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Analysis of Fire Protection System Requirements in Onshore Oil and Gas Exploration and Production Gathering Stations

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Fire Protection, Oil and Gas Gathering Station, NFPA, API, Fire Zone.

ABSTRACT
This research aims to evaluate and analyze the technical requirements of the fire protection system at the facility to ensure compliance with international safety standards and actual field conditions. The theoretical framework and evaluation instruments are based on National Fire Protection Association (NFPA) standards, including NFPA 11 (*Foam Systems*), NFPA 15 (*Water Spray Fixed Systems for Fire Protection*), NFPA 20 (*Installation of Stationary Pumps for Fire Protection*), and NFPA 2001 (*Clean Agent Fire Extinguishing Systems*), as well as standards from the American Petroleum Institute (API), such as API 2030 and API RP 2001. The research methodology uses an applied case study with a quantitative technical approach, consisting of field data collection, fire zone classification, determination of worst-case fire scenarios, and hydraulic calculations for water, foam, and pump pressure requirements. The analysis classifies the M-8 Gathering Station into eight fire zones, with Fire Zone 1 (*Crude Oil Storage Tank Area*) identified as the critical design case, having the highest fire-water demand of 1,195 GPM. The infrastructure analysis shows that the water pond capacity of 1,386 m³ and foam tank capacity of 5,151 liters are sufficient to meet a four-hour operational requirement. Hydraulic analysis indicates a required pump discharge pressure of 132.43 psig to ensure effective fire suppression. The study concludes that the designed fire protection system meets safety standards and recommends the installation of appropriate nozzles and clean agent systems to enhance fire safety and operational reliability at Gathering Station M-8.

Introduction

The oil and gas industry has a strategic role in supporting energy security and improving a country's economy (Elkhatat & Al-Muhtaseb, 2024; Fu & He, 2024; Olujobi et al., 2022). Facilities such as oil and gas gathering stations are an important part of the upstream oil and gas production chain, where the collection, separation, and flow of production fluids occur. The complexity of the system, the presence of flammable hydrocarbon fluids, and dynamic operating conditions make this facility highly susceptible to fire.

National Fire Protection Association (NFPA) and American Petroleum Institute (API) standards are global references in the design and management of fire protection systems in the oil and gas industry (Jorfi et al., 2019; Junaedi, 2020). These standards provide technical guidance on hazard classification, selection of active and passive protection types, and system testing and inspection (Liu et al., 2021; Salama & El-Sayed, 2021). However, the implementation of these standards in the context of facilities in Indonesia is still very diverse and requires a comprehensive evaluative study to ensure suitability with the actual conditions of the facilities and potential hazards (Lai et al., 2020; Sari & Adi, 2021). PT XYZ is a company engaged in upstream oil and gas exploration and production operating in the land area of Kutai Kartanegara Regency, East Kalimantan. In carrying out operational activities to produce oil and gas, the company operates temporary oil and gas collection station facilities that receive fluids from oil and gas wells before the next process is carried out, namely the delivery of oil and gas to the main station facilities for further processing (Wibowo & Nugroho, 2022).

In oil and gas collection station facilities, various equipment and buildings are operated, where their operation presents a potential risk of fire (Zhao et al., 2019; Rahman et al., 2021). The flammable characteristics of the fluids, high operating pressures, and the complexity of the equipment systems make the facility vulnerable to potential fires (Zhou & Zhao, 2020). In this context, a fire protection system is not only optional but a vital component to ensure the continuity of operations, asset protection, and worker safety (Xu et al., 2020; Sazali & Ab Rahman, 2021). Despite the presence of an existing fire protection system installed during the initial design of the oil and gas collection station, it is still necessary to evaluate its effectiveness and conformity with international standards in a comprehensive and systematic manner (Gao et al., 2021; Zhang & Zhang, 2019). This evaluation not only assesses the availability of existing fire protection systems but also examines the adequacy of these systems to function effectively in the event of a fire so that greater losses can be prevented (Ravi et al., 2020; Zhang et al., 2021).

Several previous studies have discussed fire protection systems in the oil and gas industry. Al Omari et al. (2016) conducted a study on the life extension of crude oil storage tanks and the importance of passive and active protection systems in preventing catastrophic failure. Furthermore, Fedriando et al. (2019) highlighted the operational challenges in mature fields such as the Sanga-Sanga Block, including the need for improved safety systems. Research by Bayareh and Mohammadi (2016) focused on the optimization of gas compressor stations, which included safety aspects such as fire detection and suppression. However, these studies have not specifically addressed the integration of NFPA and API standards in evaluating fire protection systems at the gathering station level, particularly in the context of Indonesian onshore facilities.

Although various studies have addressed fire protection in oil and gas facilities, there remains a gap in the literature regarding a comprehensive, standards-based evaluation of active fire protection systems at onshore gathering stations. Most previous research has focused on individual components or specific equipment without considering the system, including fire zone classification, hydraulic analysis, and the integration of foam, water spray, and clean agent systems. This study fills that gap by conducting a holistic evaluation of the fire protection system at the M-8 Gathering Station using NFPA and API standards as the primary framework. The novelty of this research lies in the application of an integrated technical evaluation approach that includes fire zone mapping, worst-case scenario analysis, hydraulic calculations, and verification of support system capacities, all of which are rarely conducted simultaneously in a single study.

The urgency of this research is strengthened by the trend of fire incidents that are still occurring in oil and gas facilities, including in onshore areas. A thorough evaluation of fire protection systems based on the NFPA and API approach is expected to provide recommendations for relevant, practical, and appropriate improvements according to the actual needs of the field. With this approach, the research will contribute not only to the technical aspects but also to the strengthening of internal policies and regulations within the national oil and gas industry. Thus, the background of this study emphasizes the importance of re-evaluating fire protection systems in oil and gas collection station facilities to improve facility resilience to potential fires.

This research aims to evaluate the technical requirements of the fire protection system at the M-8 Gathering Station based on NFPA and API standards, including the classification of fire zones and the determination of the worst-case fire scenario as the basis for system design. Furthermore, this study calculates the firewater and foam concentrate requirements, as well as the hydraulic performance of the fire pump system, to assess the adequacy of the existing fire protection infrastructure and provide recommendations for system improvement. The benefits of this research are directed toward three main aspects. For the company, this research provides a comprehensive evaluation and technical recommendations to improve the reliability and effectiveness of the fire protection system, thereby reducing the risk of fire-related losses. For the industry, it contributes to the development of best practices in fire protection system design and evaluation for onshore oil and gas facilities in Indonesia. For academia, this research enriches the literature on fire safety engineering in the oil and gas sector, particularly in the application of NFPA and API standards in tropical, developing-country contexts.

Materials and Methods

This study used an applied case study research design at PT XYZ, particularly in the development of oil and gas fields, including gathering stations. A review was conducted on the availability of existing fire protection facilities at the gathering station, and recommendations were made regarding the scope of equipment that needed to be added. The design was divided into six categories, namely:

The determination of fire zones was carried out by classifying areas based on the minimum distance between equipment of 50 ft and the presence of physical barriers such as firewalls or bundwalls, where all equipment within one bundwall was assumed to constitute a single fire zone. The mapping of fire extinguishing equipment was conducted by considering the effective range of fire hydrants and fire monitors that could reach fire areas within a radius of 75–100 ft, in accordance with the Pertamina Hulu Sanga Sanga Fire and Safety System Design Manual. The calculation of firewater requirements was performed based on the total extinguishing water flow rate for each fire zone, including the water requirement for the cooling process of equipment based on a specified surface area with reference to American Petroleum Institute Standard 2000, which specifies 0.25 gpm/ft² for vessels, 0.15 gpm/ft² for tanks, 0.30 gpm/ft² for buildings and process structures, and 0.50 gpm/ft² for pumps. For tanks, the working liquid level was assumed to be 75%, so the area requiring cooling was calculated as 25% of the total surface area of the tank.

The design of the firewater pond was determined based on the maximum water demand obtained from the firewater requirement calculations within one fire zone, with a capacity capable of supporting the extinguishing process for four hours. The design of the firewater pump referred to National Fire Protection Association Standard 20, which specifies the use of a dedicated fire pump operating in a redundant configuration, supplied by reliable power sources, and installed within a pump building, with capacity and head sufficient to meet the maximum flow rate and maintain a minimum pressure of 100 psig at the fire hydrants and fire monitors. Meanwhile, the design of standpipes consisted of vertical pipes directly connected to the firewater distribution network and hydrants or fire monitors, with dimensional and flow rate criteria that referred to National Fire Protection Association Standard 14.

Table 1. Standpipe size based on capacity and coverage radius

Total Accumulated Flow		**Total Distance of Piping from Farthest Outlet**		
L/min	**gpm**	<15.2 m (<50 ft	15.2–30.5 m (50–100 ft)	>30.m(>100ft)
379	100	2	2 ½	3
382–1893	101–500	4	4	6
1896–2839	501–750	5	5	6
2843–4731	751–1250	6	6	6
4735	1251 and over	8	8	8
Note: For SI units, 3.785 L/min = 1 gpm; 0.3048 m = 1 ft				

Source: NFPA 14 (2024) – Standard for the Installation of Standpipe and Hose Systems

Location and time of the study

PT XYZ's field is located in Sanga-Sanga District, Kutai Kartanegara Regency, East Kalimantan, about 50 km north of the city of Balikpa4pan. Coordinates 0.8°s - 1.0°s and 117.0°e - 117.3°e. The north is bordered by the Semberah field, 5the south is close to the pamaguan field, the west is bordered by the Mahakam River, the east is bordered by the Bekapai field. Figure 11 is a geographical description of the field surface of PT XYZ.

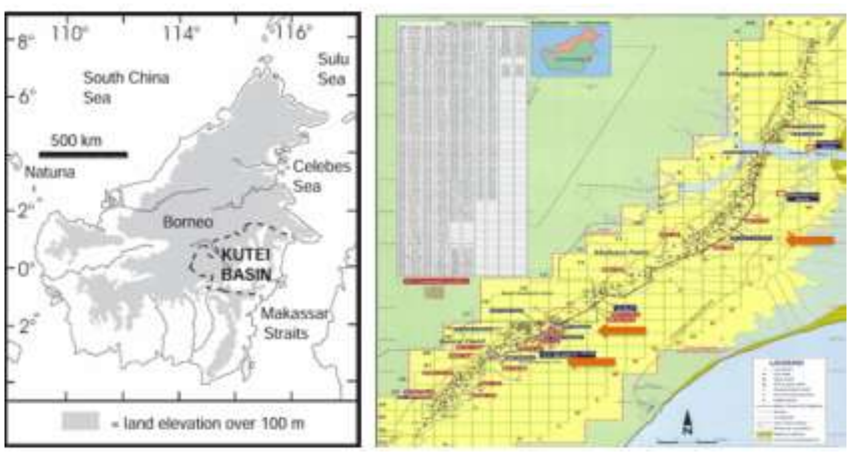

Figure 1. Field surface of PT XYZ

Source: kahfie *et al.*, 2017

Results and Discussions

Fire zone determination

Vulnerability and potential fire hazard analysis at PT XYZ's m-8 field collection station facility resulted in a detailed fire zone mapping, which is presented in table 3. This mapping is the foundation for all calculations of fire water needs and the selection of the type of active protection system to be applied. In total, the facility is classified into eight different zones, reflecting the grouping of equipment based on physical proximity and similarity of process hazards.

Table 2. Classification of PT XYZ collection station fire zone

Fire zone	Area	Equipment
Fire zone 1	Storage tank crude oil	3 ea storage tank (T-3701), T-3700, & T-3702
Fire zone 2	Manifold & separator	- V-3460 (oil separator)- V-3470 (oil separator)- V-3450 (oil test separator)- V-3150 (vlp gas separator)
Fire zone 3	Pump building	- P-3750a (crude transfer pump)- P-3750b (crude transfer pump)- P-3750c (crude transfer pump)
Fire zone 4	Compressor building	- V-3200 (fuel gas scrubber)- V-3350 (instrument gas accumulator)- Vlp compressor C-8200 & hp compressor C-8400- Vlp rental compressor crm-02- Asc. Gas compressor (C-3570)
Fire zone 5	Condensate storage tank	- Tank storage T-3720- Flare kod V-3360- Vlp condensat pump (3374a/b)
Fire zone 6	Electrical building	Generator & switch gear
Fire zone 7	Burn pit	Burn pit
Fire zone 8	Control room building	Control room main panel

Source: Results of field analysis and classification based on the Pertamina Hulu Sanga Fire System Design Guidelines (2019)

Figure 2. Distribution of fire zone area of PT XYZ collection station

Source: Results of mapping and spatial analysis at Gathering Station M-8 PT XYZ (2025)

Fire extinguishing scenario determination & fps availability review

Each fire zone has a specific extinguishing system against the type of equipment it protects. For example, for fire zones where equipment such as production tanks must have a water sprinkler system, foam chamber, and fire hydrant/fire monitor. For fire zones, other than tanks, it is enough to have a water sprinkler and fire hydrant/fire monitor. For electrical equipment and switch gear, fire suppression system or CO2 system is used for compressor building. Based on the results of the review of fps availability, some fire zones are not protected so additional fire hydrants and fire monitors are also needed. The following is the extinguishing scenario for each fire zone in Table 4.

Tabel 3. ***Fire zone area***

Fire zone	Area	Equipment	Fire Protection System Needs	Fire Scenarios
Fire zone 1	Storage tank crude oil	3 ea storage tank (T-3701), T-3700, & T-3702	- Water sprinkler active - Foam chamber active - 2 fire monitor (fm-1 & fm2) - 1 fire hydrant (fh-1)	Combination Fire: Open surface fire and Confined fire or deep seated fire
Fire zone 2	Manifold & separator	- V-3460 (oil separator) - V-3470 (oil separator) - V-3450 (oil test separator) - V-3150 (vlp gas separator)	- Water sprinkler active - Fire hydrant (fh-2) - Fire hydrant (fh-3)	Open surface fire
Fire zone 3	Pump building	- P-3750a (crude transfer pump) - P-3750b (crude transfer pump) - P-3750c (crude transfer pump)	- Fire hydrant (fh-4)	Open surface fire
Fire zone 4	Compressor building	- V-3200 (fuel gas scrubber) - V-3350 (instrument gas accumulator) - Vlp compressor C-8200 & hp compressor C-8400 - Vlp rental compressor crm-02 - Asc. Gas compressor (C-3570)	– Fire hydrant (fh-5) – Co2 or halon suppression (fire suppression)	Confined fires or deep seated fires
Fire zone 5	Condensate storage tank	- Tank storage T-3720 - Flare kod V-3360 - Vlp condensat pump (3374a/b)	– Water sprinkler active – Foam chamber active – Fire hydrant (fh-6) – Fire monitor (fm-3)	Combination Fire: Open surface fire and Confined fire or deep seated fire
Fire zone 6	Electrical building	Generator & switch gear	– Fire suppression – Fire hydrant (fh-7)	Confined fires or deep seated fires

Fire zone 7	Burn pit	Burn pit	– Fire hydrant (fh-8)	Open surface fire
Fire zone 8	Control room building	Control room main panel	– Fire hydrant (fh-9)	Open surface fire

Source: Results of field analysis and verification at Gathering Station M-8 PT XYZ (2025)

A map of the fire system's coverage area of the facility, where the orange circle represents the fire hydrant's protection range, while the red circle represents the fire monitor's spray range. This mapping is used to ensure that all areas at risk of fire, particularly in hydrocarbon processing and storage facilities, have been adequately covered by an active extinguishing system, both for direct extinguishing needs and cooling of surrounding equipment. Figure 3 is a mapping of fire hydrant & fire monitors at PT XYZ collection stations.

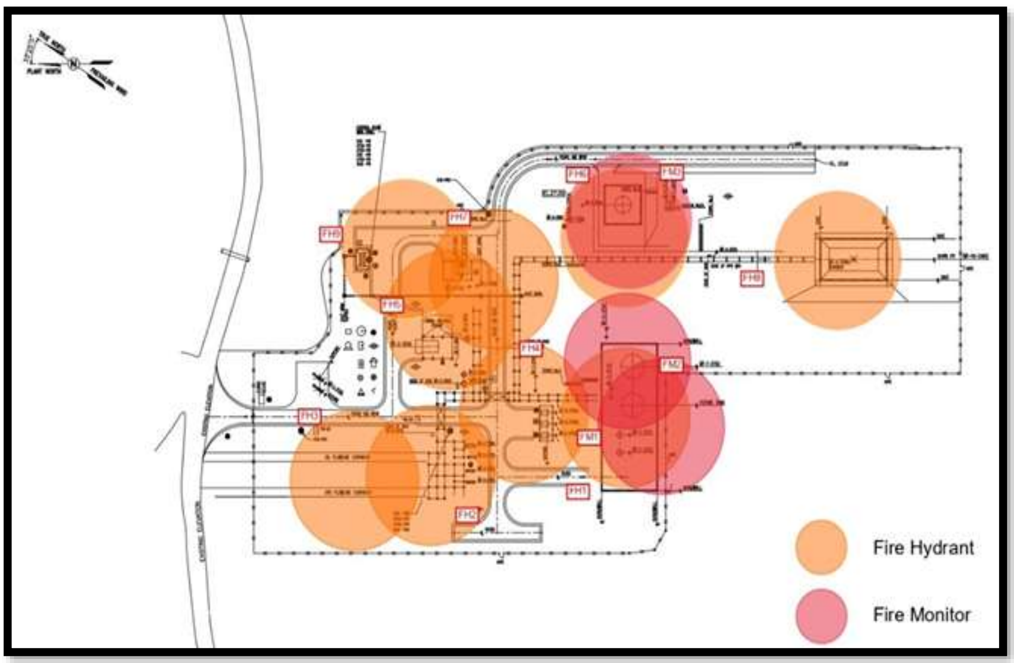

Figure 2. Mapping plan for fire hydrant & fire monitor at PT collection station

Source: Results of the redesign of the fire protection system layout based on NFPA 24 and field observations (2025)

Analysis of fire water needs at collection station facilities shows that each fire zone has different characteristics and extinguishing water needs. Fire zone 1 in the crude oil tank area is designated as a critical design case because it has the highest total water demand of 1,445 gpm, which is a combination of the need for equipment cooling and manual operation using fire hoses and fire monitors. Fire zone 2 which includes the manifold and separator requires a total of 642 gpm, while fire zone 3 in the pump building requires 389 gpm. For fire zone 4 (compressor building), water requirements are limited to manual operation of 250 gpm. Fire zone 5 in the condensate storage tank area has a relatively high water requirement of 938 gpm due to a combination of cooling of tanks, vessels, pumps, and manual protection. The fire zone 6 (generator and switchgear), fire zone 7 (burn pit), and fire zone 8 (control room) are each allocated a minimum requirement of 250 gpm for manual extinguishing. Based on the maximum requirement, the water pond calculation shows that a minimum working volume of 1,363 m³ is required to support the operation of two fire pump units for four hours. The design of the water pond with a capacity of 1,386 m³ was declared adequate because it exceeded the minimum requirements and guaranteed the reliability of the fire protection system in the worst fire conditions.

Based on the NFPA-14 standard, the total volume of water in a water pond includes the need for fire water. In this study, it is assumed that the extinguishing scenario is carried out for a fire case in one of the fire zones. The highest amount of fire water flow rate is found in the fire zone scenario-1 (storage tank area) at m-8, which is 1445 gpm. Figure 4 shows the location of the water pond plan at the PT XYZ collection station.

Figure 4. Location of the water pond plan at the PT XYZ collection station
Source: Technical documentation and field verification in the Gathering Station M-8 environment of PT XYZ (2025)

Analysis of fire water and foam needs was carried out to determine the capacity of the fire protection system at Gathering Station M-8. The total flow rate of the foam solution for critical areas (fire zones 1 and 5) is 146.1 gpm with a concentration of 3%, so the minimum volume of foam concentrate required is 1,049 liters. The foam tank is planned to have a capacity of 5,151 liters, enough to meet operational and reserve needs. The design of the water spray nozzle for tanks and separators uses a fixed water spray system (deluge system). For the T-3701 and T-3700 tanks, 22 nozzles are required with a total water requirement of 63 m³/h (276.6 usgpm). The T-3702 tank requires 26 nozzles with a total water of 76 m³/h (335.1 usgpm), being the main component of fire water demand in fire zone 1. The oil separators V-3460, V-3470, V-3450, V-3150, and T-3720 tanks have an actual water requirement of 149.1 each; 116,5; 93,4; 73,5; and 233.8 USGPM.

The fire water pump discharge pressure calculation considers the 6-inch pipe pressure drop, path length, and flowrate of each fire zone, with a minimum pressure of 100 psig. Fire zone 1 has the highest fire water demand of 1,195 gpm with a pressure loss of 20.39 psig. Fire zones 2–5 have a requirement of 392–616 gpm with δp of 0.474–3.359 psig, while fire zones 6–8 (non-process) are allocated 250 gpm for manual protection with low pressure losses. Clean gas protection systems (clean agents) are applied to sensitive rooms (zones 6 and 4). Zone 6 (generator and switchgear) requires a total of 453.6 kg, while zone 4 (compressor building) requires 235.27 kg. The nozzle design is adjusted so that discharge is achieved within the time specified by NFPA 2001, ensuring effective protection and protection of equipment against fire damage.

Conclusion

Based on the analysis of fire hydrant water demand, hydraulic calculations, and verification of supporting systems at the PT XYZ gathering station facilities, it was concluded that the active fire protection system design was adequate to handle the critical fire scenarios identified. The most critical design condition occurred in fire zone 1, the crude oil tank storage area, where the total firewater demand reached 1,195 gpm (40,972 bpd), consisting of 695 gpm for tank cooling and 750 gpm for manual firefighting, confirming that two fire pump units with a capacity of 1,500 gpm were sufficient to meet the required demand. Verification results indicated that the firewater pond working volume of 1,386 m³ exceeded the minimum requirement of 1,363 m³ for four hours of firefighting operation, while the foam tank capacity of 5,151 liters also exceeded the minimum foam concentrate requirement of 1,049 liters in accordance with National Fire Protection Association Standard 11. Hydraulic analysis showed the highest pressure loss of 20.39 psig in the pipeline to fire zone 1, requiring a pump discharge pressure of 132.43 psig to maintain a minimum spray pressure of 100 psig, while higher losses in manual hose areas in zones 6, 7, and 8 confirmed the efficiency of the 6-inch pipeline for non-manual flows. Furthermore, calculations based on the specifications and quantity of D3 orifice type-10 nozzles indicated that actual water demand could exceed the minimum area-based requirement, particularly in tank T-3702 with a demand of 335.1 gpm, highlighting the importance of nozzle-specific design. For sensitive areas, the clean agent fire suppression system designed according to National Fire Protection Association Standard 2001 required 453.60 kg of extinguishing agent for zone 6 and 235.27 kg for zone 4. Future research is recommended to further evaluate fire protection system performance through dynamic fire scenario simulations, reliability analysis of integrated fire detection and suppression systems, and optimization of water and foam distribution networks in onshore oil and gas gathering facilities.

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