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Impact of Deterioration of Flare of an Offshore Oil Platform

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Abstract: The importance of the study of the impacts of deterioration in the flare of an offshore platform is based on the fact that the corrosion and failures of the components of the flare cause the occurrence of emergency shutdowns for maintenance, causing great economic losses. In addition, it is essential to be alerted that by operational issues of security, at all levels, the offshore rig that cannot produce oil and gas flare is not reliable; because of operating conditions, the risk of fire and explosion are inevitable. Here, potential damage conditions are identified in the structure of flare as well as in an evaluation of failures due to material cracking and degradation. Monitoring alternatives are proposed to avoid or reduce the emergency stops on the offshore platform.

Key words: Flare, corrosion, failures, offshore oil platform, shutdowns.

1. Introduction

In Brazil, more than 90% of the produced oil and natural gas comes from 134 rigs in offshore fields, of which 52 are in deep waters. The Campos Basin has 55 oilfields and is about 100,000 km² in area. It currently has 2,350 wells for oil and natural gas, 41 offshore platforms production and four FPSO (Floating, Production, Storage and Offloading). About 60,000 people work in companies directly linked to oil exploration and another 50,000 work indirectly. All the oil structure accounts for 47% of the natural gas production and 80% of national oil production, i.e., the participation of the Campos Basin in the national energy production is quite significant. The Brazilian agency ANP (National Petroleum, Natural Gas and Biofuel) is the entity responsible for inspecting oil and natural gas exploration and production activities, according to the provisions of Law 9478/1997. The purpose of such inspection is to prevent failures in the operational safety of the facilities and to avoid any harm to life, environment and property [1].

Considering the strategic importance of these oil production offshore platforms to Brazilian economy, it is fundamental that production campaigns be the longest possible, and with the least disruption. However, the need to ensure the integrity and the development of processing plants makes it necessary, at certain times, to disrupt (fully or partially) oil production. This stop is called the shutdown of production, where necessary maintenance is carried out for the integrity of the project.

One of the bottlenecks in the production of oil and gas can be considered the operability of flare. It can be seen as a final security system on offshore platforms. Its function is to prevent situations of abnormalities, such as the pressure inside the lines and equipment exceeding the maximum permissible values of operation. If the flare of a platform does not work properly, it is mandatory to stop immediately the production of oil and gas on the offshore platform [2].

The flare, essentially, consists of three components: chimney, liquid seal and burner system. In addition, other equipment exists, such as vessels of high pressure and low pressure, whose purpose is to remove the condensate from the gas process plant,

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lance burners, an auxiliary gas system, integrated control system, knockout drum vessel, three stages of burning, pilot ignitors of burning of high and low pressures, and pilot flame detectors [3-5]. The processing unit of flare scheme and the top of the flare can be seen respectively in Figs. 1 and 2.

In normal conditions pilot ignitors burn, continuously and controlled, the gases from the plant, avoiding the formation of gaseous clouds, which, depending on the direction of the wind, may move towards the offshore platform and cause fires and explosions.

A gradient of temperatures is generated from the tip of the flare to the rest of the structure and it varies depending on the waste gas flowing rate and discharge speed, the number of burners, the wind speed and direction, as well as the periods that the flare operates in a continuous burning or in emergency burning. Materials that operate in temperatures higher than 400 °C may suffer degradation with time and require monitoring.

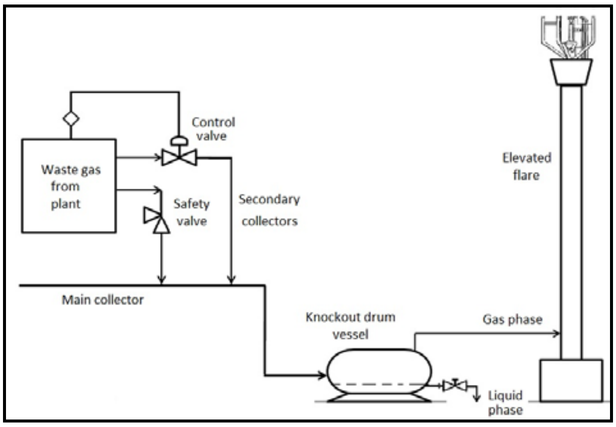

Fig. 1 Processing unit of flare scheme. Modified from [6].

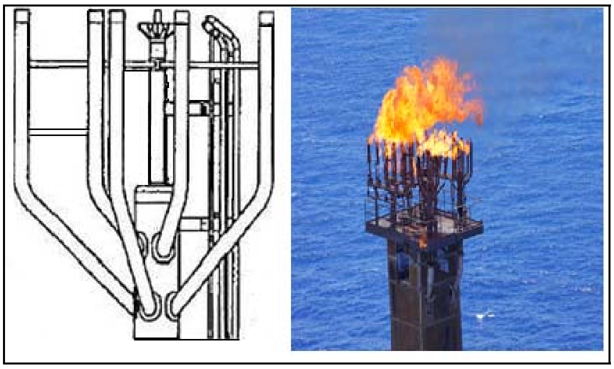

Fig. 2 Top of a flare of an offshore platform.

In case of oil refineries, oil, gas offshore platforms and petrochemical plants, studies of the corrosion processes show that about 50% of the failures of materials are credited to corrosion. The process of knowledge both of the principles of corrosion and corrosion protection, as well as the rules of fitness practice, have been a challenge in the field of engineering equipment and systematic monitoring [7]. Corrosion is generally responsible for many of the failures of equipment that make up the operating units of an oil production offshore platform, generating consequent unprepared stops, operating shorter campaigns, and resulting in prolonged times for maintenance and loss of earnings [7, 8].

When the corrosive process occurs in the burner system (flare), this becomes even more critical for the platform, as it leads to low efficiency gas burning and consequently affects the production. The deterioration and fissures found in parts of the flare generate a technical alarm for oil and gas production. Depending on the severity of the event, an emergency stop may be necessary. In this case it is obligatory to stop all oil and gas production.

When high temperature exposition causes a material degradation, the consequences may be even worst (catastrophic) since a mechanical failure may occur and the repair may include many adverse conditions (as well as acquisitions of new parts) that delay a lot the continuity of production [9, 10].

This paper presents the main conditions that lead to material failures in the flare system, the consequences of the failures and how the monitoring can be planned in order to prevent emergency stops.

2. Materials

2.1 Inspection of Corrosion, Cracks and Fissures in Flare System on Offshore Platform (FPSO)

The flare is located on the bow of the FPSO platform. Fig. 3 shows the side view and top of the platform, indicating that the distance from the floor of the boat to the flare top is of 110 m, and the distance

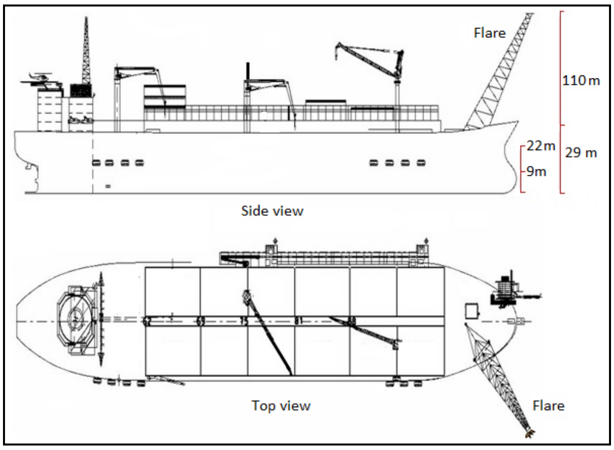

Fig. 3 FPSO scheme with location of flare.

Fig. 4 Adverse conditions of maintenance work at the top of the flare

to the seawater surface is 29 m. When the platform deck is empty, i.e. without oil storage or little oil, the level is 9 m, and when on maximum load the level is 22 m.

It is important to note that based on the location of the flare (Fig. 3), due to its height and high temperatures, any maintenance is very complex. It is essential that the platform be stopped, the equipment switched off and inerted, ensuring security for any approach and execution of any services.

Fig. 4 shows the complexity of the equipment inspection activity and small emergency repairs undertaken by professionals in the flare, considering the height and environmental conditions that predominate such as strong wind, rain and solar insolation.

The inspection of flare consists, essentially, of digital photographic documentation made by inspectors, UAV (Unmanned aerial vehicle) or helicopter, determination of thickness by ultrasound, liquid penetrant inspection (identification and characterisation of defects), as well as metallographic replica and hardness tests, to identify the mechanisms for defect formation and the accumulation of damage due to high temperature and aggressive external environment.

2.2 Case Study Involving Corrosion Problems and Failures in a Flare of an FPSO

In order to show the importance of planning the shutdowns when confronted with emergency stops, selected failure cases are presented concerning a flare system of an FPSO. It is important to mention that material failures occur due to imposed conditions that exceed the material capacity. For a flare system, these conditions are associated to mechanical stresses, due to the reduction of the material strength in high temperature and due to the cyclic loads caused by FPSO movement; or which are associated to aggressive environments, high temperature burning gases and external marine environment.

2.2.1 Mechanical Issues

Operation of lines (and supports) in high temperatures may generate additional stresses due to differential thermal expansion, reduction of Yield Strength and Creep.

Creep is a mechanism that is not predominant in the flare system since the lines exposed to the higher temperatures are designed in austenitic stainless steel, which presents good heat resistance. But in regions a little far from the burners, manufactured in carbon and low alloy steel, operating in temperatures higher than 400 °C, a microstructural evolution may occur (the ferritic-perlitic structure starts to decompose) reducing the material strength in time and creating conditions for creep voids formation. That is why this kind of material requires metallurgical inspection, time to time, by metallographic replica and hardness measurements.

Metallographic replica is a non-destructive technique that covers recognised methods for the preparation and evaluation of cellulose acetate or plastic film (called replica) that has been obtained from metallographically prepared surfaces (as polished, for defects evaluation, and etched, to see the microstructure). It is designed for the evaluation of replicas to ensure that all significant features of a metallographically prepared surface have been duplicated and preserved on the replica with sufficient detail to permit examination with an optical microscope with optimum resolution and sensitivity [11].

The replication technique is adopted for carbon steel and low alloy steel, using Nital etch, as well as for austenitic SS (Stainless steel), using electrolytic acid oxalic etch, but for the SS the intention of evaluating the microstructural evolution in time is not to treat potential mechanical issues (like creep), but to treat potential corrosion issues.

Differential thermal expansion of parts of different sizes are mainly found in welded branching (mainly when the branching line is colder than the main line and the filler metal is not similar), and the main damage is crack formation at interfaces between different thicknesses or materials, easily detected by liquid penetrant.

LP (Liquid penetrant) examination is one of the most utilised NDE (Non-destructive examination) methods in the petroleum industry. To the specific conditions of inspection on the facilities of flare, this method is quite versatile and requires minimal training compared to other NDE methods. LP examinations check for material flaws open to the surface by flowing a very thin liquid into the flaw and then drawing the liquid out with a chalk-like developer [12,13].

Fig. 5 presents two examples of observed cracks in the welded region and in the body of the tube in branching lines using collars that are thicker than the tubes creating thermal stresses. Such failures could compromise drastically the flare and force an emergency stop for repairs.

Operation of the system in high temperatures also favours the distortion of lines if they are not properly supported, since the material Yield Strength is reduced as the temperature increases and plastic deformation becomes easier. Fig. 6 illustrates the warping of a heater tubing line. In this case, the deformation is not in accordance with the standards, and may generate cracks.

A good piping support is very important when operating in high temperature but highly restrictive conditions should also be avoided since the lack of freedom in material expansion generates thermal stresses. When heating and cooling cycles occur several times during the life of the system a thermal fatigue mechanism is generated and cracks appear, as illustrated in Fig. 7. When the support is directly welded to the process piping, without transition paddles, the cracks that appear due to relaxing of the

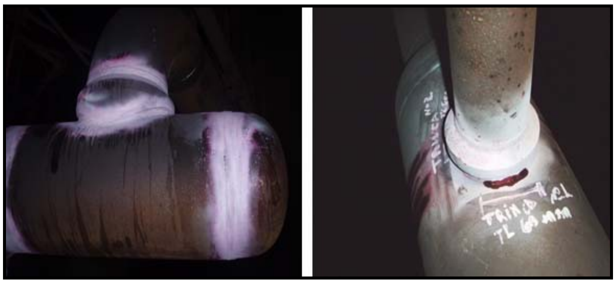

Fig. 5 Cracks and fissures identified by liquid penetrant in heater tubing.

Fig. 6 Warping of heater tubing.

Fig. 7 Cracks in the welding of supports to the main tube.

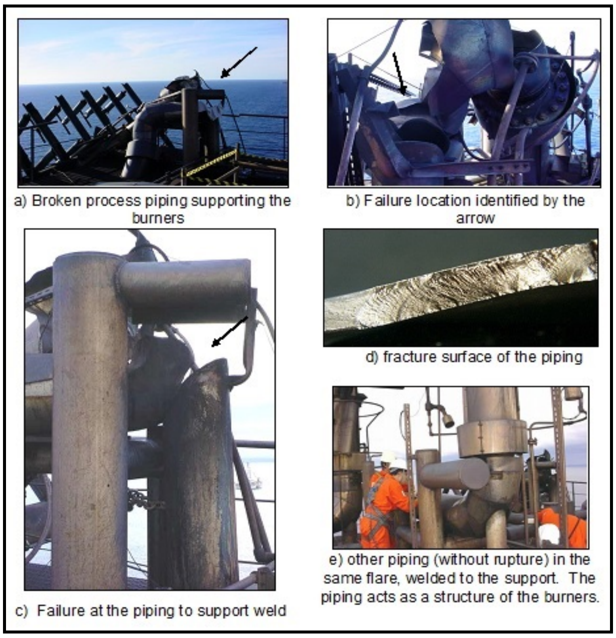

Fig. 8 Catastrophic failure of the process piping supporting the burners due to fatigue in the welded region of the support to the main tube.

thermal stresses may propagate by fatigue associated to other kind of generated stresses, like the FPSO movement, and if the cracks propagate through the process piping it may cause a critical condition.

A catastrophic mechanical failure occurred for the burner as in Fig. 8 due to the weld of the process piping directly to the trunnion support, in a condition that the piping was acting as a structure to support the burners. In the fracture surface of the process piping, it is possible to see the propagation of cracks by a fatigue mechanism. The arrow presents the failure region of a, b and c in Fig. 8. In Fig. 8d it is clear the fatigue beach marks in the fracture. In Fig. 8e, it is possible to see how the trunnion was directly welded to the main process piping and the structural condition of the process piping. To restore this equipment to operation a long time is required since a new part (piping and burners) had to be acquired.

3. Results and Discussion

Because of the conditions of high temperature and marine environment that surrounds the top of the flare, austenitic stainless steel [14-19] has been the material used and recommended for pipes and nozzles burns, as well as for firing accessories (i.e. pilots, stabilisers, bars, etc.) and the main degradation mechanism is due to corrosion.

The main corrosion issues are associated to the process side (burning waste gas) and to the external environment (high chloride content). It is very important to remember that a warm and wet condition is not good for a stainless steel with a low pitting resistance equivalent (low PREN), like the austenitic stainless steel AISI 316, due to the susceptibility to CSCC (Chloride stress corrosion cracking). At the tip it is not usually a big problem because when the flare is operating, the high temperature creates a dry condition.

The flare operating conditions, with which the deterioration is associated, are high-temperature corrosion, which results in the collapse and loss of metallic material, as shown in the destruction of the gas outlet nozzle in Figs. 9 and 10.

According to Roberge [10] and Schütze [20], high-temperature corrosion is a form of corrosion that does not necessitate of the presence of a liquid electrolyte. Gentil [21] classifies high-temperature corrosion as a form of chemical corrosion. Sometimes,

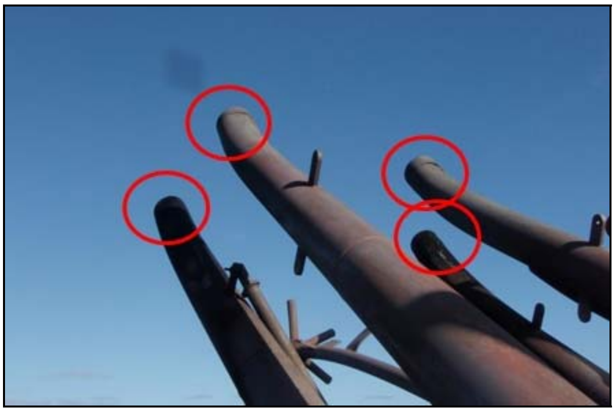

Fig. 9 Corrosion of gas burners in flare.

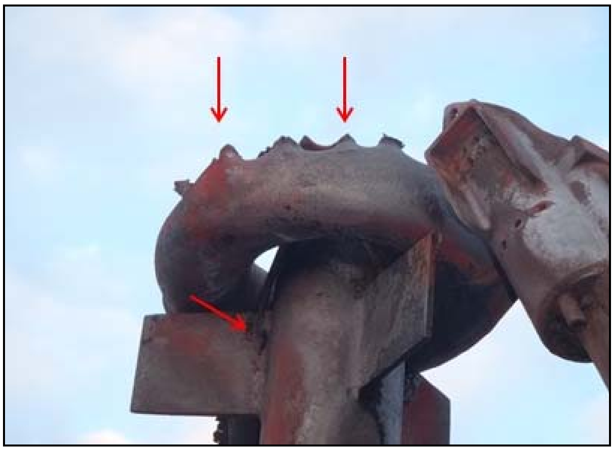

Fig. 10 High-temperature corrosion in gas burners.

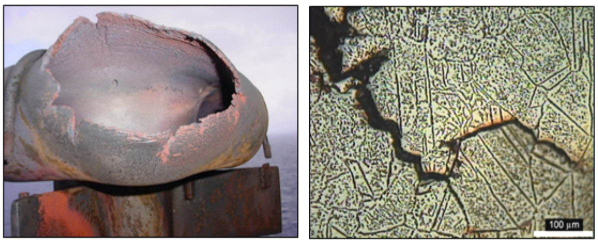

Fig. 11 Flare tip carburized and cracked due to high temperature corrosion. Austenitic structure presenting carbides. Electrolytic etch.

this type of damage is called dry corrosion or scaling. The term "oxidation" has been used as a direct reaction as the oxygen at high temperatures with the formation of oxides.

In the case of the burning of the flare, the process is complex, because several constituents may modify or change the formation of oxides, such as the presence of chloride in the form of NaCl, and sulphur present in the form H_2S can transform into SO_2/SO_3. The formation of salts in the form of chloride and sulphate can form a crust on the surface of the burner, favouring obstruction and the malfunction.

Additionally if the tips are exposed to a carburizing condition (by the flame) the material degradation is quickly, as evidenced in Fig. 11. The metallographic replication technique adopted for the tips help to understand if the material is suffering the carburization, clearly revealed by a carbide precipitation in the structure.

The carbide precipitation makes the SS less corrosion resistant since the chromium in solution precipitates as carbides and depletes the material in chromium, responsible for the surface passive layer. When the material is carburized (carbon was introduced in the alloy composition from the surface) and operates in high temperature the life is strongly reduced. This condition may be monitored by metallurgical inspection using replication technique.

When the material works in temperatures higher than 400 °C, but not directly exposed to the flame (i.e. no carburizing conditions), it is still possible to occur carbide precipitation due to the carbon content of the steel. The carbon precipitates at austenitic grain boundaries and depletes the adjacent region. This condition, called sensitization, creates a condition for intergranular corrosion to occur [22]. Fig. 12 presents several examples of austenitic structures with different levels of carbide precipitation, evaluated by replica in flare systems.

The worst condition for intergranular corrosion to be critical is not at high temperature but it is when there is a wet and warm condition, as the sensitized steel is very susceptible to CSCC. Fig. 13 shows a crack in a location a little far from the tip where the material undergone a carbide precipitation and generate a crack due to CSCC.

In order to meet the integrity and state of austenitic stainless steel tubes that make up the power structure of gas burners (that are subject to high temperatures and a constant salinity) and also considering operational

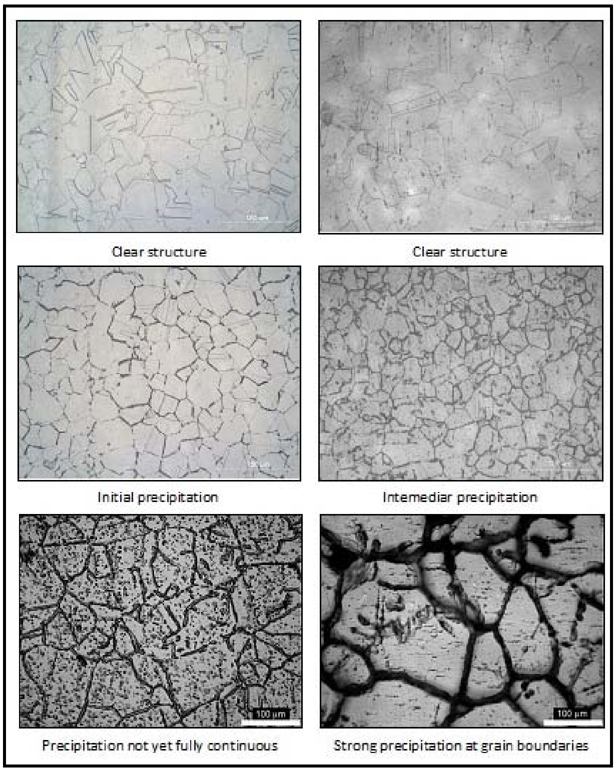

Fig. 12 Burners evaluated by metallographic replica, presenting different levels of precipitation at grain boundaries due to high temperature effects. Electrolytic oxalic acid etch.

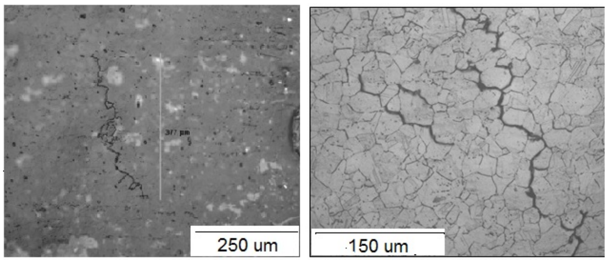

Fig. 13 Cracks due to CSCC condition in a material that is slight sensitized by the high temperature.

difficulties (if there is a need for replacement or repair), some points for evaluation of the susceptibility to intergranular corrosion shall be selected during an inspection plan. In this evaluation of the integrity of the tubes, metallographic analysis are required. Whereas the tubes were made of austenitic stainless steel, the metallographic laboratory analysis was carried out based on the ASTM E 1351 [11], in order to determine the micrographic changes that qualify the precipitation of chrome carbides at the grain boundary of austenite.

4. Transport of Materials and Critical Assessment of Emergencies and Shutdowns of Oil Offshore Platforms

4.1 Transport of Materials and Equipment

The conditions are also quite adverse for the transportation of parts and pipes that must be replaced after inspection and verification of faults, defects and corrosion. As shown in Figs. 14 and 15, the transport is performed by the lifting of parts through steel cables or chains and by helicopter depending on the wind conditions and load weight. The cost of transport, the time of lost hours and the lost profits as a result of the loss of oil production, can have a significant impact on these operations on the offshore platform.

4.2. Critical Assessment of Emergencies and Shutdowns of Oil Offshore Platforms

According to Duarte [23], an accident is an undesirable event, random, casual, which effectively causes damage to persons physically and mentally, the environment, property, or a combination of these elements. Systematic studies of a large number of

Fig. 14 Lifting of parts through steel cables or chains.

Fig. 15 Transport of parts by helicopter.

accidents are usually caused by human error materials and equipment failures that should be controlled by management guidelines, procedures and maintenance programs.

In the case of an FPSO oil platform, the activity is too complex, because it brings together a large amount of highly energized systems, with liquids and gases (flammable and combustible) flowing through ducts at high temperatures and pressures. The risks inherent in this process grow in the same proportion as the complex dynamics of control and safety devices interacting with each other [24].

The growing index of recorded incidents in a preliminary survey prepared by the Brazilian Agency ANP (National Petroleum, Natural Gas and Biofuel) in late 2014 already indicated the deterioration of some conditions of operational security. 50% of 837 recorded incidents in oil production offshore platforms, from January to November 2014, referred to emergency stops (a 158% increase compared to the number recorded in 2013). Problems detected in the main power generation were the second leading cause with 182 notifications [24].

Most oil production offshore platforms, in the specific case of premature deterioration of the flare tips of the burners became a recurring problem (excessive degradation, loss of metallic material and intense oxidation), demanding the return of these parts and peripheral components (viz. pilots, flame stabilizers, flame retention screen, etc.) much more often than was expected.

Based on reports from 30 inspections of oil rigs operating in the world, relating to the flare system, are considered the following classification criteria for the scheduled maintenance shutdown program of 15-20 days, or an emergency shutdown program of up to seven days. The results of this assessment are presented in Fig. 16.

The need to perform minor repairs or even the exchange of equipment in flares is very harmful to the process of exploration and production units, since it is not possible to perform maintenance on the system of the flare with the unit in operation. Considering the relevance of programming of production of oil and gas, the difficulties of access (e.g. height too great) and the high temperatures make any human approach on the fly impossible.

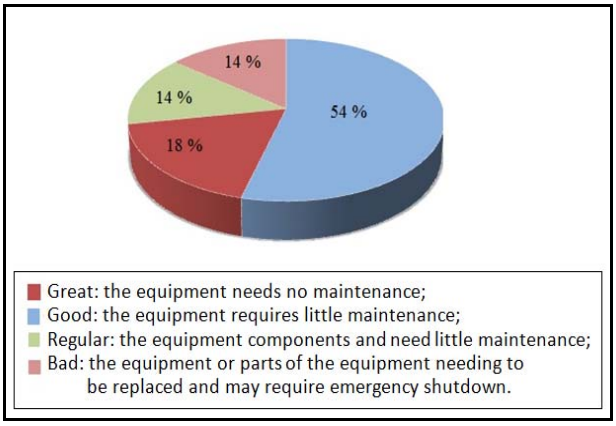

Fig. 16 Criteria and results of evaluation of flares in oil and gas offshore rigs.

Due to these factors, any needs for maintenance of the flare requires a shutdown or unscheduled production (i.e. an emergency), causing production losses of oil and gas, and consequently a financial loss of millions of dollars.

In an emergency stop because of a problem with a flare, one has to stop the entire production process and extinguish the flame to perform the required maintenance. On average it takes 20 hours (for the refrigeration of the system) to be able to begin maintenance activities, and 12 hours to return to normal production after the conclusion of service. The maintenance time and transport time of the replaced parts are also taken into consideration.

A preventive maintenance is very important to reduce the risk of failures and the inspection plan shall include critical regions to be periodically evaluated. Table 1 summarizes the main inspections with emphasis in the material behavior, to be planned for flare regions, and what kind of information shall be supplied.

Table 1 Summary of Inspections with materials behavior emphasis.

Condition in the Flare	Materials	Inspection	Objective
Exposition to burning gases	Austenitic stainless steel	Replica	Corrosion issue-define if the material is suffering carburization or sensitization
Temperatures higher than 400 °C	Austenitic stainless steel	Replica	Corrosion issue-define if the material is suffering sensitization and if yes, if it is working in a region that allows wet environment
	Carbon and low alloy steel	Replica and hardness	Mechanical issue-define if the material is suffering high temperature evolution and losing strength
Piping supports	Welded regions	Visual and dimensional	Mechanical issue-identify potential regions for cracking due to fatigue, thermal stresses and differential expansion

5. Conclusions

Based on our literature review and the inspections carried out in offshore platforms, it is concluded as below:

When the flare burner system is committed to the corrosion for the impact directly in the operation of the platform, it is necessary to interrupt the total production of oil and gas on the offshore platform for maintenance of the flare;

The need for maintenance in the flare requires a shutdown or unscheduled production (i.e. an emergency), causing production losses of oil and gas, and consequently taking a financial loss of millions of dollars;

In emergency stops, after the flame is extinguished, the refrigeration of the flare takes on average about 20 hours from the beginning of the maintenance. Depending on the type of repair and on the conditions of the time and the transport of parts, the emergency stop can take up to seven days;

The working conditions (winds, high salinity, gas flow, temperature oscillations of burns) in the flare, end up creating ideal conditions for the development of mechanical and corrosion issues that shall be continuously evaluated through preventive inspections;

High temperatures in the burner tips can propitiate carburization and sensitization (chromium carbide - $Cr_{23}C_6$ - precipitation on grain boundaries) in austenitic stainless steel and the consequent destruction of the material;

To prevent sensitization, a permanent control of the burning speed is essential, in such a way that the offset (i.e. displacement) of the flame is such that it does not burn at exactly the end of the burner nozzle;

Metallographic analyses by replica in parts near the burners are required to avoid materials degradation in time. It is important to any material (stainless steel and carbon and low alloy steel) that operates in temperatures higher than 400 °C;

Aiming at the reduction of maintenance stops, it is important to develop new models of management and control to accompany the offshore services in the system of burners (flares), and finally to use some alternative technologies, such as: thermal spray, improvement of access to the flare with the use of a lift, new technologies of surface preparation, and special coatings with resistance to weathering and high temperatures.

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