ESTIMATIVA DO TAMANHO DAS ZONAS DE ESTAGNAÇÃO NO TERRITÓRIO DA FAZENDA TANQUE DE PROPANO-BUTANO VISANDO AUMENTAR A SEGURANÇA DA INSTALAÇÃO

ESTIMATION OF THE SIZE OF STAGNATION ZONES ON THE TERRITORY OF THE PROPANE-BUTANE TANK FARM AIMED AT INCREASING THE SAFETY OF THE FACILITY

ОЦЕНКА РАЗМЕРОВ ЗОН ЗАСТОЯ НА ТЕРРИТОРИИ РЕЗЕРВУАРНОГО ПАРКА ХРАНЕНИЯ ПРОПАН-БУТАНА ДЛЯ ПОВЫШЕНИЯ БЕЗОПАСНОСТИ ОБЪЕКТА

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RESUMO

A segurança do território depende diretamente da tecnologia de armazenamento e uso de propano-butano. O artigo revela a eficiência da tecnologia de dinâmica de fluidos computacional baseada em software (CFD) baseada no software FlowVision na modelagem de zonas de estagnação e no comportamento da nuvem de mistura ar-combustível (FAM) no território das instalações de armazenamento. O armazenamento de tanques de armazenamento de propano-butano foi selecionado como objeto de pesquisa. O CAD SolidWorks foi usado no projeto de seu modelo tridimensional. Métodos usando "modelos de gases pesados dispersos" foram desenvolvidos. Baseia-se na solução numérica de equações tridimensionais de dinâmica de fluidos e gases, incluindo as leis de conservação de massa, momentum (a equação de Navier-Stokes) e equação constitutiva. Recomendações sobre as mudanças a serem implementadas durante a fase de projeto de tanques com mistura de propano e butano foram desenvolvidas a fim de aumentar a segurança das instalações em caso de despressurização do equipamento. Sabe-se que os edifícios, localizados no território, prejudicam o fluxo de ar, resultando na presença de grandes zonas estagnadas. Foi estabelecido que, como resultado do movimento do fluxo de ar através do território da fazenda de tanques, as áreas máximas das zonas de estagnação são observadas com o vento norte e o mínimo - com o vento sudeste. Usando as técnicas de modelagem tridimensional e volumes finitos, as zonas de estagnação no parque de tanques foram computadas para diferentes direções do vento e alturas de medição, permitindo uma avaliação abrangente da situação na instalação em questão e desenvolvimento de séries de medidas de segurança.

Palavras-chave: zonas de estagnação, modelagem tridimensional, dinâmica de fluidos computacional, nuvem FAM, propano-butano.

ABSTRACT

The safety of the territory is directly dependent upon the propane-butane storage and use technology. The paper reveals the efficiency of FlowVision software-based computational fluid dynamics technology (CFD) in modeling the stagnation zones and the behavior of fuel-air mixture (FAM) cloud within the territory of storage facilities. Propane-butane storage tank farm storage was selected as the object of research. CAD SolidWorks was used in the design of his three-dimensional model. Methods using "dispersed heavy gas models" have been developed. It is based on the numerical solution of three-dimensional fluid and gas dynamics equations, including the laws of conservation of mass, momentum (the Navier-Stokes equation) and constitutive equation. Recommendations on changes to be implemented during the design stage of tank farms with propane-butane mixture have been developed in order to increase facility safety in case of equipment depressurization. It is known that buildings, located on the territory, impair the airflow, resulting in the presence of large stagnant zones. It has been established that as a result of the movement of air flow through the territory of the tank farm, the maximum areas of stagnation zones are observed with the north wind and the minimum – with the southeast wind. Using the three-dimensional modeling techniques and finite volumes the stagnation zones in the tank farm were computed for different wind directions and measurement heights, enabling a comprehensive assessment of the

situation at the facility in question and development of series of safety-increasing measures.

Keywords: *stagnation zones, three-dimensional modeling, computational fluid dynamics, FAM cloud, propane-butane.*

АННОТАЦИЯ

От технологий хранения и использования пропан-бутана непосредственно зависит безопасность территории. В работе выявлена эффективность применения технологий вычислительной гидродинамики (CFD) на базе программного комплекса FlowVision для моделирования зон застоя и поведения облака топливно-воздушной смеси (ТВС) на территории объектов хранения. В качестве объекта исследования выбран резервуарный парк хранения пропан-бутана. CAD SolidWorks использовался при проектировании его трехмерной модели. Были разработаны методы с использованием «моделей дисперсного тяжелого газа». Он основан на численном решении трехмерных уравнений гидродинамики и жидкости, включая законы сохранения массы, импульса (уравнение Навье-Стокса) и определяющее уравнение. Разработаны рекомендации по внесению изменений на стадии проектирования резервуарных парков с пропан-бутановой смесью с целью повышения безопасности объекта в случае разгерметизации оборудования. Известно, что постройки, которые находятся на территории резервуарного парка, ухудшают движение воздушного потока, следствием чего является наличие больших площадей зон застоя. Установлено, что в результате движения воздушного потока по территории резервуарного парка, максимальные площади зон застоя наблюдаются при северном направлении ветра, а минимальные – при юго-восточном направлении ветра. Используя методы трехмерного моделирования и конечные объемы, зоны застоя на нефтебазе были рассчитаны для различных направлений ветра и высоты измерений, что позволило провести комплексную оценку ситуации на данном объекте и разработать ряд мер по повышению безопасности. Таким образом, это делает задачу разработки новых подходов, основанных на использовании трехмерного моделирования и технологий CFD, актуальной. Используя современные инструменты визуализации и обработки данных, можно относительно быстро и эффективно анализировать результаты расчетов и получать необходимые данные.

Ключевые слова: *зоны застоя, трехмерное моделирование, вычислительная гидродинамика, облако ТВС, пропан-бутан.*

1. INTRODUCTION

Due to the strong growth in industrial production and the increasing complexity of production processes, the issue of ensuring the safety of facilities and territories is becoming more and more relevant. At the same time, modern methods and technologies for forecasting the development of probable accidents make it possible to take into account many parameters, thereby increasing the reliability of the advance forecast results. There are a large number of papers discussing the application of computational fluid dynamics (CFD) technologies at the stage of site security analysis, but the issue remains relevant to this day because there is no generally accepted method for the prediction and prevention of accidents, as well as no rational choice of protective measures.

The use of these CFD technologies for modeling accidents at facilities where hazardous gaseous substances can be released is relevant. Propane, butane, and their mixture, being very dangerous, but have become widespread, belong

to such substances. The impact of aggressive environment, failure to comply with maintenance process parameters, and failure to conduct preventative maintenance may lead to seal failure and destruction of equipment in operation. There is a probability of formation of a fuel-air mixture (FAM) cloud. Since propane-butane is heavier than air (specific weight is 1.57 for propane, 2.10 for butane), it can accumulate in nonventilated places, distribute along the surface in the direction of air flow at large distances, forming explosive concentration zones. Therefore, there is a significant likelihood of damage to stations involved in the storage and transportation of propane-butane mixture (oil refineries and gas processing plants, terminals, port and cluster bases), neighboring facilities and residential settlements. Evaporation of 1 dm³ of liquid forms about 250 dm³ of gas. Therefore, even a small leakage of the propane-butane mixture can be dangerous since the volume of the substance can increase by 250 times during evaporation. In the case of combustion of propane-butane, it is characterized by the rapid development of fire, the explosion of tanks, and low efficiency of

conventional fire fighting equipment.

Therefore, to preserve the safety it is necessary to ensure maximum sealing of tanks, utility systems, pumps and other equipment, strictly observe maintenance process parameters and it is recommended to use additional systems and methods for predicting the behavior of FAM clouds and possible stagnation zones, i.e., the areas within the territory, where the wind speed does not exceed 0.5 m/s.

Most significantly, the legal acts at the stage of hazard identification and search of the best space-planning decisions lack comprehensive methodology for evaluation of potential stagnation zones and FAM cloud sizes using three-dimensional modeling systems and CFD-technologies (Andreev and Gridina, 2017).

Issues of emergency processes modeling have been dealt by such scholars as D.F. Nuretdinova, Ye.A. Gostenova, K.N. Abdrakhmanova and N.V. Shutov (Nuretdinova *et al.*, 2018); A.V. Solodovnikov and R.R. Tlyasheva (2006); V.N. Permyakov, V.G. Parfenov and M.V. Omelchuk (Permyakov *et al.*, 2015); M.V. Lisanov, A.V. Pchelnikov and S.I. Sumskey (Lisanov *et al.*, 2005); V.C. Marshall (1989); D.K. Bjerketvedt, J.R. Bakke and K. van Wingerden (Bjerketvedt *et al.*, 1997); W. Baker, P. Cox and P. Westane (Baker *et al.*, 1986); C.J. Saunders and M.J. Iving (2005); E. Simiu and R.H. Scanlan (1978); J.R. Bakke and O.R. Hansen (2003); G. Schmidt (2002); S.G. Davis, D. Engel, F. Gavelli, P. Hinze and O.R. Hansen (Davis *et al.*, 2014); W. Geiger (1983) and a number of other experts (ScMeroney, 1982).

2. MATERIALS AND METHODS

Let us consider the techniques used to assess emergency situations. There is a method of calculating the FAM cloud using advanced computational fluid dynamics (CFD) models of gas release and dispersion (GRAD). One of the promising turbulent models is the multi-fluid turbulence model, which makes it possible to predict the stochastic properties of combustible gas clouds. GRAD software is recommended for safety and environmental protection analysis and allows for highly precise prediction of the dynamic behavior of clouds of flammable gases (with a gas concentration between the lower and the upper flammability level), such as hydrogen, methane, etc. However, the available studies deal only with its use for the assessment of safety of hydrogen including the analysis of hydrogen emission from

pressure relief devices and determination of clearances for venting the hydrogen storages (Agranat *et al.*, 2007).

Safety Guide "Methodology for calculating the consequences of explosions of fuel-air mixtures" contains recommendations for the approximate estimation of parameters of air shock waves in case of explosions of FAM, formed in an atmosphere as a result of industrial accidents, determination of probable degree of injury of people and the degree of damage to buildings due to the blast load during accidents with FAM cloud explosions at hazardous industrial facilities (HIF). Emergencies assumed when considering the issues are partial depressurization or complete destruction of equipment containing a combustible substance in gas or liquid phase, the release of this substance into the environment, the formation of a FAM cloud, explosive transformation (burning or detonation) in the FAM cloud. It is also possible to calculate the maximum excess pressure and compression phase pulse of air shock waves, determine the additional characteristics of FAM explosion, shock wave profile, parameters of the incident wave during detonation of the gas mixture incident wave, parameters of the reflected shock wave, the wave parameters for a random combustion mode (Order of the Federal Service..., 2016). The disadvantage of this technique is the lack of possibility of taking into account the probable stagnation zones at HIF.

Program framework "Ministry of Emergency Situations Order No. 404" is based on the Order of the Ministry of Emergency Situations of the Russian Federation No. 404 "On approval of the method to define the computed estimated values of fire risk in industrial facilities", dated July 10, 2009. In particular, it allows estimating hazardous factors, realized when compressed and liquefied gas outflows from an opening in a reservoir, the mass of combustible substances, determining the maximum dimensions of hazardous areas as a result of fire hazard situations, pressure wave parameters during a gas, vapour or dust cloud combustion, dust air cloud combustion products in case of a flash fire, estimated time of evacuation (Order of the Ministry of..., 2009). However, due to a number of assumptions of this method, the calculation results may differ from the real ones, and this method does not take into account the likely stagnation zones within the site in consideration.

At the initial stage of substance propagation, the above flows (air streams of different configurations, expanding clouds) and the high density of the ejected substance prove

essential; therefore, methods using "dispersed heavy gas models" have been developed. Such models are based on the integral conservation principles in the cloud as a whole or in a cloud cross section. The most well-known implementations of "heavy gas" scattered models are the World Bank's methodology, set HGSYSEM methods (it is a package of computer models for modeling release and atmospheric dispersion of hazardous substances, which has capabilities that may not be found together elsewhere), methods, created with the support of leading research organizations DVN Technica (Norway), TNO – The Netherland Organization of Applied Scientific Research (Netherlands). Such methods have limitations, since the peculiarities of the terrain and the presence of buildings cannot be accounted for during calculations, and therefore the probable stagnation zones cannot be calculated either.

Recently, however, CFD-technology is being used as an alternative to the above method. Currently, there are many software packages that implement these technologies. Let us consider the most well-known and effective ones, as well as analyze their advantages and disadvantages. FLACS software package was developed by Norwegian company GEXCON (Bleyer *et al.*, 2012). The advantages of this software package are an accurate estimation of stagnation zones at the facility under study and injurious effects distribution zones taking into account the geometry of the surrounding area, including for explosions in premises (Agapova *et al.*, 2015). However, the program does not support entering the input technological values (pressure, temperature, size of the defective opening) for the required equipment. Here, the initial data are used as input values (material consumption, probabilistic parameters), calculated using other software products. It is also important to note that the disadvantage is the labor-intensive characteristic of preparation of input data on the geometry of the surrounding area (premises, building, structures, terrain parameters) and the program requires high user qualifications.

The ABAQUS software package was created by the American company Abaqus Inc. Advantages are the possibility to analyze the effects of air blast waves, the calculation of linear structures taking into account climatic conditions, simulation of hydrodynamic effects, air currents are given the complex geometry, allowing to calculate probable stagnation zones (Evseev, 2017). An important advantage is the software system reliability, as well as strict control of the convergence of solutions of the processes under

study, the possibility of automatic selection integration step and tasks monitoring at all stages of calculation. A significant drawback is a high cost and the lack of the possibility of calculating room ventilation and air conditioning parameters and predicting the fire and smoke propagation.

ANSYS software developed by US company Ansys Inc. The advantage is the possibility to build a 3D model in the program without additional computer-aided design systems (CAD). This program makes it possible to solve many complex problems, including the atmospheric propagation of gas emissions, modeling the oil spills in water and soil conditions, assessment of wind comfort factors in terms of construction and calculation of stagnation zones, fire and fire fighting process modeling. It is possible to obtain the calculation results in the form of video files with simulation dynamics. The disadvantages are the high cost and complexity of familiarization (Korshunov *et al.*, 2018).

FlowVision software package created by LLC "TESIS" (Russia) development team. Main advantages – the possibility of modeling of FAM cloud, calculating wind load, the external flow of structures and possible stagnation zones, prediction of the spread of pollutants in water bodies, calculating premises ventilation and conditioning parameters, prediction fire and smoke propagation (Aksenov *et al.*, 2015). Of course, software systems and methods have their advantages and disadvantages, but after analyzing the functionality, FlowVision can be distinguished due to the relative simplicity of use, complete and understandable documentation, credibility of results, reliable user support, high quality and ability to solve complex safety and environmental protection tasks at enterprises. It is also important to note that the software system has a relatively low cost and is available for calculations in schools.

In presented article, it is used three-dimensional modeling and finite volume methods using CFD-technologies based on FlowVision software. It is based on the numerical solution of three-dimensional fluid and gas dynamics equations, including the laws of conservation of mass, momentum (the Navier-Stokes equation) and constitutive equation. It is important to note that the features of this complex allow for the creation of effective emergency situation forecast and prevention systems, and render it possible to make a rational choice of protective measures using advanced visualization and data processing tools. It is also possible to select the necessary physical and chemical environmental parameters

(temperature, pressure, wind speed and direction) for the modelled object and propane-butane mixture (pressure, mass fraction, viscosity, thermal conductivity, specific heat, etc.), as well as the necessary laws characterizing the flow, mass transfer and stirring of mixture.

3. RESULTS AND DISCUSSION:

Propane-butane storage tank farm storage was selected as the object of research. CAD SolidWorks was used in the design of his three-dimensional model (Figure 1):

- 4 rail tank cars, with a volume of 54 m³ each;
- railway embankment;
- 12 surface tanks 50 m³ each;
- Arcuated hangar, 14.1x15.7x5 m;
- machine shop, 55x15x7 m;
- administration building, 20x8x6 m;
- cylinder filling plant, 37.5x9.5x4 m;
- pump and compressor room (PCR), 8.6x5.5x3.5 m.

The total site area is 30 thousand m². There are no water intake sources, artificial reservoirs, excavations, and ravines in the area of location of the objects. Using the rail tank cars propane-butane is transported, received, and transferred to tanks. Propane-butane is drained from rail tank cars in the tank farm reservoirs through the pipelines located above the ground, through drainage posts under gas pressure. Each tank contains a liquefied propane-butane mixture. Compressor equipment is located in a structure under a canopy. Liquid fed into the tank farm reservoir using the pump at PCR and gas is delivered using PCR compressor. Probable depressurization equipment areas in the studied territory are as follows:

- tank farm;
- tank car loading and receiving rack;
- cylinder filling plant;
- equipment located in the PCR;
- pipelines.

The reasons for the occurrence and development of accidents at the components of the object under study may be the following technical problems:

- breaks in pipelines, flexible conduits (hoses) due to corrosion, mechanical damage, pressure exceeding the estimated value, wear;
- depressurization of gland and end seals of pumps, compressors, valves, faucets;
- destruction of vessels due to mechanical damage, corrosion, thermal effects;
- destruction of tanks due to their overflow and thermal deformation during the expansion of liquefied gas;
- loose valves, pipe valves, taps;
- various damage to the tanks (drain valves, level gauges, safety valves, shutoffs);
- breakdowns of pump manifold flanged connections, compressors, evaporators: breakdowns of gland sealing of pumps or compressors (Tlyasheva and Solodovnikov, 2006).

After exporting the model from SolidWorks CAD to FlowVision software package, loading of environmental parameters, and setting the limiting conditions, the model is as follows (Figure 2). Locally refined grid was used in calculations; the total number of cells was 1.6 mln.

Using FlowVision software package probable stagnation zones were identified at different wind directions at a speed of 2 m/s at the height of 0.2; 0.5; 1.0; 1.5; 2.0; 2.5 and 3.0 m, some of them are presented in Figures 3, 4, 5. Stagnation zones in the figures are shown in shades of blue. The windrose diagram characteristic of Tyumen (Russia), shown in Figure 6, was taken into account.

As can be seen from Figure 3-5, the presence of buildings on the model territory significantly impairs the airflow, resulting in the formation of large stagnation zones. For clarity of the results, Figures 7, 8, and 9 show the calculated areas occupied by structures, stagnation zones, and zones where the wind speed exceeds 0.5 m/s. Thus it can be concluded that as a result of air flow movement through the territory of the tank farm, the maximum areas of stagnation zones are observed with the north wind and the minimum – with the southeast wind.

In the field emergency situation simulation, there are studies aimed at both the prediction of FAM cloud formation and the simulation of the behavior of gaseous media in other situations. Unfortunately, the authors do not pay enough attention to the stagnation zones or do not pay attention to them at all. The following should be noted among them.

V.C. Marshall in his paper confirmed that increasing the impact of vapor cloud explosion is facilitated by the presence of buildings and installations in the way of its propagation, and also highlighted the factors that contribute to its development (Marshall, 1989). Dag K. Bjerketvedt, Jan Roar Bakke, K.V. Wingerden gave the description and physics of the phenomena of a gas explosion, cloud formation, blast waves and suggested actions to improve the safety in case of gas explosion (Bjerketvedt *et al.*, 1997).

W. Baker, P. Cox, P. Westine evaluated the explosiveness arising from the release of energy from explosions of condensed substances, gas mixtures, dust, and high-pressure vessels, presented the laws of simulation of perfect and nonperfect explosions and described how to create explosion-proof facilities (Baker *et al.*, 1986). C.J. Saunders, M.J. Ivings studied the effectiveness of natural ventilation of offshore platforms with a focus on uneven ventilation inside the module and its dependence on the wind conditions by conducting detailed experimental measurements on three typical marine platforms using CFD-technologies (Saunders and Ivings, 2005).

Emil Simiu and Robert H. Scanlan discussed the issues of atmospheric thermodynamics and fluid dynamics, wind climatology and its influence on the design and calculation of engineering structures, showed the dependence of the wind load and its distribution on buildings and structures on the wind speed and came to a conclusion about the necessity of wind effects simulation tests in the calculation and design of structures (Simiu and Scanlan, 1978).

J.R. Bakke and O.R. Hansen (2003) described the approach to predicting explosive loads on ground-based petrochemical facilities, carried out a probabilistic analysis of the risk of explosion for an enterprise using FLACS software system (Bakke and Hansen, 2003). K. V. Wingerden analyzed the studies of the effect of water spraying on gas explosions in overloaded environments, identified conditions under which the water spray would be effective as a means to reduce and limit the effects of an explosion, described how to design a water spraying system to limit the effects of possible emergency gas explosions, suggesting its use as a safety improvement measure for propane-butane storage facilities (Van Wingerden, 2000).

Graubner Schmidt introduced the need for FLACS software for simulation of emergency situations, assessment of explosions and risks in

the oil industry facilities in order to prevent destruction of structures, human injury, environmental damage and economic loss, conducted a pilot study and found that FLACS software does not forecast deformation of structures in case of steam and gas cloud explosions, however, the data obtained during simulation can be used for analysis of other software products, including nonlinear behavior of structural members embedded in the structure parts (Schmidt, 2002).

Scott G. Davis, Derek Engel, Filippo Gavelli, Peter Hinze, Olav R. Hansen presented the results of using the FLACS software to determine the origin of the explosion in case of an accident that occurred at the ink and paint manufacturing plant in Denvers in 2006 and concluded that FLACS simulation can be used to study the chain of explosion events and provide a more complete understanding of the evidence, including the damage from the explosion near the field (Davis *et al.*, 2014).

Geiger W. showed that for deflagration of common explosion mode, deviations from the ideal situation can significantly strengthen or weaken the pressure build-up and concluded that it might be necessary to take into account the significantly increased pressure within the flat cloud, especially in the areas with buildings and structures (Geiger, 1983).

Robert N. conducted a laboratory research on simulation of emissions into the ground boundary required for description of movements of potentially hazardous chemicals, including propane, butane, liquefied natural gas, freon, highlighted the simulation criteria and the results of the behaviour of a dense plume in a wind tunnel, which can be used to empirically predict dispersion of vapour in case of full-scale emissions (Meroney, 1982; Pocebneva *et al.*, 2018).

Studies in the field of emergency situations simulation have been conducted by a number of other scientists and researchers, such as D.F. Nuretdinova, Ye.A. Gostenova, K.N. Abdrakhmanova, and N.V. Shutov (Nuretdinova *et al.*, 2018). Their article discussed the methodology for assessing the consequences of FAM explosion, based on which FAM cloud explosions of real accidents and experiments were simulated using PV-Bezopanost and TOXI+Risk software and the areas of damage to buildings and structures were defined. As a result, the greatest deviation from the actual and experimental values is recorded when using the PV-Bezopanost program. This method does not take into account

the mode of explosive transformation, the aggregate state of hazardous substances, the characteristics of the surrounding area, and the position of the point of initiation of the explosive cloud. These disadvantages are absent in TOXI+Risk software package, but the radii of buildings damage zones exceed the actual value of the radii of explosion by an average of 18% (Krasnogorskaya and Akhmerov, 2015).

M.V. Lisanov, A.V. Pchel'nikov, S.I. Sumskoy (2005) in their work considered a number of issues relating to the simulation of scattering in the atmosphere and assessing the effects of toxic and fire-hazardous emissions according to "TOXI-3" methodology. This method was developed by FSUE STC "Industrial Safety," and it provides the opportunity to calculate the characteristics of hazardous cloud moving in the atmosphere within the framework of "heavy gas" scattering model, which is based on the integral conservation laws. Calculation of the various emission scattering patterns was performed: bulk and prolonged, with obstacles and without them. It was further concluded that standard techniques based on the Gaussian model are not capable of predicting, with a sufficient degree of accuracy, the scattering of "heavy gas" from both the bulk and prolonged sources. The error value is 400-500%. "TOXI-3" method showed a good ability to forecast the concentration fields and the size of the cloud for emissions from long-acting sources. Calculations, according to this method, are in good agreement with the experimental data (Lisanov *et al.*, 2005).

Questions of the relevance of determination of stagnation zone sizes for facilities with the probable release of propane-butane have been considered in studies of such scholars as R.R. Tlyasheva and A.V. Solodovnikov (2006); V.N. Permyakov, V.G. Parfenov and M.V. Omelchuk (2015); N.N. Krasnogorskaya and V.V. Ahmerov (2015). Similar to the research presented in this article, these authors directly linked to the sizes of stagnation zones with facility safety, and during simulation took into account the real development of the production facility and the terrain (Tlyasheva and Solodovnikov, 2006; Permyakov *et al.*, 2015; Krasnogorskaya and Akhmerov, 2015; Baimakhan *et al.*, 2008).

Studies by R.R. Tlyasheva and A.V. and Solodovnikov are deep in nature and are aimed at improving the safety of a typical outdoor site of an absorbing gas fractionating unit (Tlyasheva and Solodovnikov, 2006). Just as in the research results presented in this article, R.R. Tlyasheva and A.V. Solodovnikov point to the necessity to

take into account the dimensions of stagnation zones at the facility design stage, but at the same time, in their recommendations for space-planning decisions, considerable emphasis is made on turning the object around its axis in order to minimize the likelihood of formation of stagnation zones of considerable size. It should be noted that these authors proposed an interesting algorithm for the optimal placement of gas analyzers in the territory of a production facility. Compared with the works of A.V. Solodovnikov and R.R. Tlyasheva (2006), this paper analyses the stagnation zones at a liquefied hydrocarbon gas storage facility.

The joint research V.N. Permyakov, V.G. Parfenov and M.V. Omelchuk (2015) give an assessment of stagnation zones for a typical gas filling station, which allowed us to find the optimal location of structures on the tank farm site. Also the methodology for assessing the safety of light hydrocarbon storage facilities in emergency situations was developed, scientifically substantiated and confirmed by laboratory studies for the first time, which allows for a comprehensive assessment of stagnation zones using 3D modelling systems and selecting the most effective safety solution at all stages of a facility's life cycle (Permyakov *et al.*, 2015; Kireev *et al.*, 2016). Compared with the works by V.N. Permyakov, V.G. Parfenov and M.V. Omelchuk (2015), in the presented study, zones of stagnation are estimated at a greater number of heights, the storage facility is somewhat simplified, mainly the most common components are left, but at the same time tanks on tank car loading and receiving rack was added.

N.N. Krasnogorskaya and V.V. Ahmerov (2015) chose a fuel filling station with multiproduct fuel dispensers as an object for study. The authors have resolved the issues of finding stagnation zones and the formation of liquefied hydrocarbon gases FAM cloud in the territory of this facility. The research proposed an algorithm for selecting measures to improve the safety of operating an integrated fuel station and recommendations aimed at reducing the probability of formation of LHG FAM during the technological process, improving the scattering of explosive fuel vapors at the multi-product fuel-dispensing units and at improving the emergency response process (Krasnogorskaya and Akhmerov, 2015). Compared with the scientific work of N.N. Krasnogorskaya and V.V. Ahmerov this research simulated a propane-butane mixture storage facility, where the probability of formation of fuel-air mixture cloud is higher by ten folds. In contrast to all of the above research, in this study, the

calculation of possible stagnation zones was made taking into account the wind speed prevailing in Tyumen (Russia), as well as the wind pattern, characteristic for the area. New-generation software package FlowVision was used in the calculations.

4. CONCLUSIONS:

Using the three-dimensional modeling techniques and finite volumes the stagnation zones in the tank farm were computed for different wind directions and measurement heights, enabling a comprehensive assessment of the situation at the facility in question and development of series of safety-increasing measures:

1. Changing the elevation of the tank;
2. Ensuring safety at the design and construction stage, including the rational arrangement of the tank farm structures, depending on the distance between the objects and on the wind rose diagram;
3. Selection of rational arrangement of gas detection sensors;
4. Analysis of the possibility of implementing technical measures aimed at improving the safety of the facility.

The importance of today's safety challenges requires intensive development of application programs, without which it is almost impossible to create effective emergency forecasting and prevention systems. Thus, this makes the task of developing new approaches based on the use of three-dimensional simulation and CFD technologies relevant. Using advanced visualization and data processing tools, one can relatively quickly and efficiently analyze the results of calculations and obtain the necessary data.

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Figure 1. Layout of propane-butane tank farm (top view): 1 – arcuated hangar; 2 – machine workshop; 3 – administration building; 4 – cylinder filling plant; 5 – pump and compressor room; 6 – rail car tanks; 7 – railway embankment; 8 – tanks.

Figure 2. The model view after loading the parameters in FlowVision (side and top view)

Figure 3. Typical stagnation zones for north wind (speed 2 m/s, top view): a) at a height of 0.2 m; b) at a height of 3.0 m

Figure 4. Typical stagnation zones for northwest wind (speed 2 m/s, top view): a) at a height of 0.2 m; b) at a height of 3.0 m

Figure 5. Typical stagnation zones for west wind (speed 2 m/s, top view): a) at a height of 0.2 m; b) at a height of 3.0 m

Figure 6. Tyumen (Russia) wind rose diagram

Figure 7. Reliance of the area occupied by buildings on measurements height

Figure 8. Reliance of size of probable stagnation zones on the wind direction at different measurement heights

Figure 9. Reliance of size of probable areas with wind speed exceeding 0.5 m/s on wind direction at different measurement heights