Risk assessment of storage tanks in the oil and gas industry

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Abstract. Accidents at oil and gas facilities are among the main causes of environmental pollution and loss of life. In the interests of solving the problem of ensuring the safety of oil and gas facilities, a review of the state of oil and gas facilities in the republic of Yemen was carried out, statistical data on accidents were analyzed, Defined the events that cause a fire in hazardous situations and build scenarios for the occurrence and development of fires through the study of an accident in the Aden refinery, also assessment of the mass of flammable substances entering the surrounding space as a result of fire hazardous situations, construction of fields of hazardous factors of fire for various scenarios of its development, assessment of the consequences of exposure to hazardous fire factors on people, and a base was developed for risk assessment and management.

1 Introduction

The oil and gas industry in the Republic of Yemen has been of strategic importance since its opening in the mideighties of the last century until today, as a result of its contribution to the domestic product and the general budget of the republic [1]. A large fraction of economy and hence huge number of jobs depend on them, both directly and indirectly. Therefore, any disruption is likely to cause a lot of damage, and economic and environmental impacts.

The security risks in the oil and gas industry facilities are real and must be assessed to determine whether the

Security measures employed are adequate or need enhancement.

The purpose of this study was to assess the risks in oil and gas storage tanks and to study the distance that must be maintained between oil and gas facilities and other buildings (schools, roads, hospitals, etc.)

2 Overview of the state of oil and gas facilities

The oil and gas sector in the Republic of Yemen has enjoyed strategic importance since its inauguration and therefore, many facilities have been designed and built to preserve oil and gas products and transport them from one place to another [1].

In this article, have reviewed some information about the most important oil and gas facilities in the republic of Yemen.

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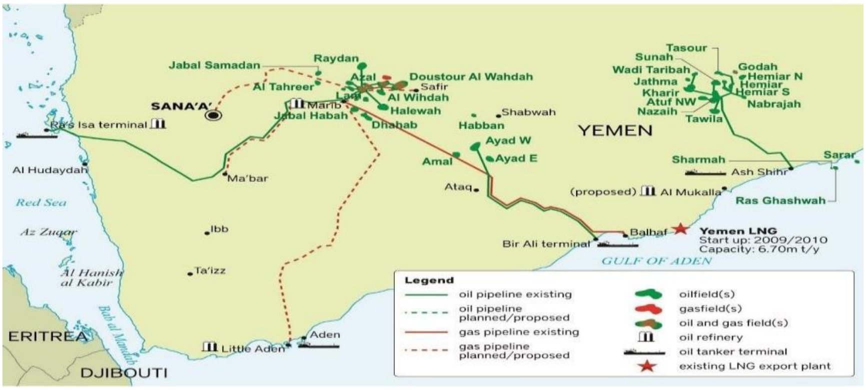

Fig. 1. Oil and gas facilities in the Republic of Yemen.

A) Refineries

There are 4 refineries in the republic of Yemen, where currently only the Aden refinery and the Marib refinery are operating, while the refineries in Ras Isa and AL-Shahr do not work [2],[3].

1. The Aden refinery [4]- is the largest industrial enterprise in the country and one of the oldest refineries in the republic of Yemen, built by British petroleum company in 1954. The capacity of the Aden refinery is about 5 million tons of oil per year. In 1977, it became state property, although the refinery is 66 years old, it still operates with good efficiency, thanks to its constant maintenance, it processes about 170 thousand barrels per day.
2. The Marib refinery is one of the most important oil production facilities in Yemen, built by the American Oil Company, Hent in 1986. The capacity of the Marib Refinery is about 10 thousand barrels per day. After the end of the working contract signed with the Hand company, it became the property of Yemen in December 1995[4].

According to the Statistical Survey of World Energy, the proven gas reserves in the Republic of Yemen are 490 billion cubic meters, or about 0.3 percent of the global volume. Most of the gas is located in the Marib-Al-Jouf fields, it is mainly pumped to increase oil production.

The Yemeni LNG export plant in Balhaf opened in 2009 and is led by the French oil company Total, which is the largest industrial project in the Republic of Yemen, is based on the proven industry standard C3 / MR APCI and consists of two parallel processing lines with a total guaranteed production with a capacity of 6.7 million metric tons per year. In addition, two storage tanks with a volume of 140,000 m ^ 3 are in operation, as well as ancillary facilities such as power generation, desalination, wastewater treatment and steam generation. This allows the plant to operate efficiently, reliably and environmentally in accordance with applicable international standards.

B) Oil and gas pipelines

The republic of Yemen has an 872-mile oil pipeline network that links three major oil provinces with five export terminals: Aden, Ras Isa, Hodeidah, Bir Ali and Al-Shahr.

In 1985 designed and built the first 270 miles pipeline from the Marib Basin to Ras Isa, the largest export terminal in the Red Sea, with a capacity of 400,000 barrels per day. The Ras Isa terminal is operated by Safer and has a storage capacity of 3 million barrels [5].

The Republic of Yemen has 3 main lines to transport crude oil from production areas to seaports in both the Red Sea and the Arab Sea, and therefore there are three ports for exporting crude oil to the international market:

1) The port of Ras Isa is located on the Red Sea in Al Hodeidah governorate as an island for a tank farm for the loading and unloading of crude oil vessels for export.

2) The port of Al-Shahr (Daba) - located on the shores of the Arab Sea in the Hadhramaut governorate, which has the right to load and dispatch ships with crude oil.
3) Port of Balhaf (Bir Ali) - located on the shores of the Arab Sea in Shabwa governorate, which has the authority to load and dispatch crude oil vessels for export purposes from the West Ayad sector of limited use, due to limited production in this sector and the possibility of connecting to neighboring fields. This port has five tanks, each with a capacity of 126,000 barrels. The port was established in 1990.

The pipelines have been the target of repeated attacks that have reduced the flow of oil production and export.

According to the Ministry of Oil and Mineral Resources of the Republic of Yemen, more than 92 oil and gas facilities such as (refineries, oil and gas pipelines, ports, oil and gas export terminals, gas stations) stopped work in the period from 2011 to 2020 due to many problems that arose on them, therefore, statistical analysis was carried out data on accidents.

3 Analysis of the accident rate of oil and gas facilities

The collection and analysis of accident data is widely recognized by the hydrocarbon industry as an essential element in an effective safety management system. Therefore, we collected and analyzed data for accidents that occurred in the last ten years in oil and gas facilities in the Republic of Yemen. Depending on open data of civil defense department, also Google data for employees of oil and gas companies.

It is known that every year in the world at oil refining facilities there are up to 1,500 accidents, 4% of which are accompanied by massive loss of life. The annual material damage from these accidents exceeds $ 100 million. The accident rate of enterprises is constantly growing [6].

The main emergency scenarios that pose a danger to the enterprise and the adjacent territory are a strait fire, an explosion of fuel assemblies and an emergency gas contamination. So, for the period from 2011 to 2020, 329 hazardous incidents occurred, including 171 fires (51.98% of the total number of emergencies), 142 explosions (43.16%), 16 emissions of hazardous substances (4.86%). Based on the analysis of the causes of dangerous events that occurred, it can be concluded that in most cases, the factor of accidents is the human factor (terrorist, violation of safety rules, technological process), technical failures (lack of periodic inspection and neglect in the process of maintenance), lack of equipment and off-design external influences [7],[8],[9].

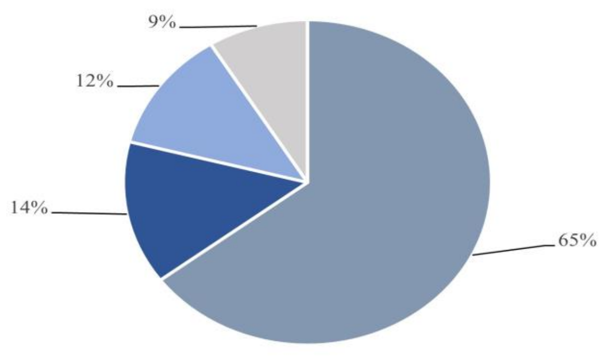

Fig. 2. Analysis of the causes of accidents at oil and gas facilities in the Republic of Yemen.

Analysis of the results of investigating the causes of accidents at oil and gas enterprises of the Republic of Yemen over the past 10 years (2011-2020) shows that the unsatisfactory state of the security services is their main cause, and a considerable part of accidents on oil and gas pipelines occurs due to the lack of necessary protection, lack of equipment and off-design external influences [2],[9].

4 The case of study

Fire accident at the Aden refinery.

One of the most recent accidents happened on January 11, 2019. There was a huge fire after an explosion inside a refinery in Aden (Figure 3) [10]. Sources confirmed that the explosion occurred in one of the transport pipes, after which the fire spread to tank number 313 and to neighboring tanks, as a result more than 15 workers and firefighters were injured [11].

According to a local security source, the cause of the accident is unknown. Union sources at the Aden refineries pointed out that the fire caused the structure of the tank to fall, which was split in two by iron erosion, and that all tanks were at risk even before the fire as a result of negligence.

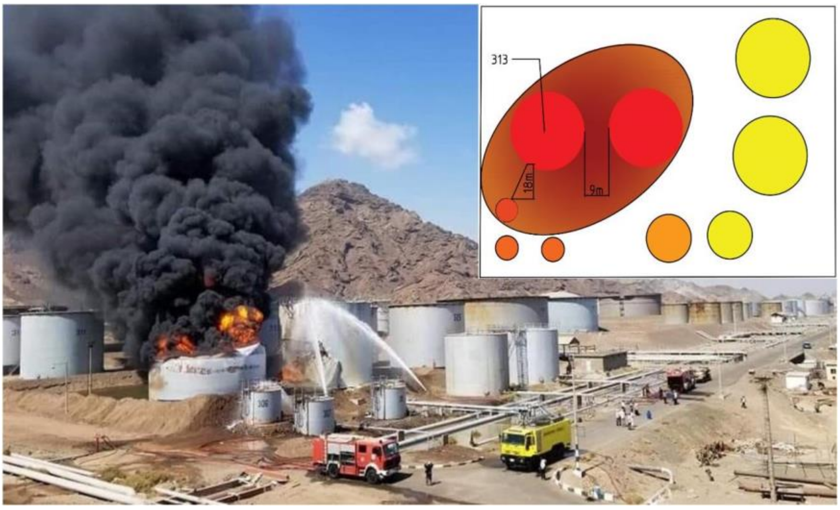

Fig. 3. Fire in refinery.

According to the methodology [12],[13] for determining the calculated values of fire risk, at production facilities, when analyzing the fire risks of objects of the fuel and energy industry with the circulation of flammable gases and liquids, as a rule, initiating events are considered, characterized by depressurization and complete quasi-instantaneous destruction of each unit of technological equipment. In addition, when considering a scenario for the development of a fire hazardous situation, it is necessary to consider all the options for other factors, for example, the strength and direction of the wind, liquid temperature, gas pressure, and others. Thus, for a production facility, even with a relatively small number of units of technological equipment, the number of scenarios for the development of fires and explosions, the hazardous factors of which must be assessed, can be about a thousand, which is practically impossible without the use of appropriate software [14], [15].

In the beginning, the events initiating fire hazardous situations are identified and scenarios of the occurrence and development of fires are built.

To construct a set of scenarios for the occurrence and development of fire hazardous situations at the object under consideration, the method of logical event trees was used. The construction of logical trees of events underlying the assessment of fire risk for the object under consideration was carried out based on the event being considered as initiating fire hazardous situations and fires at the refinery:

- depressurization of tanks with the formation of a spill in the embankment,
- complete destruction of tanks with the formation of a spill in the embankment and overflow of a part of the liquid beyond the embankment. Figure 4 shows the frequency of occurrence of events initiating fire hazard situations for the equipment of the Aden refinery, taken in accordance with the methodology for determining the calculated values of fire risk at production facilities (Scenario tree) [16],[17].

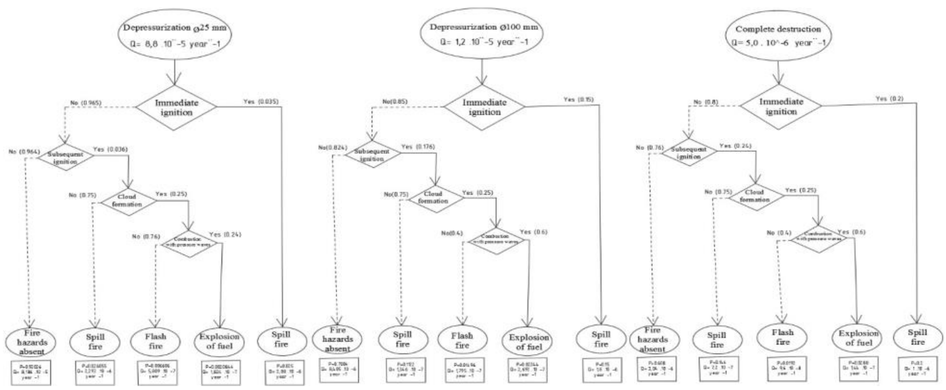

Fig. 4. Scenario tree.

By studying site fire scenarios by using the software "PromRisk" [15], we can know the limits of the largest scenarios that can occur and with which we can design the site boundaries and provide some information for workers on site and in the surrounding areas.

Assessment of the mass of flammable substances entering the surrounding space as a result of fire hazardous situations.

The amount of combustible substances that enter the surrounding space, which can form explosive gas-vapor-air mixtures or spills of combustible liquefied gases, flammable and combustible liquids on the underlying surface, is determined based on the following assumptions:

a) a calculated accident occurs in one of the tanks;

b) the entire contents of the tank or part of the product enters the surrounding space. In this case, if there are several tanks at the facility, the calculation should be carried out for each tank.

The mass of the liquid entering the surrounding space during the depressurization of the tank is determined by the formula:

$$m_l = V_l \cdot \rho_l, \tag{1}$$

where, m_l- mass of the liquid, kg; ρ_l- fluid density, kg/ m³; V_l- liquid volume in tank, m³.
The mass of the liquid received by gravity during the complete destruction of the ground liquid leaving the reservoir is determined by the formulas:

$$m_l = G_L \cdot \tau + \pi {d_l}^2/4 \cdot (\textstyle\sum_{i=1}^{n} L_I) \cdot \rho_l \tag{2}$$

$$Q_l = \mu \cdot d^2/4 \cdot \sqrt{2gH_l} \tag{3}$$

where, m_l- mass of the liquid, kg; ρ_l- fluid density, kg/ m³; G_l – initial flow rate of liquid flowing out of the reservoir through a depressurized pipeline, kg/s; τ – estimated shutdown time of pipelines associated with depressurization, s; Q_l – volumetric flow rate of liquid outflow; d_l – diameter of pipelines, m (in the case of different diameters of pipelines associated with the place of depressurization, the volume of outgoing fluid is calculated for each pipeline separately); L_I - length of the i-th section of the pipeline from the locking device to the place of depressurization, m; n – the number of pipeline sections associated with the depressurization site; H_l – height of the liquid column (from the upper liquid level in the tank to the level of the depressurization point), m; μ – coefficient expiration; g – acceleration of gravity, m/ s² (g= 9,81).

Table 1. To format a table caption, use the Microsoft.

Equipment identification		**(Tank 313) 5000 м³ oil**	**(Tank 306) 100 м³ oil**
Depressurization ∅25 mm.	Area of emergency oil spill, m²	424,4	268,4
	Mass of liquid spilled, kg	15809,6	9998,9
	Mass of formed vapors, kg	481	304,2
Depressurization ∅100 mm.	Area of emergency oil spill, m²	6790,7	2000
	Mass of liquid spilled, kg	252954,2	74500
	Mass of formed vapors, kg	7695,2	2266,4
Complete destruction	Area of emergency oil spill, m²	65027,8	11907,8
	Mass of liquid spilled, kg	3725000	74500
	Mass of formed vapors, kg	73694,7	13494,9

In figure 5 show the areas when a mass of oil is ejected from tank 313 and tank 306 with a) depressurization ∅25 mm, b) depressurization ∅100 mm, c) Complete destruction, entering the surrounding space as a result of fire hazardous situations.

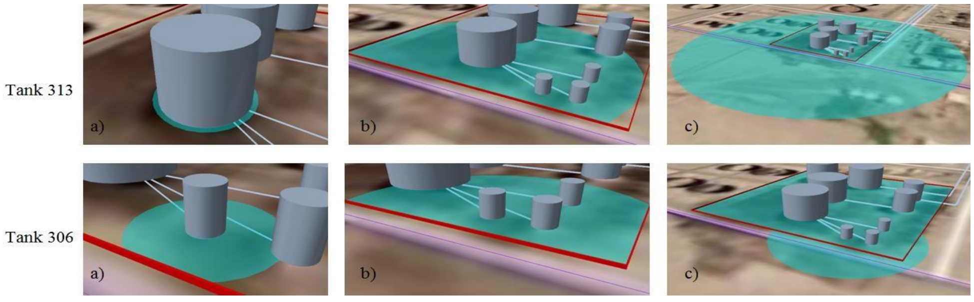

Fig. 5. Tank 313 and 306 with a) depressurization ∅25 mm, b) depressurization ∅100 mm, c) Complete destruction.

To localize the fuel spill in case of an accident and also to reduce spill area recommend erecting a monolithic reinforced concrete wall (embankment) around the park of tanks so that the technical parameters for the embankment device must correspond based on the volume of the tanks at the building rating.

Construction of fields of hazardous factors of fire for various scenarios of its development, when constructing fields of hazardous factors of fire for various scenarios of its development, the following are considered:
1) thermal radiation during torch burning, fires of spills of combustible substances on the surface and fireballs;
2) overpressure and a pressure wave pulse during combustion of a gas-vapor-air mixture in open space;
3) overpressure and a pressure wave impulse upon rupture of the reservoir as a result of exposure to the fire center; 4) fragments formed during the explosive destruction of technological equipment elements; 5) expanding combustion products during the implementation of a fire-flash ect.

Heat flux (aka radiant heat exchange, intensity or density of heat flux, thermal radiation) is a part of thermal energy transmitted through some arbitrary area per unit of time. Thermal radiation is a type of energy transfer [18].

The thermal radiation of the flame depends on many factors – the diameter of the combustion zone, the temperature and thickness of the flame, the concentration of soot, various chemical components of combustion products, etc[19]. The intensity of thermal radiation q, Kw / m², for a liquid spill fire is calculated by the formula:

$$q = Ef \cdot Fq \cdot \tau \tag{4}$$

where E_f– average surface intensity of the thermal radiation of the flame, Kw / m²;
F_q – a geometric view factor that defines the fraction of energy radiated by the fire that is intercepted by the receiving object (angular irradiance factor);
τ – atmospheric transmissivity to thermal radiation.

The angular irradiance factor F_q is determined by the formula:

$$F_q = \sqrt{F_V^2 + F_H^2} \tag{5}$$

where F_V, F_H – irradiation factors for vertical and horizontal.

In figure 6 a) show the values of the heat flux density at various distances from the edge of the fire area. B) The graph shows the dependences of the heat flux on the distance from the edge of the fire for all specified wind strength options. C) The graph shows the overpressure of the explosion and the momentum of the compression phase at various distances from the center of the cloud. D) explosion overpressure field in tank 313.

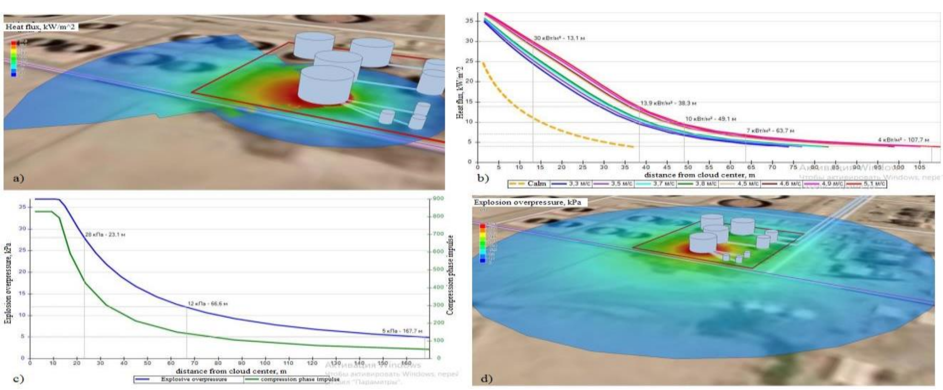

Fig. 6. Tank 313 a) show the values of the heat flux density at various distances from the edge of the fire area. B) The graph shows the dependences of the heat flux on the distance from the edge of the fire for all specified wind strength options. C) The graph shows the overpressure of the explosion and the momentum of the compression phase at various distances from the center of the cloud.

Also, to calculate the conditional probability of human injury by thermal radiation at a point located at a distance from the edge of the fire area using formula:

$$Q_d = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Pr-5} exp\left(-\frac{U^2}{2}\right) \cdot dU \tag{6}$$

where Pr - values probity-Functions.

Necessary to know the distance of the point to the zone where the intensity of thermal radiation does not exceed a safe value (4 kW / m²).

In figure 7a illustrating the values of the conditional probabilities of human injury by thermal radiation at various distances from the edge of the fire area and in figure 7b graph shows the dependences of the conditional probability of injury to a person on the distance from the edge of the fire for all given options of wind strength.

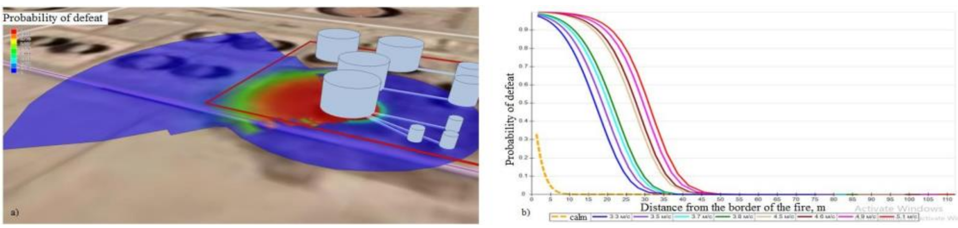

Fig. 7. a) values of the conditional probabilities of human injury by thermal radiation at various distances. b) graph the dependences of the conditional probability of injury to a person on the distance from the edge of the fire for all given options of wind strength.

The results show that the 313 tank and causes an area fire in storage tanks, thermal radiation intensity of area fire increases along with the development of combustion. The maximum radiation intensity in flame center is 43.1 kW/m2. The apparent radiation intensity is first decreased and then remains at 24.8 kW/m2 with combustion stability and atmospheric turbulence effect. The flame height is about 23 meters, the maximum smoke velocity is 5.1 m/s.

5 Conclusion

During the work, a review was carried out for oil and gas hazardous facilities in the Republic of Yemen. The analysis of accidents at oil and gas facilities over the past 10 years (2011-2020) in the Republic of Yemen was carried out.

The results of the investigation into the causes of accidents at oil and gas enterprises in the Republic of Yemen show that the unsatisfactory state of the security services is the main reason, and a large part of accidents at the refineries occurs due to the lack of necessary protection and periodic inspection, insufficient attention during maintenance, not calculated external influences.

As a result of the calculations, graphs of dependencies of hazardous fire factors were obtained (heat flux density for all directions and wind forces, excess explosion pressure and impulse of the compression phase from the distance to technological equipment, graphs of the probability of injury to people in all scenarios.

All this makes it possible to conduct a deep analysis of the fire hazard of the technological equipment used, as well as to develop measures aimed at reducing the fire hazard of the facility and ensuring the required level of fire safety for people - both employees of the enterprise and the population in the adjacent territory.

According to the damage / injure criteria, when thermal radiation intensity is 37.5 kW/m2, the equipment's and buildings could be damaged completely within the scope of 40.25 meters from designated target position to the center of pool fire, and all people dead within one minute [20]. Under the condition of simulation, thermal radiation intensity remains at 24.8 kW/m2 and the injury radius is 28.46 meters which could damage adjacent 5 tanks (306, 307, 315, 317, 318) and the pipelines between tanks on the storage tanks and even causes secondary fire explosion.

The accident in Aden refinery consequence is very serious. The results are of important for the study of fire development law and environmental impact assessment and safety design in storage tank area.

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