ASSESSMENT OF THE RANGE OF DANGER ZONES DETERMINED IN A FUNCTION OF LNG CHEMICAL COMPOSITION

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Abstract: Nowadays, when we try to automatize all activities, there is a growing demand for energy in all forms. Increasingly we reach for new energy sources that can be problematic to store or to transport, owing to their toxicity or explosive propensity. The article examines the issues of determining danger zones occurring as a result of liquefied natural gas (LNG) release. The range of danger zones caused through LNG release depends on a multitude of factors. The basic parameter that needs to be considered is a type of the released substance as well as the manner of its release. The range of a danger zone is determined by, inter alia, the concentration of a released substance and the atmospheric conditions existing at the time when depressurization occurs. The article analyses the problem of the range of danger zones in a function of wind speed and surface roughness with a defined value of Pasquill stability for various LNG types, starting with pure methane, and ending with the so-called LNG-heavy. The difficulty of the task becomes more complicated when the analysed surface over which a depressurization incident takes place involves water. The problem deepens even further when the analysed substance possesses explosive properties. Then, apart from regular substance concentration, upper and lower flammability limit ought to be considered. Calculations were conducted with DNV-Phast software, version 7.11.

Keywords: LNG chemical composition, explosion risk area, upper and lower explosion limit

INTRODUCTION

A growing demand for energy is contributing to the increased interest in other energy sources than those previously used. Although solar and wind power engineering is developing, that technology is not yet able to cover the growing demand for energy (Farfan and Breyer, 2017). The need to find ever newer forms of energy and to diversify it frequently entails the danger related to storing and transporting hazardous substances (Bubbico, 2009). Even though we realize that the use of certain substances as an energy source may contribute to the occurrence of a dangerous situation – we choose the lesser evil, i.e. we use the hazardous substance while simultaneously trying to create an early warning system against a possible catastrophe (Liu et al., 2017). We plan transport routes ensuring their highest possible safety (Landucci et al., 2017). At the same time, the manner of hazardous substance storage poses a multitude of problems, particularly if it is an explosive substance (Liu, 2017). At that point it becomes necessary to define an explosion risk area (Krata and Szlapczynska, 2017). A simulation related to determining danger zones is a good method of obtaining preliminary information on the range and the impact of any possible instances of depressurization of tanks or systems transporting such substances (Ślączka, 2011), (Atkinson, 2017). Such information is useful in devising early warning plans and systems. The information regarding explosion risk zones or poisonous substance risk zones enables limiting risks and minimizing losses, and consequently protecting people, property and the environment to the highest possible degree against the effects and consequences of the use of hazardous materials (Basu and Verma, 2017). Devising a spatial model enables estimating the proximity of risk-prone areas

by calculating the distance separating those objects from tanks, warehouses or routes of vehicles carrying hazardous substances (Mabrouk et al., 2017).

METHODOLOGY OF RESEACH

In order to determine explosion risk areas, the manner of substance release as well as its type needs to be defined first of all. Liquefied natural gas (LNG) was considered. For the purpose of reproducing real conditions, two LNG types were analysed – light and heavy LNG (Sedlaczek, 2008). Both of these LNG types are delivered to the transhipment and regasification terminal in Świnoujście (Poland). The chemical composition of both the LNG types is presented in table 1.

Table 1
LNG parameters

Component	LNG-Light [%mole]	LNG-Heavy [%mole]
Methane	95.40	87.00
Ethane	3.20	8.37
Propane	0.00	3.00
Butane	0.00	1.20
Pentane	0.00	0.23
Nitrogen	1.40	0.20

Source: (http://www.polskieLNG.pl, 2018)

Additionally, a simulation for pure methane was carried out. One type of depressurization incident was examined involving a sudden explosion, the so-called 'catastrophic rupture'. It is a fairly specific way of substance release, owing both to its range and the depressurization process itself. This is the most dangerous scenario, aiming to model a situation in which a fuel tank is damaged and the entire substance accumulated in it is rapidly and instantaneously released in all directions without any limitations. Such an approach renders LNG being treated as a uniform mass which spreads at huge speed. In the analysed case it was assumed that for this scenario the entire capacity of a Q-flex type vessel is instantaneously released. Although ships of that type feature four or five separate tanks, but in the event of a sudden explosion the most dangerous scenario can be adopted in which subsequent tanks explode virtually at the same moment, on account of a huge amount of energy released from the first tank. Therefore, 98.5% of a Q-flex loading capacity was assumed as the amount of the released substance. The remaining part of unused space is allotted to any possible gas created from liquid LNG. The initial temperature of the LNG in the tank was assumed to be -163 °C. The analysis was conducted for D Pasquill stability. Water was assumed to be the surface area over which LPG is released. Hence, relative air humidity amounts to 0.9. Water temperature as well as air temperature at the height of 10 m above water surface were set at the level of 9.85 °C. Solar radiation flux is equal to 500 W/m². Calculations were carried out for variable surface roughness, since along with a change in wind speed, water conditions are subject to change as well. These two parameters were permanently tied to the Beaufort scale, which combines sea surface conditions with wind speed. A compilation of the analysed wind speeds and the corresponding wave heights are presented in table 2.

Table 2
Wind speed and the assigned wave height

Wind speed [m/s]	Description of wind conditions	Wave height [m]	Description of water conditions	Beaufort scale
3.0	Light breeze	0.2	Small wavelets	2
5.0	Gentle breeze	0.6	Large wavelets, crests have a glassy appearance	3
10	Fresh breeze	2.0	Moderate waves, many white horses are formed	5
15	High wind	4.0	Sea heaps up, streaks of foam are formed	7

Unfortunately, it is impossible to consider danger zone ranges for permanent surface roughness properties, since when wind changes its parameters over water surface, it immediately causes a change in wave height – that problem does not occur when similar wind changes are analysed for land conditions. The analysed wind speed ranges started with 3 m/s, and ended with 15 m/s. The maximum wind speed value is never reached in practice for the examined region, which is why no higher values were taken into account. The adopted wind speed values are dictated by the choice of Pasquill stability scale. For the selected D value there is no limit of a maximum wind value, while wind speed equal to 5 m/s is adopted as a minimum value for daytime conditions and 3 m/s for night-time conditions. Thus, the value of 3 m/s does not exceed the Pasquill stability scale, and at the same time it is close to the average wind speed value registered in the examined area, which is why the value was included in the analysis.

RESULTS AND DISCUSSION

All the calculations were carried out for the upper and the lower explosion limit, thus all the calculations were preceded by the determination of these two parameters. For both mixtures as well as for pure methane the UFL, LFL, LFL-fraction values are presented in table 3.

Table 3
Upper and lower explosion limit values

Explosion limit	Concentration [ppm]		
	LNG heavy	LNG heavy	LNG heavy
Upper flammability limit (UFL)	156386	165893	165000
Lower flammability limit (LFL)	39784	43888	44000
LFL-fraction	19892	21944	22000

The data obtained in the simulation with the use of DNV-Phast version 7.11 of the software are presented in the tables below (table 4 – table 6).

Table 4
Range values in the function of wind speed for pure methane

Concentration	Ranges for wind speeds [m]			
	3 m/s	5 m/s	10 m/s	15 m/s
UFL	2730	1850	1036	1006
LFL	3536	8122	4702	4534
LFL-fraction	11131	17285	7175	7692

Table 5
Range values in the function of wind speed for LNG-light

Concentration	Ranges for wind speeds [m]			
	3 m/s	5 m/s	10 m/s	15 m/s
UFL	3063	1834	1190	1277
LFL	3939	8842	5048	4719
LFL-fraction	9788	16097	8358	6730

For UFL level, along with a rise in the share of gases in greater heat of combustion, the rage of danger zones grow as well. The relationship is not as visible for LFL level and LFL-fraction. The obtained ranges for both above-mentioned levels are virtually constant for a set wind speed and variable methane content.

Table 6
Range values in the function of wind speed for LNG-heavy

Concentration	Ranges for wind speeds [m]			
	3 m/s	5 m/s	10 m/s	15 m/s
UFL	4029	4011	1565	1522
LFL	5357	6475	5132	5056
LFL-fraction	10550	15158	7982	7598

For UFL level, with a constant methane share and variable wind speed, a decrease of danger zone radius is observed, which suggests a large participation of surface roughness coefficient. However, for LFL and LFL-fraction, ranges change in a nonlinear fashion in a function of wind speed, and thereby in a function of surface roughness coefficient. It can be observed that the share of these two parameters is not constant, which complicates the analysis.

CONCLUSION

In order for a gas fuel to explode, three elements are required: fuel, oxidizer, and ignition-initiating factor. Yet, the very presence of fuel and oxidizer is not sufficient – they still need to occur in the right proportions. The share of individual ingredients is defined by concentration flammability limit. If the fuel amount in a mixture is low, the amount of heat that will be emitted during ignition is insufficient to heat the adjacent fuel portion – in that case we deal with lower flammability limit. A similar situation occurs in the event of too low amount of oxidizer – that amount is defined by the upper flammability limit. For the substances analysed it becomes evident that along with a rise in average molar mass, the ranges of danger zones grow for the concentrations corresponding to upper flammability level. In the case of ranges of danger zones determined for UFL, the energy carried by wind affects the afore-mentioned ranges to the least degree, since during an explosion the substance has huge energy, in which the share of wind energy is scant. In the case of analysed mixture, methane concentration was changing. It was decreasing for the benefit of other hydrocarbons, such as ethane, propane, butane or pentane. These substances have lower concentration flammability limit, i.e. in the air for ethane the limit ranges from 3.0 to 12.4% of gas in the air, for propane from 2.1 to 9.5%, for n-butane the values oscillate between 1.8 and 8.4%, and for n-pentane the values range between 1.4 and 7.8%. What is more, for each of the above-mentioned hydrocarbons along with the increase of molar mass, the heat of combustions rises as well, that affects the value of the energy that a substance possesses in the event of an explosion. This translates into an increase in the range of a danger zone.

When determining the ranges of danger zones for low concentrations, when energy has been largely dispersed, the significance of molar mass of the spreading gas rises. For low concentrations the energy related to explosion no longer has such great importance. In the case of permanent wind speed maintained, the greater the molar mass, the smaller the range

of danger zone for the LFL-fraction level. It is not a directly proportional relationship, though. It suggests that surface roughness and wind speed need to be considered still. Surface roughness is highly significant in determining the zone of an explosive substance range, since it is typically the surface roughness that causes a decrease of the range zone despite the growth in wind speed. It is an evident example of the fact that surface roughness plays an important role in the analysed scope of concentrations. However, the trend does not always persist. For selected wind speeds, and thereby for selected surface roughness values, wind speed, whose rise results in range zone growth, prevails. It means that one cannot a priori assume the dominance of one factor over the other. All the interactions are of mutual nature, thus typically all possible interactions ought to be cross-considered. Although it complicates the analysed situation, it contributes to a more precise determination of a danger zone.

REFEENCES

Atkinson, G., Cowpe, E., Halliday, J. and Painter, D. (2017). A review of very large vapour cloud explosions: Cloud formation and explosion severity. Journal of Loss Prevention in the Process Industries, 48, pp. 367-375.

Basu, R. and Verma M. (2017). An expected consequence approach to assessing the viability of multimodal transportation of crude oil in eastern Canada. Case Studies on Transport Policy, 5(3), pp. 518-526.

Bubbico, R., Cave, S. and Mazzarotta, B. (2009). Preliminary risk analysis for LNG tankers approaching a maritime terminal. Journal of Loss Prevention in the Process Industries, 22(5), pp. 634-638.

Farfan, J. and Breyer, C. (2017). Structural changes of global power generation capacity towards sustainability and the risk of stranded investments supported by a sustainability indicator. Journal of Cleaner Production, 141, pp. 370-384.

Krata, P. and Szlapczynska, J. (2017). Ship weather routing optimization with dynamic constraints based on reliable synchronous roll prediction. Ocean Engineering, 150, pp. 124-137.

Landucci, G., Antonini, A., Tugnoli, A., Bonvicini, S., Molag, M. and Cozanni, V. (2017). HazMat transportation risk assessment: A revisitation in the perspective of the Viareggio LPG accident. Journal of Loss Prevention in the Process Industries, 49(A), pp. 36-46.

Liu, X., Li, J. andi Li, X. (2017). Study of dynamic risk management system for flammable and explosive dangerous chemicals storage area. Journal of Loss Prevention in the Process Industries, 49 (B), pp. 983-988.

Mabrouk, A., Boulmakoul, A., Karim, L. and Lbath, A. (2017). Safest and shortest itineraries for transporting hazardous materials using split points of Voronoï spatial diagrams based on spatial modeling of vulnerable zones. Procedia Computer Science, 109, pp. 156-163.

PolskieLNG.pl, (2018). Polskie LNG Official Website. [online] Available at: http://www.polskieLNG.pl

Sedlaczek, R., (2008). Boil-Off in Large and Small Scale LNG Chains, Diploma Thesis, Faculty of Engineering Science and Technology, Department of Petroleum Engineering and Applied Geophysics.   Available   at: http://webcache.googleusercontent.com/search?q=cache:IXeBpJEYMswJ:citeseerx.ist.psu.edu/ viewdoc/download%3Fdoi%3D10.1.1.470.6116%26rep%3Drep1%26type%3Dpdf+&cd=1&hl=pl &ct=clnk&gl=pl&client=firefox-b-ab [Accessed 22 Jan. 2018].

Ślączka, W. (2011). Estimation of the consequences of LNG vessel tank leakage in the port of Świnoujście. Scientific Journals Maritime University of Szczecin, 25(97), pp. 70–76.