\frac{a*\Delta t}{\Delta y^2},\ r_z=\frac{a*\Delta t}{\Delta z^2},$$

$$\delta_i^2u_i^n=u_{i-1}^n-2u_i^n+u_{i+1}^n.$$

Splitting each iteration into steps allows to use the sweep method to solve equation system, which has complexity *O(n)*, comparing to *O(n_2)* for Gauss method.
Equation (7) could be presented in a form of $au_{x-1}^{*}+bu_{x}^{*}+cu_{x+1}^{*}=d$:

$$a=\frac{-r_x}{2};\ b=1+r_x;\ c=\frac{-r_x}{2};$$

$$d=u_x^n+\frac{r_x}{2}\delta_x^2u^n+r_y\delta_y^2u^n+r_z\delta_z^2u^n.$$

For equation (8):

$$a=\frac{-r_y}{2};\ b=1+r_y;\ c=\frac{-r_y}{2};$$

$$d=u_y^n+\frac{r_x}{2}\delta_x^2(u^{*}+u^{n})+\frac{r_y}{2}\delta_y^2u^n+r_z\delta_z^2u^n.$$

For equation (9):

$$a=\frac{-r_z}{2};\ b=1+r_z;\ c=\frac{-r_z}{2};$$

$$d = u_z^n + \frac{r_x}{2}\delta_x^2(u^* + u^n)$$
$$+\frac{r_y}{2}\delta_y^2(u^{**} + u^n) + \frac{r_z}{2}\delta_z^2 u^n$$

Obtained equation system has a form, shown on fig. 1.

b_1	c_1	0	0	0	0	…	d_1
a_2	b_2	c_2	0	0	0	…	d_2
0	a_3	b_2	c_3	0	0	…	d_3
0	0	a_4	b_4	c_4	0	…	d_4
0	0	0	a_5	b_5	c_5	…	d_5
…	…	…	…	…	…	…	…
…	0	0	0	0	a_m	b_m	d_m

Fig.1. The general view of the obtained equation system

Equation system can be solved using the sweep method: in direct part we should get rid of the coefficients a_i:

$$a_i^* = 0\ ,\ b_i^* = b_i - \frac{a_i c_{i-1}^*}{b_{i-1}^*}\ ,\ c_i^* = c_i\ ,$$

$$d_i^* = d_i - \frac{d_{i-1}^* a_i}{b_{i-1}^*}.$$

On the reverse step we find the values of u_i:

$$u_m = \frac{d_m^*}{b_m^*}\ ,\ u_{i-1} = \frac{d_{i-1}^*}{b_{i-1}^*} - \frac{c_{i-1}^*}{b_{i-1}^*}u_i\ .$$

First we calculate all values of u^*, then u^{**} and u^{n+1}.

The use of numerical methods for simulation of the state of the railway transport tank involves splitting the tank into elementary components. Thus, the tank means a tank cargo as well as the cargo of its the wall. To achieve the acceptable performance on a desktop computer the number of elementary cells should not exceed N = 1000000. Let's give an estimate of the size of the elementary cell. Typical railway tank size is 10.8 x 2.6 x 2.6 meters. Let's assume, that the tank has a cylindrical shape, then it's volume is equal to

$$\mathrm{V} = 1 * \pi * r^2 = 10.8 * \pi * 2.6^2 = 229m^3.$$

Volume of elementary cell V_e is equal to

$$V_e = \frac{V}{N} = \frac{229m^3}{1000000} = 0{,}000229\,m^3 = 229cm^3\ .$$

If elementary cell is a cube, then the length of the cube size $\mathrm{l_e}$ is equal to

$$\mathrm{l_e} = \sqrt[3]{V_e} = 6.11cm.$$

This size of the elementary cube is inappropriate for modelling of the tank wall, where the values of the temperature gradient is quite significant, and a thickness of which is 2 to 3 cm (less than the size of the elementary cell). Therefore, for the simulation of the tank wall we choose the parallelepiped cell shape, one of its facets is reduced, while others overlap in size with normal cells. The length of the facet in 5 mm provides for from 4 to 6 layers of cells on the wall of the tank, which will correctly simulate the heat transfer process. Dimensions of unit cells are shown in figure 2. Using the sells of different dimensions allows to apply the mathematical model to the wide range of tasks but increases the number of operative memory necessary for the simulation process.

The cause of the possible explosion is an increase in temperature and pressure of gas mixture in the tank, which could lead to the immediate destruction of the tank wall by increasing static load or, under certain conditions, the flash gas mixture, which leads to an explosion of the tank with a large probability. The equation of state of gas mixtures can be described by the equation of Van der Waals (10),

$$\left(p + \frac{a\upsilon^2}{V^2}\right)\left(\frac{V}{\upsilon} - b\right) = RT\ , \qquad (10)$$

where *p* - gas pressure, *V* – gas volume, *T* – temperature, *υ* – number of moles of substance, *R* – the gas constant, *a, b* – corrections to the equation of state of an ideal gas.

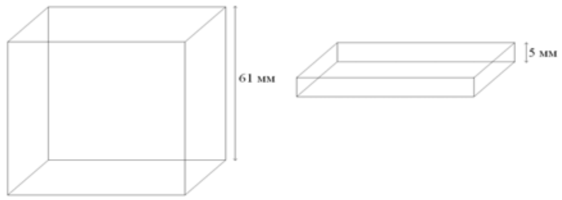

Fig.2. Elementary cells of liquid cargo(left) and solid wall (rigth)

Assuming that the volume of the gas and the amount of substance do not change, we twice apply the formulae (10) to the gas with parameters (p_1, V_1), and (p_2, V_2) correspondingly and divide the received correlations one by one

$$\frac{p_2 + \frac{a\upsilon^2}{V^2}}{p_1 + \frac{a\upsilon^2}{V^2}} = \frac{T_2}{T_1}\ ;\ p_2 = \frac{T_2}{T_1}p_1 + \frac{a\upsilon^2}{V^2}\left(\frac{T_2}{T_1} - 1\right).$$

Thus, having the value of the gas temperature allows us to determine the pressure inside the tank at any moment of time which enables to evaluate the time from the moment the fire appears to the appearance of the emergency situation.

Prediction of the affected area from the explosion of the railway tanks with superheated liquid

During heating from an external heat source liquid begins to evaporate in the tank. Gas that is stored in the tank has a limited volume and rapidly saturated by liquid vapour. After saturation of gas, liquid evaporation stops. Eventually, when the temperature of the liquid is raised to a boiling temperature, boiling fluid does not take place and liquid becomes overheated. After achieving this, explosion due to rapid evaporation of overheat liquid becomes possible(Boiling liquid expanding vapour explosion, BLEVE). It should be mentioned, that non-combustible liquids could also explode.

Explosion occurs when the tank shell is damaged. When a large amount of gas is coming out of the tank to surrounding environment quickly, pressure inside the tank drops, gas ceases to be saturated and instantaneous evaporation of large amount of overheated liquid starts. Pressure inside the tank explosively rises to the level that far exceeds the initial, then tank shell is destroyed and the blast occurs [7]. The main hazards during the explosion are tank fragments, shock wave and ball of fire. Fireball is formed only in case when liquid is combustibility. Among listed hazards, tank fragments have the biggest damage area. Let's consider the relationships that allows to determine the radius of the zone of injury.

To calculate the pressure on the surface of the tank at the time of the explosion the following equation is used [8]:

$$P_b = P_{sb}[1-\theta]^{-2k/(k-1)};$$

$$\theta = \frac{0.035(k-1)(P_{sb}-101)}{\sqrt{[1+0.058P_{sb}](kt/M)}},$$

where: P_b is a gas pressure directly before the explosion kPa, P_{sb} – overpressure at the time of the explosion, T – gas temperature at the time of the explosion, in Kelvins, M – molecular weight of gas, k – coefficient of heat radiation per volume unit at a given pressure.

Calculation of the mass of the i[th] fragment could be performed using following expression [8]:

$M = \frac{dM(i)}{di} = M_0 B\lambda i^{\lambda} e^{-Bi^{\lambda}}$, where M_0 – total mass of fragments (is equal to the mass of the tank), i – fragment number, B and λ – parameters of the distribution law. As noted in [7], usually fragments of cylindrical-shape objects ranging from one to five.

Having fragments mass and pressure of the shock wave, it becomes possible to calculate initial fragments velocity using equation [8]

$v = 2.05\sqrt{\frac{P_{sb}D^3}{M}}$, where D – fragment diameter, in inches, M – fragment mass, in pounds. *[v]*= feet per second. Transferring v in meters per second, the following relation for determining the radius of maximum damage area in meters can be obtained:

$R = \frac{v^2}{g}$, where g is the acceleration of free fall.

Designing of the system of railway emergency situation development prediction

Based on the described relationships the computer program of state prediction (forecast) of a railway tank during fire has been developed. The program implements a finite-element algorithm of simulation of the thermodynamic state of substance [9]. The program provides the ability to set geometrical parameters of the tank, setting characteristics of the heat source and the transported substances.

The module consists of the following major components: kernel software that performs simulation, computer model of the railway tank, user interface module that provides the ability to enter information about the initial state of emergency situation and shows the simulation results in form of graphs of temperature in different layers of content from the tank temperature. Also, UI module builds projections of 3-dimentional temperature maps.

Computer model of the tank consists of structures of the elementary cell and class that describes general system properties. Some difficulties in the simulation were caused by the fact that the railway tank has a cylindrical shape, and the cell walls have parallelepiped shapes with sides ratio close to 10:1. Cells with special sides ratio were introduced in order to cope with strong differences between adjacent cells. Side area of these cells depends on their placement.

According to the method of Douglas-Hann, calculation of the temperature field of the tanks for each time requires three consecutive iteration of all cells in the system. Thus, within a single iteration results of processing cells do not affect each other, which, taking into account the large number of cells (hundreds of thousands), allows efficient usage of parallel computing, getting the benefit from performance by using a large number of processor cores.

User interface of the system is shown on figure 3.

Number of simulations of the state of railroad tank heated with external heating source was made using the described system.

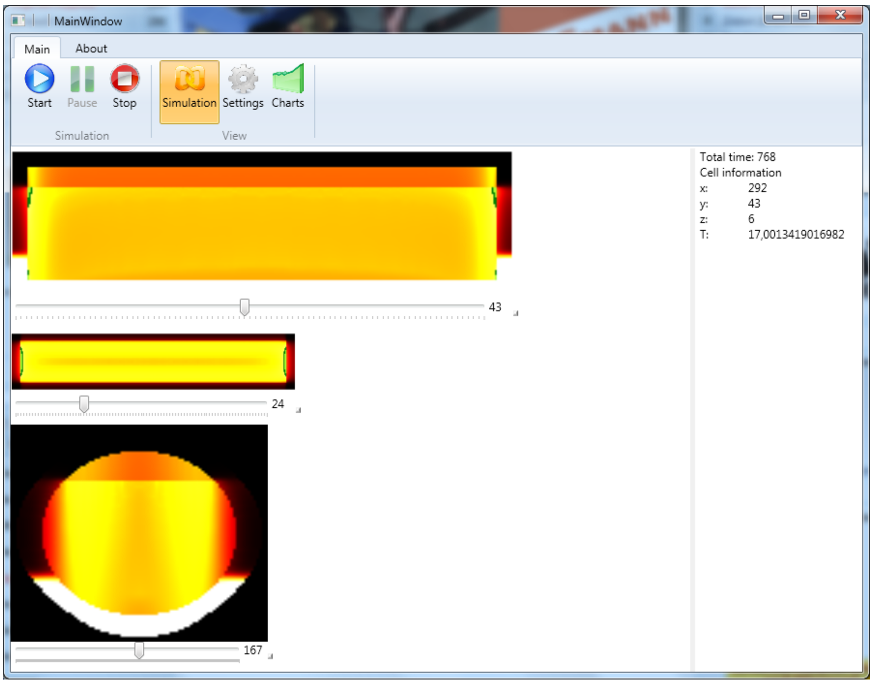

Fig.3. Main window of the system of the railroad emergency situation development prediction

In sources [3, 10] the experimental data obtained by heating railroad tank filled with water could be found. Appropriate finite-elements models of railway tanks were developed and used for prediction of the tank state. Parameters of the model and comparison of prediction result with experimental data are shown in table 1 and figures 4 - 5.

Conclusions

So, with the described statements and the results of numerical simulation of the railway tank state during the emergency situations on railway transport, it is possible to make a forecast of emergency situation on the railway transport using Data mining methods by defining the radius of the injury zone from the tank fragments that appears as a result of explosion of the tank. Obtained results can be used in decision-making during liquidation of emergency situations and as a component of information technology of forecasting of the state of rapid emergency situations on railway public transport.

Table 1. Simulation paremeters of railroad tank filled with water

Parameter name	Parameter value	Parameter name	Parameter value		
Wall size 1	0,03 m		Wall	Liquid	Gas
Wall size 2	0,03 m	Heat transfer	0,0005	0,01	0,005
Fill level	0,75	Density	7600	1000	1,3
Peak source temperature	1500	Specific heat	500	1800	730
Mx	5	Border temperature	1770	370	-
My	1,5	Convection level	0	0,1	10
Mz	0	Cells count	1000000		
Gx	1	Time step	1		
Gy	1	Initial temperature	290		
Gz	0,002	Tank length	10,8		
		Tank diameter	2,6		

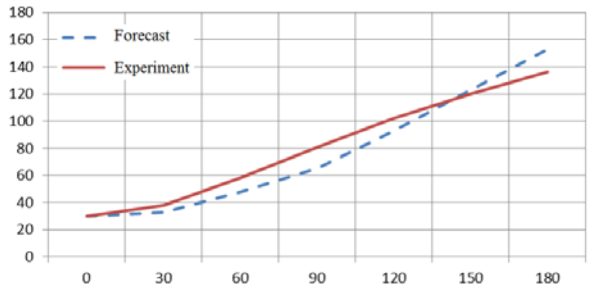

Fig.4. Comparison of liquid temperature prediction with experimental data

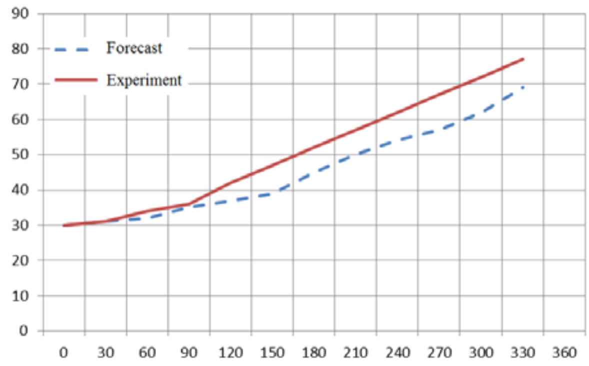

Fig.5. Comparison of gas temperature prediction with experimental data

REFERENCES

[1] Miheev M., Miheeva A., *Fundamentals of Heat Transfer*, Energia, Moscow (1977)

[2] *Railroad-Highway Grade Crossing Handbook* safety.fhwa.dot.gov/xings/com_roaduser/ 07010/sec03.html.

[3] Soren Underlien J., *Passive railroad-highway grade crosings*, Lyngby Research Park Scion-DTU (2007),19

[4] Savchuk T. O., *Simulation results of the temperature field of railway tank*, Bulletin of Khmelnitsky National University, nr 1 (2011)

[5] *Naive Bayes and Decision Trees for Function Tagging* www.aaai.org/Papers/FLAIRS/2007/Flairs07-118.pdf

[6] Barsegian A.A., Kuprianov M.S., Stepanenko V.V., Holod I.I., *Methods and models of data analysis: OLAP i DATAM i NJN*, BHV-Petersburg (2004)

[7] Baker W.E., Cox P.A., Westine P.S., Kulesz J.J., Strehlow R.A., *Explosion Hazards and Evaluation*, M Mir (1986)

[8] Held M., *Fragment mass distribution of high energy projectiles*, Propellants, High Explosives, Pyrotechnics, nr 15, (1990)

[9] Savchuk T. O., *Development of approaches to non-statistical forecasting of the physical state of train cargo*, Bulletin of Kremenchuk State Polytechnic University named after Mikhail Ostrogradskiy, nr 5, (2011)

[10] *US Coast Guard Office of Research and Development. Fire testing of independent fiberglass fuel tanks with and without protective coating of fire retardant paint*, Report AD 740783. Washington, DC, (1972)

***Authors**: Ph.D. Tamara Savchuk, professor of computer science department, Vinnitsa National Technical University, Ukraina, tel. +380664124037, savchtam@rambler.ru; M.Sc. Andriy Kozachuk, Vinnitsa National Technical University, Ukraina, tel. +380973418499, kozachuk35@rambler.ru; Ph.D. Konrad Gromaszek, Lublin University of Technology, Poland, tel. +48815384317, k.gromaszek@pollub.pl; M.Sc. Laura Sugurova, Kazakh National Technical University after K. I. Satpaev, Almaty, Kazakhstan*