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Assessment of industrial safety at oil refining facilities based on stochastic modeling

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Abstract. The article deals with the estimation of negative influence (impact), provided by dangerous factors, appearing during fire hazardous situation. It is clear, that both thermal stream and inner overpressure mutually can lead to the machine depressurization and destruction, which can cause cascading troubles, making situation more hurtful, than it was. The application of mathematic model is suggested in order to estimate the probability of equipment backstop integrity, which guarantees the evaluation of prevention possibility of the Domino effect.
Keywords: process equipment; emergency situation; normal distribution; standard deviation; expected value; cascade accident progression

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Introduction

The problem of oil and gas facilities and pipelines ensuring safe operation as a part of technological basements on oil and gas production is claimed to be extremely acute and actual [1,2]. Scientific and technical researches, negotiated nowadays, are directed on quality increasing of production sphere technical regulation in area of resource security and reliability, also they are claimed to guarantee regular requirements of production equipment, infrastructure, personal and population safety [3].

An achievement of required safety level and accident consequences minimization on hydrocarbon feedstock facilities obligates further development and improvement of methodical justification for the activities, referred to trouble-free exploitation of oil and gas equipment and pipelines [4,5].

A significant constructive variety of equipment used at technological installations for oil and gas processing, large-scale industrial technologies, a wide range of fire hazard properties of initial hydrocarbon raw materials, intermediate components and commercial oil products are all the reason of an extremely high level of potential hazard, which is generating during the operation of oil and gas production facilities [6]. A priori there is a constant potential hazard, which is able to cause negative cases, like technical failures, accidents and breakdowns, which are the result of capacitive equipment, unit or process pipelines depressurization. In addition to that, there is a high possibility level for further local accidents to grow up to the catastrophic measures involving fires, explosions, leading to considerable material losses, ecological harm, and injuries among the personal, also leading to the fatal outcome [7,8]. In this chain of negative events, the most unfavorable is a case in which hazardous factors, arising during the accident, will initiate further damage or destruction and

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depressurization of process equipment, which undoubtedly leads to an increase in the amount of combustible substances involved in the emergencies formation. Mentioned above way is classified as progressive destruction, appearing as a specific Domino Effect, which means: unfavorable scenarios for the accident to grow up, in which (in case of defense system imperfection and (or) personal incorrect actions) it is possible for the accident harmful factors to overcome emergency unit, equipment item or facility boundaries, and hazardous substance involvement in the nearby none-emergency facilities, growing up to the further accident development stage [9,10].

Foreign specialists found out [11,12], that the biggest number of cascading accidents (55-80 %) occurs while preserving automobile and aviation motor fuels, volatile solvents, mixtures of hydrocarbon gases in various states of aggregation, moreover, increase in storage tonnage and production platform area decrease incredibly enhancing possible negative effects.

Methods

Despite the considerable successes in overall accidents rate reducing at hazardous oil and gas productions facilities [13], the relevance of development of some new methods for oil and gas equipment and pipelines danger estimation still remains. These methods are based on realization possibility of accident cascade development estimation in order to improve the efficiency of technosphere and fire risks management systems, as well as to support management decisions. At the same time, the researchers attempts are focused on the development of universal models for a comprehensive assessment of the level of risks of various natures in the conditions of oil and gas production in the presence of a local source of danger and the resulting hazardous factors [14,15].

Ipso facto, cascade growing of an accident forecasting means to be rather difficult trouble [16,17], as it is being affected by many factors, which cannot be easily formulated, such as technological process consummation degree, engineering quality, amount of technological machinery, qualification level of the personal, weather conditions and so on. Meanwhile, it is the obvious hypothesis, that the main option, which can prevent an accident progressive character, is to secure machinery and pipelines integrity, which can be conditionally defined like:

$$N \leq G, \quad (1)$$

where N – whole amount of negative factors (internal – overpressure and temperature of the facilities process environment, external – appearing as a result of an accident or fire – pressure wave impulse, heat radiation, etc.), G – the material equipment ability to perceive external and internal negative factors (strength, bearing capacity, etc.).

Results and Discussion

In order to preliminary estimate the level of the process environment negative impact and hazardous factors on the equipment technical condition, using as an example a typical thermal cracking separator under the condition of a hypothetical fire, calculations were realized according to the methodology [18]. All calculation results are presented in Table 1.

Table 1. The mechanical stresses when a heat flow is affecting to the walls of the machinery calculating result

Technical condition characteristics	Temperature, °C				
	50	60	70	80	90
Mechanical tension as a result of internal pressure, MPa	123.7	127.5	131.4	135.2	139.1
Mechanical tension as a result of heat radiation, MPa	0	25.2	50.4	75.6	100.8
Total tension, MPa	123.7	152.7	181.8	210.8	239.9
Allowed tension, MPa	188.9	186.5	184.1	181.7	179.3

Initial data: process environment – gasoline fraction, machine diameter – 1.5 m, wall thickness – 12 mm, operating pressure – 1.8 MPa, operating temperature – 50 °C, wall material – steel 09G2S, allowed stresses at design temperature 188.9 MPa.

The results, which are given there in the table, indicate that the wall temperature rising above 60 °C leads to efficiency interruption and also leads to the origin of depressurization risk, respectively increases the amount of combustible substance, involved in fires with possible cascade growing of the hazardous situation. The results graphic interpretation of the calculations is shown in the Fig. 1.

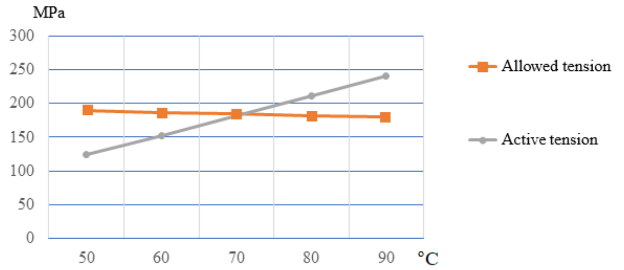

Fig. 1. The comparison of active and allowed tension inside the facilities walls during the fire

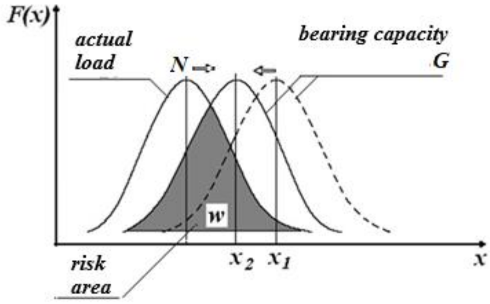

Fig. 2. Estimation of impermeability condition of technological condition principle graphic illustration: w – accident risk area, x_1 – primary moment of time, x_2 – calculated moment of time

The fire hazardous situation analysis was fulfilled in quasi-stationary conditions, without taking into the consideration the thermal stream dynamic character effect on the facilities, without thermal insulation, without consideration of the thermophysical features of the process environment, without consideration of the wall material. Such deterministic setting makes the final solution for the dangerous situation growth forecasting rather labor-consuming and less perspective [19,20].

In order to estimate the cascade growing of fire-danger realization probability on the oil refining facilities, an algorithm based on stochastic modeling was developed.

Wherein, some simplifications and assumptions were accepted, and one of them is a possibility for these appearances to be described by the random number apparatus. The values, given in the inequality (1), whether the information is lacking, or it is unreliable, can be described due to classical laws of distribution, if we know the expected value and standard deviation.

According to the position, given in the study [21], an application of the function distribution law of random argument, we have:

$$f(N)=\frac{1}{\sqrt{2\pi}S_N}\exp\left[-\frac{(N-M_N)^2}{2S_N^2}\right], \tag{2}$$

$$f(G)=\frac{1}{\sqrt{2\pi}S_G}\exp\left[-\frac{(G-M_G)^2}{2S_G^2}\right], \tag{3}$$

where $f(N)$, $f(G)$ – distribution functions for the cumulatively acting technological effects (burden) and load bearing capacity (mechanical strength) equipment wall material, M_N, M_G – expected values for the cumulatively acting technological effects (burden) and load bearing capacity (mechanical strength) equipment wall material, S_N, S_G – standard deviations for the cumulatively acting technological effects (burden) N and load bearing capacity (mechanical strength) equipment wall material G.

The difference $G-N$ also will be allocated according to the normal law $g(G-N)$ with expected value M_g with dispersion D_g:

$$M_g = M_G - M_N, \tag{4}$$

$D_g = D_N + D_G,$ (5)

$S_g = \sqrt{D_g},$ (6)

where g – sought for random value distribution function $(G – N)$, M_g, D_g, S_g – meanings expected value, dispersion and standard deviation of the difference $(G – N)$, D_N, D_G – dispersions for the cumulatively acting technological effects and load bearing capacity.

The process facilities and pipelines impermeability can be estimated in case we have distribution parameters g(G – N), due to calculated probability value:

$$P(0 < R - Q < \infty) = \int_0^\infty g(R - Q)d(R - Q) = \Phi\left(\frac{M_g}{S_g}\right), \quad (7)$$

where $\Phi\left(\frac{M_g}{S_g}\right)$ – a tabulated normal distribution function.

Impermeability will be provided whether during an accident the probability value, calculated according to the Eq. (7), is close to one.

Respectively, depressurization risks H apparatus can be estimated due to:

$H = 1 - P,$ (8)

where P – depressurization maintenance probability in case of fire-danger situation.

In the algorithm for the technical state estimation of the equipment mutually competing processes are considered: on the one hand technical loads increasing intensity, on the other hand – damage growing amount and durability decrease with rising temperature from equipment walls and technological environment. These counter-directed processes are graphically given in the Fig. 2.

Apparatus technical condition will be characterized by some value between ($X_1 – X_2$), which can be matched with operability reserve value, also increasing area where both distribution functions f(N) and f(G) cross, allows us to estimate possible depressurization probability or technological apparatus total distraction in case of ($X_1 – X_2$) = 0, which physically means equality between acting loads and durability of the material.

Conclusion

Thus, basing on the negative impact analysis of the harmful factors, that can lead to the temperature increase up to the 20 °C and higher, the loss of material durability occurs as a result of thermal stream action, which in the fullness of time combined with internal overpressure, supposed to lead to the facilities depressurization or distraction.

It is proposed to estimate the probability of the accident cascade growth for the oil and gas process equipment based on model, which is formulated by the estimation of vessel depressurization probability, which works under the pressure.

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