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DANGERS AND HAZARDS AT WORK IN AREAS JEOPARDISED BY AN EXPLOSIVE ATMOSPHERE

Knežević Nebojša[1],

[1]*Civil Engineering Institute "IG" Banja Luka, Bosnia and Herzegovina, e.mail.izg@blic.net*

SUMMARY

The term "explosive atmosphere" is frequently encountered in industry. Typically hazardous areas are found in chemical plants, refineries, paint and varnish workshops, plants for goods grinding, in the storages of combustible gas, liquids and solid substances. In such hazardous areas we must always pay attention to all normal but also abnormal work conditions that can trigger an explosive atmosphere to occur.

Areas at risk of an explosive atmosphere involve diverse hazards (fire risk, injury risk, natural disaster risk, explosion risk etc.). In view of this, it is important to define a level and limits of risk assessment that is conducted in a plant at risk of an explosive atmosphere.

Risk assessment in areas that are at risk of an explosive atmosphere must identify and analyse any hazard or a possible event that could cause an explosion. This paper has conducted a risk assessment at work positions and Ex areas at risk in in Brod Oil Refinery. Risk assessment was conducted in 2015.

Key words: *explosive atmosphere, explosion protection, causes of ignition.*

INTRODUCTION

An explosive atmosphere is considered a mixture of combustible substances with air in the form of gas, vapour or fog, in atmospheric conditions, in which fire spreads to the entire unconsumed mass after it has started. The area in which the explosive atmosphere is present or its presence can be expected in quantities that demand special measures with regard to technological and other procedures, method of the execution of electrical and mechanical installations etc. is called an area at risk. Mixtures of the above listed substances with air can be combustible or explosive [1], they are made of:

- combustible gases
- vapour and fog of combustible liquids
- combustible dust

Researches relating to the causes of ignitionwere conducted by several researchers [2,3,4,5], whoestablished that the most frequentcauses of ignition in areas at risk of an explosive atmosphere (hazardous zones) are combustible gases and vapour, as shown in figure 1.

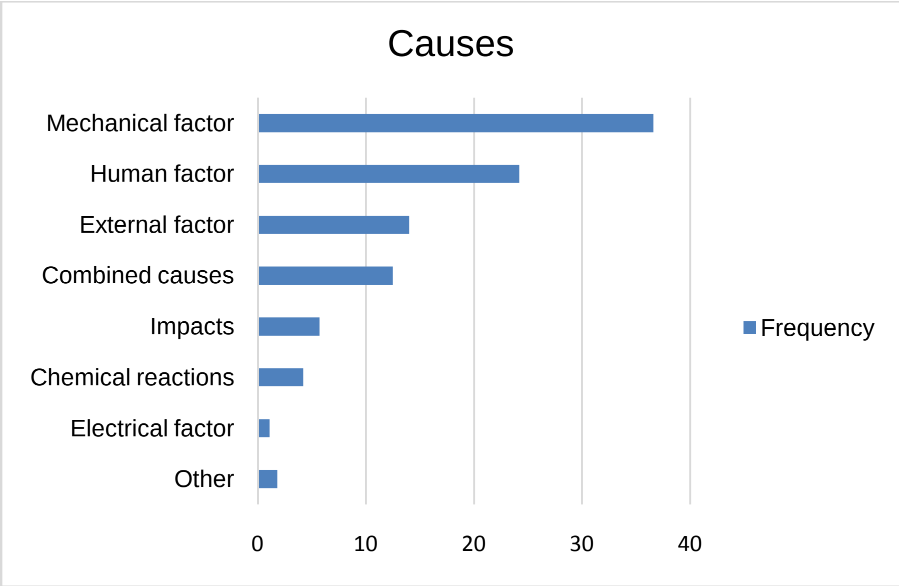

Figure 1 Causes of ignition in an explosive atmosphere

According to some authors, the causes of accidents occurring during the transport of hazardous substances with a very high percentage of accidents (12.369 accidents), as a result of MHIDAS (Major Hazard Incident Data Service) database analysis, are combustible substances leakage, fires, explosions etc. Period that was used in the research are individual decades spanning from 1930 to 2000.More than half of accidents occurred on road (63%), and the rest on railway (37%).The most frequent accidents are combustible substances leakage (78%), followed by fires (28%), explosions (14%) and generation of a cloud of combustible gas or vapour (6%), which is given in a graph in figure 2.

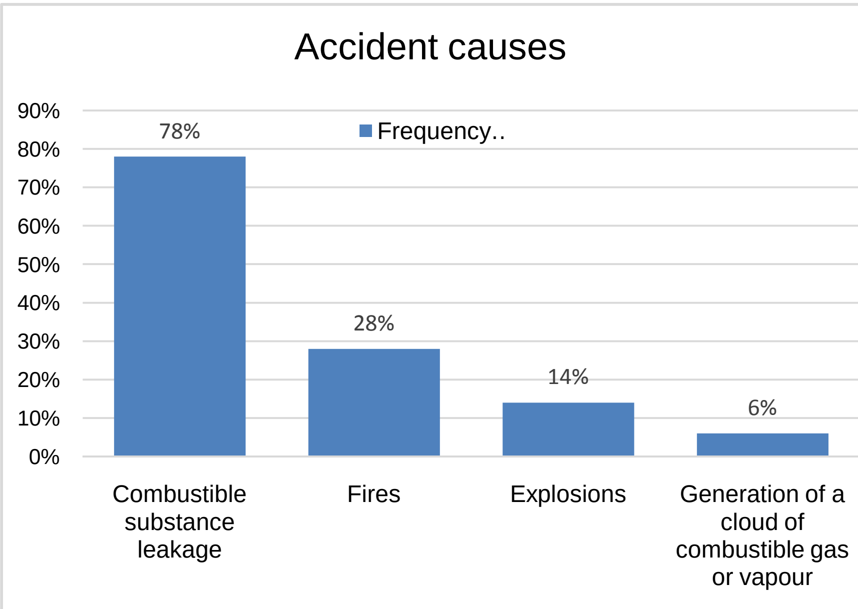

Figure 2 Causes of accidents occurring during the transport of hazardous substances

Technological process of crudeoil separation consists of extraction of individual components by heating the oil. This process is called fractional distillation. Acquired results are classified into five elementary groups (fractions): • kerosene (from 150 to 300 ºC), • gas oil (250 – 300 ºC), • 100 • lubricating oil (above 300 ºC), • paraffinoil (above 350 ºC). The rest of the crude oil after distillation is called "goudron".

Crude oil separation crude oil entails risk of fire in the entire process, however, some fractions are differ by their degree of fire sensitivity. These hazards are most intensive in the “lightest” fractions, and by further separation they gradually decline [7].

Elementary concept of classifying hazardous zones is based on diverse degree of probability that an explosive or combustible concentration of gas or vapour can occur; they are determined in the function of choosing explosion protection (Ex protection) for electrical apparatus in areas that are jeopardised by the presence of combustible vapours and gases.

So-called hazardous zones are formed in the hazardous areas in plants in which an explosive atmosphere of gases and vapours occurs, and dependent on the intensity of sources of hazard, frequency of their occurrence and duration, notably:

- hazardous zone 0 is an area in which an explosive atmosphere is present permanently or for a longer period of time
- hazardous zone 1 is an area in which it is probable that an explosive atmosphere will occur during the normal plant's operation
- hazardous zone 2 is an area in which it is not probable that an explosive atmosphere will occur during the normal plant's operation, and if it still occurs, it will only last for a short period of time

Jeopardy of an area depends on the possible gas or vapour concentration, which is expected in the area, as well as on the area ventilation conditions, ventilationhas no influence on the frequency of the sources of hazards, but it can have an impact on dissemination and duration of the sources of hazards.

Explosive atmospherecan occur if an uncontrolled leakage of combustible gas, combustible liquid or vapour occurs. When combustible substancesmix with air, an explosive atmosphere is formed. If the concentration of substances in the mixture is within the explosive limits (between the lower and upper limit) the presence of an active source of ignition can ignite the mixture and cause an explosion.

Lower explosive limit – is a minimalconcentration of combustible gas, liquid and vapour, which together with air can cause an explosion. Upperexplosive limit– is a maximal concentration of combustible gas, liquid and vapour, which together with air can cause an explosion.

Table 2 Tabular overview of explosive limits of some substances

Combustible substance	Lower explosive limit	Upper explosive limit
Natural gas	5%	13%
Diesel fuel	0.6%	6.5%
Gasoline	0.6%	8%
Propane	1.5%	9.5%
Acetylene	2.5%	81%

Table 3 Temperature of the ignition of some gases and vapours of liquids

Combustibleagent	Ignition temperature (°C)
Propane (gas)	450
Hydrogen (gas)	560
Acetylene (gas)	305
Gasoline and crude oil (vapours)	220 and higher
Butane (gas)	372

Crude oil processing is hazardous in its entire process; however, some fractions differ as regards the degree of fire sensitivity. These hazards are most intensive in the “lightest” fractions, and by further separation they gradually decline. This is logical since in combustible liquids it is their vapours that burn. The easier these vapoursare released, or generated, the hazard is higher. In the process are applied higher temperatures, and often an increased pressure. Causes of ignition of combustible vapours can be diverse, such as: inadequate electrical apparatus and installations,overheated heating bodies, static electricity, sparks, open fire, atmospheric electricity etc.Especially sensitive are the phases of decanting as well as combustible liquids storing.

HAZARDS THAT OCCUR IN CRUDE OIL PROCESSING PLANTS

Technological processes, as well as works with open flames near combustible liquids, gases, explosive and other substances that can cause fire must be organised in such way that, dependent on the nature and conditions of works, any fire hazard is removed.

Analysis of fire protection (e.g. oil platforms, oil pipelines and gas pipelines, oil refinery plants etc.) is based on a systematic and comprehensive observation and analysis of the processes and substances, as well as causes of ignition, which in certain interactions can bring about an unwanted explosion;this should be expanded by fires that can be a cause and consequence of explosions with catastrophic proportions.

Places in which great tragedies can occur under certain extraordinary circumstances are production plants, storage areas (over ground silos), decanting and manipulative areas in which oil derivatives are loaded and unloaded from tank trucks and tank wagon, and pipelines and other installations for the manipulation of oil derivatives.

Table 4 Overview of places in the process of work with the highest exposure to hazards and dangers

Place of a work process	Hazards and dangers
Combustible liquids decanting spot	• mechanical hazards of things, tools, devices • hazards of gases, vapours and fumes • hazards of fire and explosions
Combustible liquids storages	• mechanical hazards of things, tools, devices • hazards of gases, vapours and fumes • hazards of fire and explosions

Complexity of new plants on the one hand and lack of maintenance (or insufficient maintenance) of old plants on the other hand, in conditions when these are jeopardised by an explosive atmosphere, makes a serious source of hazard or technological risk.

Oil refineries face the highest hazard of fire due to:

- hazard of leakage of the vapours of combustible liquids
- hazard of reducing the pressure in devices and installations, which can lead to the "suction" of fire and generation of fire and explosions
- hazard of corrosion and creation of small crevices, which generates a possibility for air and flame to enter, i.e. leakage of vapours of combustible liquids
- damages, malfunctions and unprofessional maintenance of electrical installations

Hazard in workplace implies the facts and conditions that under certain conditions can jeopardise the lives and health of workers, and most frequently cause physical injuries, and sometimes death. Hazards can be mechanical, chemical thermal (hot and cold substances and objects), caused by electricity, fire and explosion etc.

In case of explosion, hazards to which workers are exposed are reflected in the following:

- hazards of uncontrolled flame
- effects of pressure
- hazard of flying objects
- reduction of oxygen for breathing

Although an explosion occurs instantly, there are several phases in which it develops: the first shockwave of explosion, flying parts of the equipment or parts of walls, roof, floors, doors, windows, ceiling (depending on the pressure of the impact) etc. Accumulated heat can case a secondary fire, burns and secondary damages to the structure. Very hazardous and dangerous are interactions of substances that are generated by combustion during the explosion, where the concentration of oxygen reduces in the area, which can cause the asphyxia of workers [8].

Such areas in workplaces must be fitted with a special warning. Ex symbol warns the workers and other people of risks of explosion in certain part of the workplace due to the presence of combustible substances in the form of liquid, vapours, gases or dust. It is important to know that, once the explosive atmosphere is generated, the size of danger depends on the scope and hazardous consequences of ignition [9].

In the plants that are exploited for a long period can be generated an increased volume of combustible materials, new sources of leakage, and also electrical and non-electrical causes of ignition of an explosive atmosphere due to the presence of aggressive substances, inadequate maintenance, fatigue of material etc.

Electric motor power (EMP) in an area jeopardised by an explosive atmosphereis one of possible efficient causes of ignition of the explosive atmosphere and generation of an explosion. There have been conducted tests of the efficiency of ignition causes generated by damages to the rotor ball cage in the conditions when an explosive atmosphere is really present. During the tests, motor is filled with mixtures of diverse combustible gases and air.

Table 5 shows test results of experimental researches of risks of ignition in an explosive atmosphere for conditions of the rotor without damages and for the level of damagesII, when conducting trials of short circuit with a reduced voltage, with 250 A electricity (for level II). Trials were conducted in a way that the electric motor was filled with mixturespropane/air, hydrogen/air and acetylene/air [10] as shown in table 5.

Table5 Results of testing electric motor in an explosive atmosphere

Condition of the electric motor (rotor ball cage)	Test mixture within the electric motor	Explosion occurred YES/NO
Undamaged	propane/air	NO
	hydrogen/air	NO
	acetylene/air	NO
Level of damages II	propane/air	NO
	hydrogen/air	NO
	acetylene/air	YES

As seen in table 5 no explosion occurred during the operation of the electric motor with a functioning rotor in an explosive atmosphere of propane, hydrogen and acetylene (with the provision of the required protection against overload for “Ex e“ motors). The same table shows that an explosion occurred at the level of damages II when the motor was operating in an environment of an explosive mixture of acetylene, evenwith the provision of the required protection against overload for “Ex e“ motors.

Employer is obliged to employ organizational and technical measures in order to prevent any occurrence of explosion, to implement all prescribed measures of protection from explosion and to assess the risks of its occurrence. The first step is the prevention of the occurrence of an explosive atmosphere (primary explosion protection); in facilities where this is not feasible, any occurrence of a source of the ignition of such atmosphere must be prevented. In case of the occurrence of an explosion, the employer is obliged to mitigate its action and to prevent the explosion dissemination in space (secondaryexplosion protection).

An example of the probability of existence of an explosive atmosphere and causes of ignition in some hazardous zones is shown in figure 3[11].

This example shows that in zone 2 is rarely expected the occurrence of an explosive atmosphere; if it does occur, it lasts for a short period so that only normal operation of devices is to be taken into consideration because any coincidence of the occurrence of both the causes of ignition and explosive atmospherebears very small probability. In zone 1, where the occurrence of anexplosive atmosphereis expected, malfunctions of devices and installations must be considered. In zone 0 where the permanent (continual) occurrence of an explosive atmosphere is expected, no occurrence of causes of ignition must be allowed even during sporadic malfunctions.

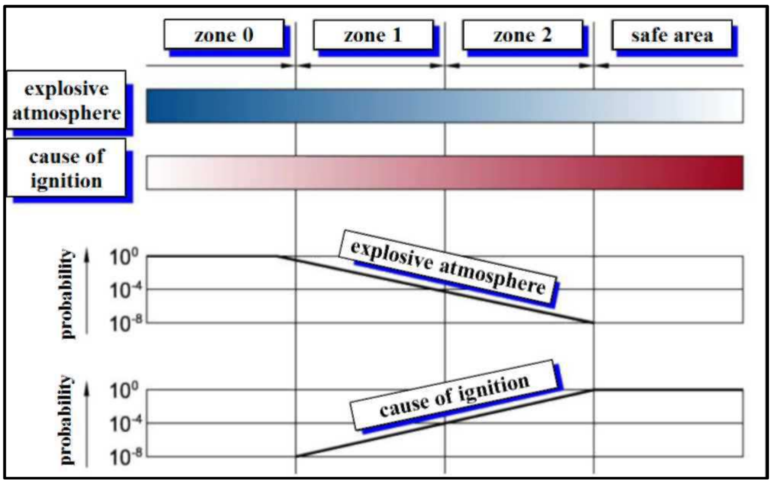

Figure 3 Probability of existence of an explosive atmosphere and causes of ignition in some zones

Civil Engineering Institute “IG” Banja Luka conducted an assessment of specific risks that are generated or can be generated due to the occurrence of an explosive atmospherein the plants of BrodOil Refinery during October 2015. The assessment comprised 3 sectors (energetics, production and dispatch of finished products), that house adequate plants, i.e. sections of the technological process.

In 2011, Brod Oil Refinery registered fire and explosion in the plant (section 35) for hydro-desulphurisation of diesel fuel;a short circuit occurred during the commissioning of a spare pump, where the connection box of high voltage cables in the pump electric motor exploded.
Energetics sector comprises the following sections or plants: compressorstation, boiler room, waste water treatment, preparation, distribution and providing all furnaceswith heavy oil. Production sector comprises: washing and treatment of liquid gas, treatment of residue gases. Sector of production and dispatching of finished products has 2 departments: department of manipulation and dispatch of finished products and department of manipulation and processing of finished products.

Zones at risk of an explosion in the plant, selection of electrical devices in line with the defined hazardous zones, characteristics of fire load in plants, possible causes and places of fire generation were analysed, and an assessment of risk was given for each plant as well as risk mitigationoptions were proposed.
These analyses of fire load assessment of each plant (low, medium, high), listed all possible risks of possible fires: subjectivefactor, electric installations, malfunctions of pumps and leakage in flange joints, static electricity, atmospheric discharges, pipeline breaking.

Analysis also stated that the listed sectors with related plants (sections),in their so-far operation, have not suffered any major changes or malfunctions of any type, especially fires or explosions, although even with all safety functions installed in the plant, since the measures of safety also comprise organisational-technical measures, there is a possibility of certain types of malfunctions in some plants due to deviation and non-compliance with significant conditions for works in an “Ex” atmosphere.

Plants that do not use explosive substances such as compressorstation, have no potential hazards; it is sufficient to abide by the prescribed instructions and organisational measures.
In plants defined as plants with an explosive atmosphere (department of manipulation and dispatch of finished products, department of manipulation and processing of finished products, department of washing and treatment of liquid gas) were identified lacks that could be a potential hazard.
Risk assessment considers all persons exposed to hazards. This includes workers who are assigned to work in plants, i.e. workers in maintenance of the plant (mechanical and electrical maintenance).

Procedures for a safe work prescribed by the Ex-Manual must incorporate instructions that are described in detail and clearly enough so that the personnel in charge of their implementation might follow up without problems. Prior to the implementation of these procedures in a real assignment, it is necessary to confirm the proficiency of personnel through a programme of training and assessment of understanding of prescribed procedures.

Responsibility of all involved in the elaboration and implementation of the activities in areas at risk of an explosive atmospheremust clearly be defined [12].

Measures for prevention/mitigation of the mentioned risk reflect in the application of modern methods of diagnostics on the condition of electrical motors, which can detect damages in an early stage. In the continuation is given a tabular overview of the identified lacks:

Table 6 Identified lacks in risk assessment (Department of manipulation and processing of finished products)

Risk assessment	Identified lacks
Critical	Not identified
High risk	• Non-electrical equipment of the pump for transport of agents has no plaque on the casing with elementary data and data for “Ex” execution • Newly installed control-measuring devices for monitoring the process of production has no attestations, issued by the Commission for explosion protection of the RepublikaSrpska, on compliance of equipment and devices that have explosion protection
Medium risk	• Bypasses for equalisation of potentials on flanges of pipes, valves; • Cables left behind, which are not used in the plant (they are not adequately protected or removed) • Lack of lids on the ma4rks on some electrical motor • Removed thermal insulation from pipes (partially) • Absence of „Ex“ marks at the entry to the plants
Low risk	• Absence of technological marks on the plant elements • Collection of impurities in cable canals • Damages to the mechanical protection of cables

MEASURES OF SAFETY AND PROTECTION AT WORK AND FIRE PROTECTION IN WORK AND TECHNOLOGICAL AREAS AT RISK

Measures of protection at work establish the obligation to apply special rules of protection at works through the following procedures:

1. trainings in the field of protection at work
2. notification and reporting based on the developed risk assessment for workplaces, this refers to the introduction of the employees to risks and hazards
3. jobs with special work conditions, risk assessment identifies hazards for each workplace, and special rules of protection at work are applied, which relate to the method of works execution

4. means of work and work environment, risk assessment for workplacesestablishes means of work, which are used in the process of work, as well as the work areas and premises
5. personal protection agents and equipment, risk assessment for workplacesestablishespersonal protection means that are used during work
6. work with hazardous materials, risk assessment for workplacesestablisheshazardous substances that occur in the technological process

Prior to the commencement of training the personnel to work safely in line withEuropean Directive 89/391/EEC [13], the employer is obliged to conduct a risk assessment that will show the hazards, dangers and efforts in a workplace where a trained worker works, and what measures of protection at work must be prescribed for these hazards, dangers and efforts. When the listed elements have been established and when sufficient knowledge exists for them, the employer is obliged to develop a training programme for safe work, and organise the form and procedures of training and knowledge verification. This document prescribes the application of the following trainings: Theoreticpart of workers' training for safe work; practical part of workers' training for safe work; training the employer or employer's authorised person for protection at work; training the authorised person for protection at work; training in the field of fire protection; training workers to provide first aid; training for work with combustible liquids and gases; training interns.

FIRE PROTECTION MEASURES

In line with legal regulations relating to fire protection and based on the assessment of risk of fire and technological explosion, and categorisation based on fire and explosion, measures for prevention of hazards of fire and explosions have been defined. These measures imply the functioning of fire detection system and gas detection system, stable and mobile cooling systems, fire extinguishing as well as the communication system. Periodicinspections are conducted by authorised legal or physical entities on which special records are kept in line with the Rulebook of preventive measures for a safe and healthy work in plants at risk of an explosive atmosphere [14].

Inspection and maintenance of technological installations, equipment and devices can only be performed by experienced personnel, whose training comprised the studying of diverse types of explosion protection and practical work with installations, equipment and devices, and knowledge of adequate rules and regulations, as well as general classification of hazardous areas. Such personnel must regularly renew gained knowledgein line with European Directive IEC 79-17 (EN 60079-17) [15].

Organisation measures of protection comprise:

- good knowledge and compliance with rules of fire and explosion protection when implementing the technological process
- introducing the subject in the production process to elementary sources of ignition in a given technological process or operation
- conducting regular control and inspection of protective and control-measuring devices
- establishing and keeping records and plan of overhauls, cleaning, lubrication etc.
- conducting trainings in the field of fire and explosion protection and testing the knowledge for each workplace
- training workers to use equipment and extinguishers for initial extinguishing of fire
- establishing procedures for warning, localisation and extinguishing of fires
- establishing routes for the evacuation of people, equipment and material in case of fire

EXPLOSION PROTECTION MEASURES

Legislation that regulates the establishment of minimal requirements of safety and protection of workers' health, and technical supervision over the plant, equipment, installations and devices in areas at risk of an explosive atmosphere, propose the technical and/or organisational measures that are in accordance with these elementary principles:

- prevent the creation of an explosive atmosphere
- prevent the ignition of an explosive atmosphere
- reduce hazardous action of the explosion in order to protect workers' health and safety

These measures sometimes must be amended or combined with the measures against the dissemination of an explosion and measures within the regular maintenance.

MEASURES FOR PREVENTION OF AN EXPLOSIVE ATMOSPHERE

In order to reduce a possibility of the generation of an explosive atmosphereand limit the hazardous areas, it is necessary to apply the following measures:

- application of closed technological processes
- using welded joints instead of flange joints
- application of general and local ventilation (natural or controlled forced ventilation)
- inertisation(especially in the presence of combustible dusts)
- technological discipline or raising awareness of workers who perform the work
- preventivemaintenance of the technological equipment with timely replacement of seals and various parts that can leak combustible agents
- installation of detectors of vapours or gases of the combustible agents (so-called. gas detection)

CONCLUSION

The analysis has shown that the zones at risk of an explosive atmosphere in oil refineries have certain probability of risks of fire and explosion, and that this probability ranges from $10^{-4}$to 10°. In certain plants with an explosive atmospherewere identified lacks that could be potential hazards to fire and explosion occurrence, hence preventive and protective measures have been prescribed therefor. In order to prevent unwanted events that could potentially jeopardise health safety of workers, i.t. damage the plant, it is necessary to ensure the application and control of the measures listedin the Rulebook of preventive measures for a safe and healthy work in plants at risk of an explosive atmosphere, which assumed the provisions of Atex-137, and related standards. The introduction of a clearly defined maintenance system for devices and equipment, regular technical supervision and comprehensive education of personnel in Ex-areas, can ensure an acceptable level of risks and accomplish satisfactory safety of workers and plants in oil refineries.

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