SAFETY ASSESSMENT OF FLARE SYSTEMS BY FAULT TREE ANALYSIS
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ABSTRACT
Flaring is a combustion process of waste gases from the oil and gas industry. The escape of these gases from the flare stack without been burned is known as Flameout. These released gases can present human and environment toxicity as well as they can lead to a vapor cloud explosion (V.C.E), if conditions are provided. The flameout events which can occur by environmental, equipment and human factors have not received significant attention compared to other types of flare incidents, most probably due to the fact that they may stay unnoticed if detected and successfully reignited in the early hours. In this work we define some performance indicators extrapolated from a prepared fault tree. They are subsequently assessed through probabilistic methods to evaluate our system safety. The investigation carried out is aimed at better understanding of flameout occurrence mechanisms.

Keywords: flare system, flameout, modeling, fault tree analysis.

INTRODUCTION
Flare systems in oil and gas plants play critical roles in their safe operation. They are generally used to handle materials vented during normal operations, start-up, and emergency conditions and are designed to dispose safely the corresponding waste gases and discharged liquids. There are three main kinds of flare systems in oil and gas industry: elevated flares, ground flares and low pressure flares. Elevated flares are a normal feature of a refinery or a petrochemical plant and are handled under normal and emergency circumstances [1, 2].

The hazards associated with flare systems are numerous, among which, we can mention: embrittlement or corrosion due to low temperature causing failure of the pipe collection system in the flare system, an explosion in the flare system, heat radiation, liquid carryover from the flare, flameout (emission of toxic materials from the flare).

In the context of safety and environment impact of the flares systems, some authors have investigated the flaring reduction [3] or recovering [4, 5]. In this paper we focus on flare hazards, in fact on flare flameout hazard conditions using Fault tree analysis. The latter has been widely used to calculate the reliability of a complex system. It is a logical and diagrammatic approach to the evaluation of the possibility of an accident occurrence as a result from sequences and combinations of failure events [6].

Very few investigations on the flare flameout are described in the literature. The work of O. Zadakbar et al. [1] is focused on the flare flameout impact on the environment and human life.

This paper is organized as follows: In section 2,
we define our case study and we give the system’s descriptive figure. Section 3 introduces some formal definitions concerning the fault tree analysis and shows the developed fault trees with the failure rate of the elementary events. Section 4 presents the results obtained. Finally, we draw conclusions and discuss some future investigations.

EXPERIMENTAL

Case study
The case study referred to the work of LNG complex at GL1/Z-SONATRACH - Algeria, which comprised three flare systems: a cold flare system for gases of a temperature lower than 0°C, a hot flare for gases of a temperature higher than 0°C, and the tank flare system for excess vapors from the LNG storage tanks. The hydrocarbon gases entering the hot/cold flare systems in each unit flew through a main header to knockout drums where any hydrocarbon liquids present were removed and sent to the flare stack to be burned at a distance from the complex [7].

On the ground of the feedback experiences described in refs. [8 - 10], we concluded that the cold flare was the most exposed to a flameout risk and which is why we focused on it in our research. A descriptive figure of the steam assisted flare system is given (Fig. 1).

Analysis of a flameout incident
In order to identify the sequences of the probable causes of this incident, a fault tree analysis was carried out on the ground of the experience feedback of

Fig. 1. A steam assisted flare system [11].
Table 1. Occurrences probabilities (λ) of elementary events.

<table>
<thead>
<tr>
<th>Elementary event</th>
<th>Occurrence probability (λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure on ignition device</td>
<td>$1.14 \times 10^{-4}$</td>
</tr>
<tr>
<td>Ignition pipes clogged</td>
<td>$5.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>Mechanical failure</td>
<td>$1.38 \times 10^{-6}$</td>
</tr>
<tr>
<td>Instrumentation failure</td>
<td>$0.1 \times 10^{-6}$</td>
</tr>
<tr>
<td>Manual valve blocked close*</td>
<td>$0.29 \times 10^{-6}$</td>
</tr>
<tr>
<td>Operator fault</td>
<td>$2.85 \times 10^{-5}$</td>
</tr>
<tr>
<td>Condensate presence in the FG</td>
<td>$1.14 \times 10^{-4}$</td>
</tr>
<tr>
<td>Pipe not drained</td>
<td>$3.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>Nitrogen valve opened</td>
<td>$3.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>FG supply interrupted at source</td>
<td>$3.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>Isolation of the FG line for works</td>
<td>$1.14 \times 10^{-4}$</td>
</tr>
<tr>
<td>Wind Speed $&gt; 120$ km/h</td>
<td>$5.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>Pumping phenomenon</td>
<td>$2.28 \times 10^{-4}$</td>
</tr>
<tr>
<td>Relief PCVs closed</td>
<td>$1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Switching to another flare</td>
<td>$5.7 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

FG: Fuel gas.
PCVs: Pressure control valves.
*: Probability from OREDA database [13]. The others probabilities are made by a voting system from a group of qualified plant staff (production – technical – safety) taking into account information feedbacks and some statistics.

Fig. 2. Flameout fault tree.
GL1/Z - Sonatrach complex [8 - 10] and that of other complexes [12] as well as of the technical knowledge about the flares systems.

The analysis by a fault tree known in the literature as “FTA” (fault tree analysis) is a deductive method, starting from elementary events and leading to a undesirable event (top event). The latter is obtained by a hazard study for a given system. FTA is usually used to predict the reliability of complex systems in many engineering fields, such as nuclear, space and aeronautics, oil, gas and petrochemical industry, etc. The failure probabilities of the components are considered as exact values in conventional fault tree analysis. However, it is often difficult to estimate them precisely because of insufficient data or vague characteristics of the events.

Definition of events:

The principal event (flare flameout) is the undesirable event that we are studying.

The intermediates events (flame detachment, a defect in the ignition pilot system, etc.) refer to the causes for other events. For example, the combination of intermediate events leads to the principal event.

The elementary events correspond to the events at the most detailed level of the system analysis.

Figs. 2, 3 and 4 depict the fault trees of our system.

RESULTS AND DISCUSSION

The Fault Tree module of GRIF (graphical interface for reliability) software developed by SATODEF & TOTAL [14] is used to calculate the probabilities concerning our system from the elementary failure rates given in Table I.

The probabilities (λeq) generated are as follows:
F1: Probability of flame detachment.
F2: Probability of pilot low supply pressure.
F3: Probability of flare flameout.

The performances set for our system are:
P1: ability to avoid flame detachment.
P2: ability to avoid pilot low supply pressure.
P3: ability to avoid a flameout.

The failure rates (F1, F2, and F3) are considered to be unreliable, so:
P = 1 - F
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The calculations show that the performances indicators of our system can reach more than 99%. This is due to implementation of an adequate protection and prevention barriers set up in our case study.

CONCLUSIONS

Even though flare flameout is not a frequent risk like others flare incidents (explosion, heat radiation, liquid carryover from the flare), it can be very dangerous because of the further accidents it can generate in prolonged duration with risks of toxic emission or ignition and vapor cloud explosion. By evaluating the performances indicators of a LNG flare, we can conclude that the safety level of our system in respect to a flameout incident is acceptable.

We propose the method developed for safety assessment of systems where specific incidents are difficult to be predicted. Although a significant research effort has been made to improve the knowledge on this phenomenon, future work is required to evaluate the performance of complex system in the field of safety.

Acknowledgments

The authors thank the chief of GP2Z complex - SONATRACH Technical Department for his help.

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