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Assessing Fire and Explosion Risks Associated with Gas Turbines Using the Fire and Explosion Index

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ABSTRACT

Gas turbines are extensively used across various industries, such as power generation, aviation, and petrochemical sectors, where they handle flammable fuels and operate in conditions with inherent fire and explosion risks. This research paper provides a detailed analysis of applying the Fire and Explosion Index (F&EI) to evaluate the risks linked to gas turbines. The study highlights the importance of using the F&EI as a proactive tool for identifying potential hazards and developing effective safety strategies. The research findings reinforce the value of this method in classifying and prioritizing safety measures to ensure a suitable level of safety is maintained.

1. INTRODUCTION

Gas turbines operate under high temperatures and pressures, making them particularly vulnerable to catastrophic failure in the event of a fire or explosion. This can result in extensive damage and potential destruction of the turbine and surrounding infrastructure. A fire or explosion accident in a gas turbine can have significant and far-reaching consequences.

The need for fire risk assessment in a gas turbine is paramount, given the intrinsic flammability of the fuels they operate on and the high temperatures and pressures involved. Gas turbines are used in critical applications such as power generation, aviation, and industrial processes, making the potential consequences of a fire incident severe, both in terms of safety and economic impact. Evaluating fire risks using tools like the Fire and Explosion Index (F&EI) is essential to identify vulnerable areas and implement mitigation measures **[1]**. It allows for the development of comprehensive fire prevention, emergency response, and safety strategies, by assessing the fire and explosion risk and classify it, so provides prioritization regarding maintenance and protection programs. Ensuring that the system under control operates with the suitable level of protection **[2]**.

2. LITERATURE REVIEW

The fire and explosion index is a widely recognized tool in the risk assessment of industrial facilities, offering a structured framework to evaluate potential hazards and implement safety measures. These indices play a critical role in identifying high-risk scenarios, estimating the likelihood of accidents, and prioritizing mitigation strategies, ultimately contributing to safer industrial operations. A significant body of research highlights the importance of fire and explosion indices in industrial safety. For instance, indices such as the Mond Index and the Safety Weighted Hazard Index (SW&HI) have been instrumental in pinpointing hazardous processes, facilitating targeted risk management strategies **[3]**. Additionally, these indices provide quantitative outputs, enabling comparative evaluations across facilities and processes to prioritize safety measures effectively **[3]**. Regulatory frameworks such as the Seveso III directive further underscore their importance by mandating detailed risk assessments for facilities handling hazardous substances, emphasizing the need for robust methodologies in fire and explosion risk analysis **[4]**.

Methodological advancements in fire and explosion risk assessment have also been the subject of extensive study. Semi-quantitative methods, which integrate multiple factors to provide comprehensive risk evaluations, have been extensively discussed in the literature [5]. In recent years, the integration of semi-quantitative and probabilistic approaches has emerged as a promising direction. This hybrid methodology enhances the precision of risk evaluations, enabling more informed decision-making in safety management [6].

Despite their utility, limitations in fire and explosion indices are acknowledged in the literature, particularly their reliance on qualitative assessments, which may lead to oversights in certain risk evaluations. Researchers emphasize the need for continuous improvement and adaptation of these methodologies to address emerging risks and ensure comprehensive safety measures. This evolving focus reflects a broader trend in industrial safety research, aiming to develop more robust, accurate, and adaptable tools for hazard assessment.

3. SYSTEM IDENTIFICATION

Gas turbines are complex machines used to convert fuel energy into mechanical power through combustion and rotation. They are commonly used in power plants, particularly in combined cycle systems, to generate electricity. Here is an expanded look into gas turbines, along with a discussion on potential fire and explosion hazards within these systems [7].

3.1 Overview of Gas Turbines

A gas turbine generally consists of three main parts [8]:

Compressor: Draws in and compresses ambient air to high pressure.
Combustor: Mixes the compressed air with fuel, usually natural gas, and ignites the mixture to produce high-temperature, high-pressure exhaust gases.
Turbine: The hot gases expand through turbine blades, which convert the thermal energy into mechanical power. This power is used to drive the compressor and, in power applications, to generate electricity.

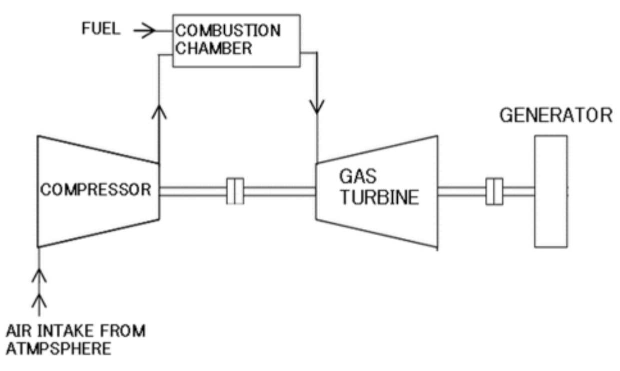

Figure 1: Block diagram of gas turbine.

3.2 Fire and Explosion Scenarios in Gas Turbines

Fires and explosions in gas turbines are rare but can have severe consequences, including damage to equipment, prolonged downtime, and safety risks. Here is how these incidents can occur:

Fuel Leaks:
Gas turbines typically use fuels like natural gas, which is highly flammable. If a leak develops in the fuel supply line, fittings, or fuel injectors, gas can accumulate in confined areas. When exposed to an ignition source (like hot surfaces in the combustion chamber or a spark during start-up), the leaked gas can ignite, leading to a fire or even an explosion in extreme cases.

Hot Surface Ignition:
During operation, components of the turbine, particularly in the combustor, reach extremely high temperatures. If fuel or oil leaks onto these surfaces, it can spontaneously ignite. This scenario is particularly dangerous during shutdown when cooling mechanisms are less effective, and hot parts can stay heated long enough to ignite leaked fuel.

Delayed Ignition:
When starting up a gas turbine, fuel is injected, and ignition follows. If there’s a delay in ignition or if the fuel accumulates before ignition, a larger-than-usual volume of fuel may be present when the spark occurs. This can cause a "flashback" or explosion as the accumulated fuel ignites suddenly.

Combustion Instability:
Combustion instability happens when there are fluctuations in the combustion process. Factors like improper air-fuel ratios or contaminants can lead to pockets of unburned fuel, causing explosive "popping" or “puffing” within the combustion chamber. In severe cases, these instabilities can lead to thermal and pressure stresses, resulting in equipment damage and fire risks.

Lubrication System Fires:
Gas turbines have a complex lubrication system that prevents friction damage to moving parts. Leaks in the lubrication system can lead to oil dripping onto hot surfaces, resulting in fires. As the lubricant is flammable, it can burn readily and spread, posing a serious fire risk if not managed properly.

Electrical Failures:
Gas turbines rely on a variety of electrical components and control systems to regulate operation. Short circuits or electrical faults can produce sparks, leading to ignition if flammable materials are nearby. Electrical issues may also cause sensors to malfunction, potentially leading to uncontrolled fuel flow or delayed ignition.

4. METHODOLOGY

4.1 Fire and Explosion Index

The Fire and Explosion Index (FEI) is a quantitative risk assessment tool commonly used in the process industries to evaluate the potential risk of fire and explosion incidents in a facility [9]. It provides a systematic way to estimate potential hazards and assess the impact of a fire or explosion on the plant, personnel, and environment [9]. Developed by Dow Chemical Company, FEI is part of the Dow's Fire and Explosion Hazard Classification Guide, widely adopted for process safety and hazard management. This index supports decision-making by quantifying potential hazards and facilitating risk management efforts [10].

The FEI is calculated by scoring various factors related to the materials, process conditions, and equipment in a given section of a plant [11]:

Material Factor MF, This reflects the inherent hazard associated with the chemicals used, based on flammability and reactivity.

General process hazard factor, these factors account for the specific conditions of the process, like operating pressures, temperatures, and the presence of potential ignition sources.

Special process hazard factor, these factors account for additional safety issues, such as poor equipment condition or insufficient emergency response systems.

The result is a numerical value, which can be used to assess the relative risk of fire and explosion hazards within a facility. A higher F&EI value indicates a greater potential for these hazards, highlighting areas that require more robust safety measures, enhanced storage practices, or improved emergency response plans. By identifying and calculating the F&EI, organizations can proactively address potential risks and implement strategies to mitigate them, thereby enhancing safety and minimizing the likelihood of fire and explosion incidents [12].

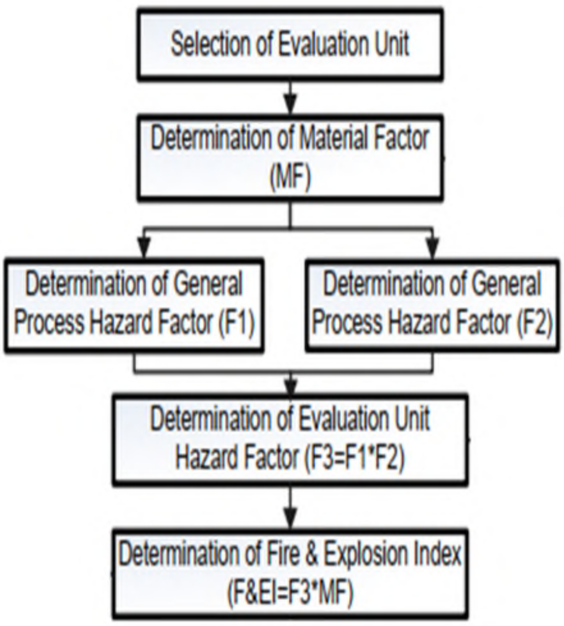

Figure 2: Diagram of F&EI determination

5. CASE STUDY

5.1 Calculation of F&EI

Step 1: Determine the Material Factor (MF)

For natural gas, the Material Factor is commonly set to **16**, based on its flammability, volatility, and reactivity properties. This is a standard value used in many FEI applications for natural gas [13].

Step 2: Assign General Process Hazard Factors (F1, F2, etc.)

These factors reflect the specific conditions under which the gas turbine operates. Here are the most relevant factors and typical ranges based on typical gas turbine operating conditions [14].

- **Operating Pressure (F1):** For high-pressure systems, such as a gas turbine combustion chamber with pressures in the range of 10–20 bars, the factor typically ranges from **0.8 to 1.0.** We assume **F1 = 1.0** as it represents high pressure.
- **Operating Temperature (F2):** Gas turbines reach very high temperatures during combustion (often 1,000°C or more), which poses a significant fire risk. This often results in an **F2 factor of 1.2.**
- **Material Handling and Proximity to Ignition Sources (F3):** Since the fuel supply and combustion are integral to the turbine operation, we can assume the system is close to ignition sources, which yields **F3 = 1.1.**
- **Ventilation (F4):** Proper ventilation is crucial to prevent gas accumulation. In a well-ventilated outdoor setting, **F4** could be **0.8**; however, for an indoor or semi-confined setup, **F4 = 1.0** would be more appropriate. We assume **F4 = 1.0.**

Step 3: Assign Special Process Hazard Factors (F5, F6, etc.)

These factors address additional safety and design issues in the gas turbine system [14].

- **Inventory Factor (F5):** Since gas turbines usually have a continuous flow of fuel rather than large stored quantities, **F5** might be **0.9.**
- **Equipment Condition (F6):** in this case of study maintenance is frequent and equipment is in good condition, **F6 = 0.9** be conservative.
- **Emergency Shutdown Systems (F7):** the turbine has a robust emergency shutdown and suppression system, **F7** is **0.8** for this calculation.

Step 4: Calculate the Fire and Explosion Index (FEI)

The FEI is calculated as:

FEI=Material Factor × (F1×F2×F3×F4×F5×F6 ×F7) (1)

Substituting in the values:

FEI=16 × (1.0×1.2×1.1×1.0×0.9×0.9×0.8)

The calculated Fire and Explosion Index (FEI) for the gas turbine system using natural gas as fuel is approximately **13.69.**Interpretation of the FEI Score

Table 1 is a listing of the F&EI values versus a description of the degree of hazard that gives some relative idea of the severity of the F&EI **[14]**.

Table 1: Degree of hazard for F&EI

F&EI index range	Degree of hazard
1-60	Light
61-96	Moderate
97-127	Intermediate
128-158	Heavy
159-up	Severe

Light Hazard (1-60): Generally low fire and explosion risks. Often managed with standard safety protocols **[15].**

Moderate Hazard (61-96): Higher risk, typically found in areas with some flammable materials or mild process conditions.

Intermediate Hazard (97-127): Requires more extensive safety measures. Often seen in facilities with reactive chemicals or significant ignition sources **[15].**

Heavy Hazard (128-158): High-risk operations with elevated fire or explosion potential. strong containment, isolation, and emergency systems are essential like liquefied petroleum gas Stations **[16].**

Severe Hazard (>158): Extreme fire and explosion risks, demanding comprehensive safety protocols, possibly with restricted access and specialized containment.

With an FEI score of 13.69, our gas turbine system falls into the Light Hazard category, indicating relatively low fire and explosion risk. This score suggests that while basic fire safety measures should be in place, no extraordinary controls are required.

5.2. The Area Of Exposure

- **The radius of exposure**

The F&EI, which was determined previously, is converted to a Radius of Exposure by multiplying it by a factor of **0.84** or by using Figure 3. This radius of exposure is to be shown on plot plans for the Manufacturing unit with the primary item of process equipment as the center of a circle using the Radius of Exposure. This is determined in feet **[12].**

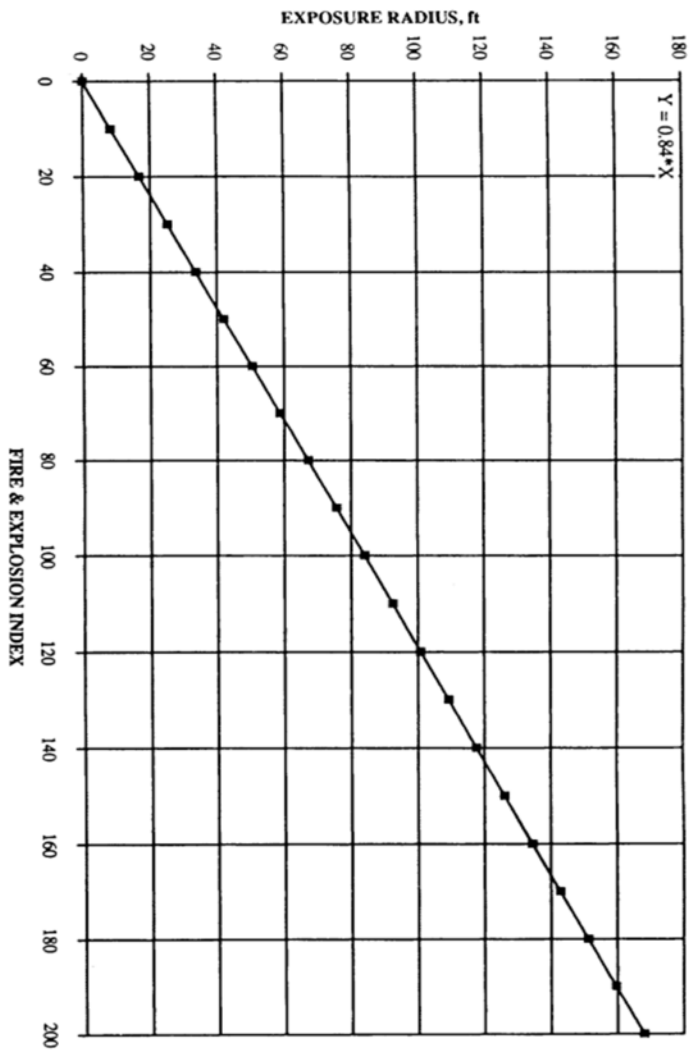

Figure 4: Radius of exposure

R= F&EI * 0.84 (2)

R= 13.69*0.84

= 11.5 feet = 3.5 m

- **The area of exposure**

The Radius of Exposure defines an Area of Exposure. The Area of Exposure is calculated with the equation:

Area = π*R² (3)

Area = 38.5 m²

The volume is expected to be the amount of the Manufacturing Unit at risk in the event of a fire or explosion caused by an incident in the F&EI process under study. Where the height of exposure is equal to the radius of exposure.

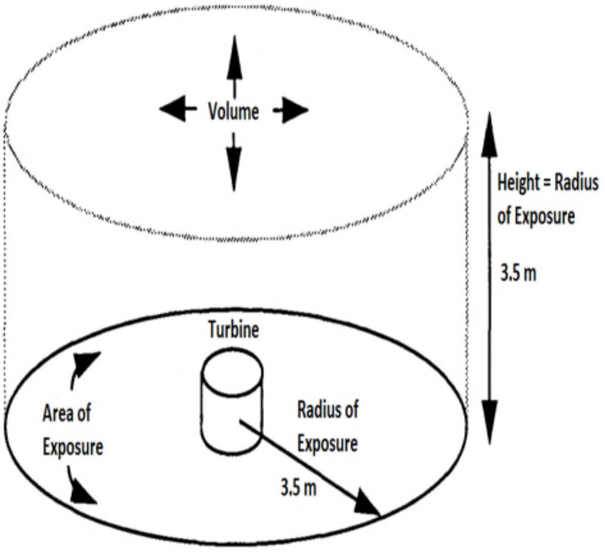

Figure 4: the volume of exposure of fire and explosion event in a turbine system

6. CONCLUSION

In conclusion, the utilization of the Fire and Explosion Index (F&EI) in risk assessment has proven to be a applicable and simple tool in enhancing safety practices across various industrial sectors. This research has underscored the significance of F&EI as a quantitative method for evaluating the potential fire and explosion hazards.

By considering factors such as the type of flammable materials, process characteristics, possible scenario, F&EI offers a comprehensive view of the inherent risks and supports the development of robust safety strategies and emergency response plans.

Moreover, this work provide an example of the applicability of the F&EI index in risk assessment in a turbine section, spotting the lights on this quantitative method as an effective approach to assess fire and explosion risks. The application of F&EI index in the units of the plants allow the classification and prioritizing the units due to their vulnerability to fire and explosion hazard, which allow the optimization of emergency plans and scheduling the procedure of maintenance of prevention equipment and firefighting systems.

In acknowledging the robustness of our study, it is equally important to candidly address its limitations, which offer valuable insights into the boundaries and considerations of our research findings. FEI primarily focuses on fire and explosion hazards but does not cover all types of industrial hazards (e.g., toxic release). In other hand the F&EI index still need the judgment of the expertise people, which can be vary from person to another, the need of human experience and judgement in risk assessment makes this procedure limited and subject to agreement

between all parties participating in it. Therefore, it is more qualitative in some aspects, as it relies on a scoring system that might vary in accuracy based on subjective judgments of process conditions.

While FEI gives an initial risk assessment of fire and explosion potential, other assessment methods (like LOPA) provides a more comprehensive assessment of whether sufficient protections are in place and whether additional protection layers are necessary. Through future studies, a combination approach between FEI and assessment method ensures that all risk factors are appropriately mitigated for safe operation

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