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Black Smoke Assessment of Low Pressure Flare in South Pars Gas Field Off-Shore Platform Based on FLARENET Simulation and Flied Experiences

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Flaring is the combustion process used for the safe disposal of large quantities of waste gases and vapours in the petroleum and natural gas industries. Due to the fact that toxic and greenhouse gases are the main products of flaring which has devastating impact on environment and also ruin distinction of the operators of the plant specifically when accompany with black smoke, in the recent years, researchers and policy makers are focused on these issues by finding solutions and legislating protocols and environmental regulations. The present study revolved around potentials of smoking of Low Pressure (LP) flare system of South-Pars Phase 1 platform to throw some light on the exact operational and theoretical reasons and ultimately propose a practical solution in order to sort out the issue considering off-shore restrictions. In addition to investigating possibility of liquid carry over with waste gas to flare tip, the LP flare System is simulated for continuous scenario for evaluating composition of waste gas, moreover, the adequacy of knock out drum is assessed regarding its size and efficiency of separation of gas and liquid. The study showed that the low momentum of waste gas mixture is the main reason of smoking and injection of air as assistance creates effective mixing and smokeless flaring.

1. Introduction

Generally, Flaring is the inherent part of every oil and gas plants to supply safety for process and prevent fatality and damage to the asset. However, it brings about serious environmental issues if it is not design properly. It is estimated that maximum 200 billion cubic meter gas is being flared every year. Incomplete burning would always accompany with noticeable black smoke which could be tarnished the reputation of the plant or platform in addition to association with environmental problems due to releasing toxic gases. Therefore, necessary measurements need to be taken on one hand, by officials by means of speculating strict regulations and one the other hand, by researchers to propose technical solutions to eradicate this issue. Brzustowski (1976) stated that the most common practical method of suppressing smoke in flares is the addition of steam. The steam has the greatest effect when it is injected into the flame at/or just above the discharge plane of the flare tip, in such a way that it can also entrain some air into this region. When steam is not available compressed air could be used. Shore (1996) presented that some gases are more likely to be smoky because they contain a greater proportion of carbon than others or because their cracking temperature is lower than others. Smokeless flaring of low-pressure gas is significantly more difficult than smokeless flaring of high-pressure gas. When flaring a high pressure gas, not only is the gas lighter, but the gas velocity at the flare tip usually creates sufficient turbulence to ensure the proper air and gas mixing required for smokeless combustion. While, the flash gas coming off a low-pressure separator or any other equipment would have higher molecular weight requiring more air for complete combustion. If the low-pressure gas is allowed to burn without the introduction of sufficient outside air or steam, the flare tends to smoke excessively. In addition, the flame becomes too close to the flare tip causing flare tip damage (Obawole et al., 2001). Mashour (2009) has patented a new smokeless flaring technology using high-pressure air. This technology is called High Pressure Air Assist System (HPAAS) and has been

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successfully implemented on dozens of flare systems in Saudi Arabia. It uses supersonic air injection nozzles to inspirit smokeless air at a much higher efficiency than any previous smokeless high-pressure air-assisted flare technology. The main objective of the present work is to investigate various reasons for black smoke formation of flare on South Pars Phase1 platform and find the solution to sort out the issue applying field experiences and results of flare network simulation with Aspen Flare System Analyser V7.1.

1.1 Process Description

The South Pars Gas Field has been initiated for the exploitation of a 1,000 MMSCFD of gas and condensate reservoir located in the Persian Gulf. The phase 1 facilities are designed to allow free flow of well fluids from the wellheads to the refinery without any requirement for compression or pumping. The fluids from the wellhead platform are routed to a manifold which enables production from either platform to be routed to each processing train.

Each train consists of: Primary separation/cooling, gas dehydration and condensate dewatering in which gas is processed to reach certain specification in order to transport into on-shore facilities. Dehydration is accomplished by contacting the gas with lean Triethylene Glycol (TEG). The water rich TEG is sent to the Glycol Regeneration Package (GRU) where the water is stripped from the TEG so it can be reused. Figure 1 indicates the schematic diagram of Phase1 main process and GRU facilities.

1.2 Phase 1 LP Flare System

The LP Flare allows the safe flaring of hydrocarbon gas from equipment with a design pressure of less than 16 barg. A continuous flow of low pressure gas is come from the produced water degassing vessel and the GRU. Also, the LP Flare is continuously purged with fuel gas. The LP flare system consist of flare headers which collects hydrocarbon releases from LP process equipment and routes them to LP Flare KO drum. The LP flare KO drum is designed to separate entrained liquid droplets greater than 600 microns in diameter from the flared gas for all flaring conditions, with maximum liquid level in the drum.

2. LP flare black smoke

Noticeable black smoke has been observed during continuous flaring which is very harmful for the environment. Figure 2 illustrates the black smoke in the flaring. In order to solve the issue, a comprehensive study has been carried out by means of brain-storming in order to find out the probable reasons. Based on the investigations main reasons of black smoke are categorized as following;

2.1 Liquid in the Vent Stream

This is very ubiquitous to consider presence of liquid in vent stream when smoking is observed in the flaring. Liquid in the vent stream can extinguish the flame or cause irregular combustion and smoking.

According to the site visit, when LP flare is unloaded completely, at the first hours and when the liquid level in KO drum is low enough, no black smoke is observed, however, as soon as liquid level in the LP KO drum increases, combustion is accompanied by black smoke. The possible reasons for presence of liquid in the LP KO drum is low enough, no black smoke is observed, however, as soon as liquid level in the LP KO drum increases, combustion is accompanied by black smoke. The possible reasons for presence of liquid in the LP

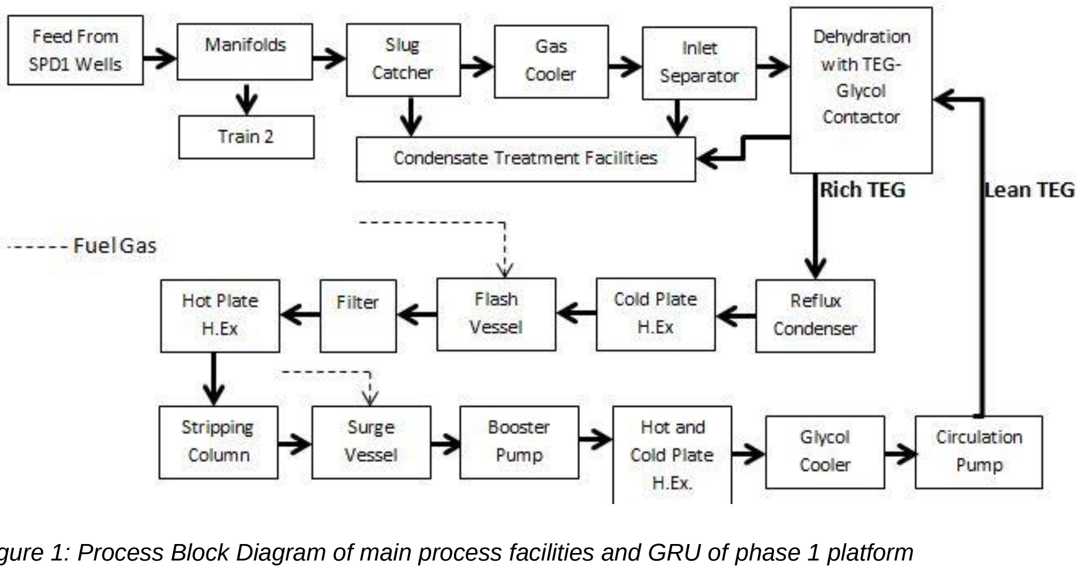

Figure 1: Process Block Diagram of main process facilities and GRU of phase 1 platform

Figure 2: Black smoke in flare of phase 1 platform

flare system could be inadequate size of KO drum and liquid levels in the drum which could reduce the volume available for vapour/liquid disengagement. This should be considered when defining liquid level high (LAH) for the KO drum. As a matter of the fact, when LAH which causes pump to start is not designated properly, the possibility of liquid carry over with gas is escalated.

2.2 TEG presence in vent stream

Because of the sensitivity of TEG based on the operator experience, it is specifically considered as one separated item. In GRU package, TEG enters still column containing two parts of random packing. It also passes re-boiler working at 204 °C prior to stripping column. The stripping gas (LP fuel gas) is also enter the surge vessel continuously and flows up through the structured packing in stripped column in counter-current flow with glycol. During this mass transfer process most of the left over water in glycol will be removed. The stripping gas is routed to LP flare header at the outlet of still column. Glycol could also be found on LP flare network from another source in GRU package. This is the glycol flash vessel in which its pressure should be maintained at 5.2 bar with LP fuel gas by means of a pressure control valve.

2.3 Inadequate Mixing and incomplete combustion

When hydrocarbon composition is the main material sent to flare tip, one of the factors that control black smoke is the H/C weight proportion. The more the proportion value, the less black smoke is formed. Regarding gas mixture contains different hydrocarbons with H/C smaller than 0.25, smoke would be generated during burning. The main reason for this is inhomogeneous mixing of waste gas. According to the API 521, one of the important criteria for non-smoke flaring process is the heating value of the mixture. Gases that have a high enough heating value which is usually greater than 200 Btu/Scf (7,443 kJ/m^3) for unassisted flares sustains combustion on their own without any auxiliary fuel additions.

2.4 Waste gas momentum

It has been studied that the momentum of waste gas playing significant role in burning operation. If the waste gas pressure (momentum) is not adequate to provide smokeless burning, other energy sources (e.g. steam or air), or a combination of energy sources can be used to compensate low momentum of gas and make the burning complete.

3. Flare network simulation

In order to find out the real composition and also the heating value of the burning mixture on the downstream of KO drum, the LP flare system is simulated by means of Aspen Flare System Analyser V7.1. Phase 1 LP flare system comprises of two headers called continuous and non-continuous which are connected to LP KO drum separately. The adequacy of LP flare system is checked with only continuous sources to the flare header, since in non-continuous mode (emergency situation), smoking is not a concern. The specifications and operating conditions of continuous sources tabulated in the Table 1. LP Flare network is simulated applying mentioned data in the Tables 1 and available compositions. Also as-built piping sizes, elevation, material and thicknesses are utilized in simulation. The LP flare is sized to give low back pressures in the header equal to 0.013 barg. Figure 3 shows flare network simulation in Aspen Flare System Analyser V.7.1.

4. Results and discussion

4.1 Simulation Results

The LP flare network is simulated to find the composition of fluid at flare tip and ultimately evaluate the heating value of the mixture. The data of each source are extracted from project documents and a scenario is defined in the software that includes all of the continuous sources. The pressure of the fluid at the outlet piping from

Table 1: Specifications of continuous sources to LP flare network

LP Continuous Sources	Pressure (barg)	Temperature (°C)	Mass Flow (kg/h)	Composition
Purging fuel gas	3	20	0.7	Fuel gas composition
Produced Water Package Train 1 & 2	2.8-3.2	20	10	Fuel gas composition
GRU-Still Column-Train 1 &2	0.15	85	1,280	Stripping gas composition at outlet of still column
GRU-PCV-Train 1&2	1.01	80.8	160.5	Vapour composition of flash vessel

LP KO drum to flare tip is low enough that the gas mixture could be considered as ideal. The net lower heating value of the burning mixture is calculated 16,560 kJ/m^3 which indicates that the heating value of the burning mixture generated from LP flare network is more than criteria (7,443 kJ/m^3) and doesn't need extra injection of gas with higher heating value.

4.2 KO Drum Sizing

To ensure whether liquid droplets carry over with gas in the KO drum, the sizing of existing equipment is checked with the common procedure elaborated in the API standard 521. It is assumed that the relief time to be 20 minutes and liquid that accompany with vapour release has volume of 1.5 m^3. Also, the Maximum relief load during emergency situation is 4,802 kg/h. the vapour density and viscosity is 0.74 kg/m^3 and 0.012 cp respectively. Liquid flow rate is considered to be 10 kg/h with density of 985.6 kg/m^3. The Drop out velocity is then evaluated from Eq(1).

$$U_c = 1.15\sqrt{\frac{gd_p(\rho_L - \rho_v)}{C\rho_v}} \tag{1}$$

Where, Uc is the drop out velocity, dp is the particle diameter and C is the drag coefficient. The drop out velocity is found 3.41 m/s. Sizing of knock out drum is continued applying trial and error procedure regarding diameter and length of the drum. Here, the length and diameter of existing drum is used to check whether its size is adequate for the worst scenario occurring during emergency situation (D=1.1 m and L=3.3 m). Liquid volume in the KO drum would be liquid streams that accompany a vapour release and condensate that separates during a vapour release; A_{L1} and A_{L2} signify these parameters and calculated as below;

$$A_{L1} = 1.5 \times \frac{1}{3.3} = 0.4545\ m^2 \tag{2}$$

$$A_{L2} = \frac{0.0028}{985.6} \times 20 \times 60 \times \frac{1}{3.3} = 0.00103\ m^2 \tag{3}$$

$$A_V = A_{Total} - (A_{L1} + A_{L2}) = 0.0495\ m^2 \tag{4}$$

The vertical space for vapour flow (hv) is found 0.583 m. Liquid drop out time is then found utilising vapour space and drop out velocity equal to 0.17 s. The vapour velocity is also calculated as following;

$$u_v = \frac{R_v}{A_V} = 3.65\ m/s \tag{5}$$

Where R_v is the vapour volumetric flow rate. The key factor in sizing the knock out drum is that the minimum time for vapour passing the drum from inlet nozzle to outlet nozzle (called T/T length) should be equal to the drop out time of liquid droplets accompany with vapour, the minimum length of the drum is then found;

$$L_{min} = u_v\theta = 0.62\ m \tag{6}$$

It should be mentioned that L_{min} must be less than or equal to the assumed cylindrical drum length, L; otherwise, the calculation must be repeated with a newly assumed cylindrical drum length. The minimum required length for the drum in this study is smaller than assumed (existing) length, therefore, the existing KO drum size is adequate to handle relief stream during emergency and continuous circumstances.

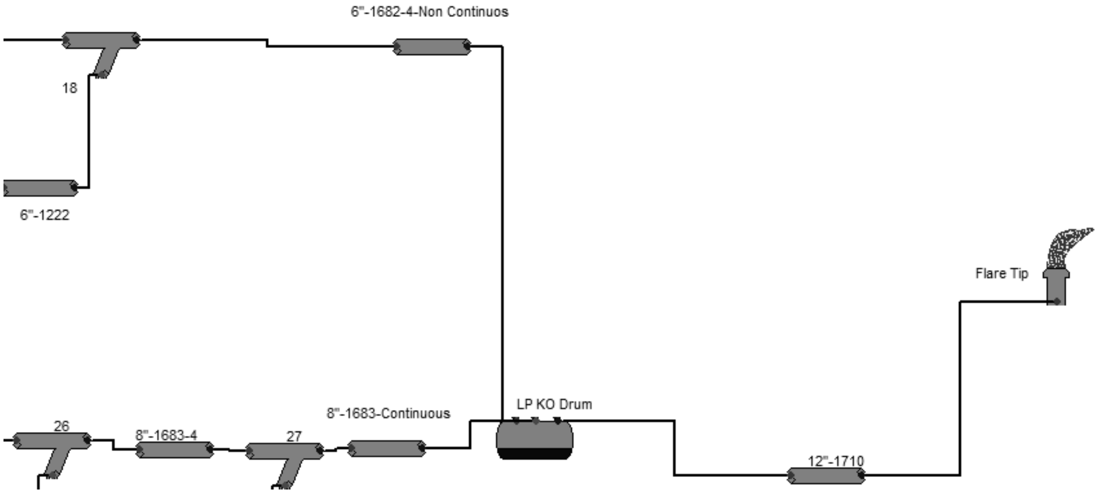

Figure 3: Part of LP flare network simulation area in FLARENET software

4.3 Modification in GRU package

During a renovation of platform in a frame of revamping project, several modifications have been carried out in the GRU package and many of the equipment are replaced with new ones. Moreover, the adequacy of mentioned equipment regarding size, internal and etc. are checked and improved in the case of inappropriate situation. As an example, the still column packing were replaced with structured packing Mellapak 250Y which alleviate the flooding of the bottom packed section and make contribution for effective TEG and gas separation. A new pressure control valve is also provided for fuel gas routes to surge vessel and still column. Even after revamping project, the black smoke is observed in the LP flare and the presence of TEG on the downstream of KO drum is not proven by the field experience.

4.4 Gas Momentum

The continuous operating conditions for Phase 1 LP flare is often low flow rates composed of purge gas (LP Fuel Gas), control valve leakage, or tank vapours. This mixture of gas exits at a low velocity and smokes continuously. A common smokeless method for low-pressure flares is to use a low-pressure air-assist. Despite high heating value, due to low pressure in the LP flare network of phase 1 platform the momentum of waste gas is not adequate and it burns without introduction of outside air or steam, thus, it needs assist media. Because of the off-shore restriction, using steam is not possible on phase 1 platform, thus, air assisted is more preferable. Air-assist flares use blowers to force air to the tip which is designed to promote air-fuel mixing and provide stable burning. The supplied air adds momentum and serves as a portion of the required combustion air.

5. Conclusion

Recent changes in the attitudes and policies of individuals and agencies worldwide have resulted in the need for fewer smoking flares, e.g. one of the goals of the Kyoto Protocol is a reduction in worldwide flaring. A good flaring management could lead to reduce the emission of toxic gas which ultimately minimizes the impact of flaring on the environment. One of the basic principles to limit the hazardous gas emission in the case that no flare gas recovery projects are feasible is to make flaring combustion as efficient as possible. Based on the present study, Incomplete burning on the flare tip, presence of liquid in the flaring gas, low heating value of the burning product and low gas momentum are the most common reasons for observing black smoke during flaring. The mentioned reasons are investigated for LP flare system of phase 1 platform specifically with in-depth knowledge including both theoretical and field experiences of veteran operators and it is concluded that the most probable reason is the low momentum of flaring gas mixture. According to common practice when waste gas pressure is low, steam or air need to be provided as assistance to improve the level of momentum and produce complete combustion and smokeless operation. Injection of steam is not feasible on phase 1 platform due to some reasons including unavailability of steam on the platform, steam boiler and steam delivery system specifically for the flare system is not cost effective and lack of space for required equipment and facilities. Therefore, the most suitable and cost effective air assisted design considering existing facilities and equipment with minimum changes and modifications is applicable for South Pars phase 1 platform.

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