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Assessment and Modernization of Fire Protection Systems through Hazard Identification and Risk Assessment in Oil & Gas Facilities

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Abstract: *Oil and gas installations combine large inventories of flammable hydrocarbons with high-temperature and high-pressure processing, storage, transfer and utility operations. The submitted study examines hazard identification, risk assessment and modernization of fire protection facilities in an oil and gas refinery environment. The research framework combines accident-causation concepts, hazard identification, quantitative risk assessment, HAZOP-oriented review and evaluation of fixed and mobile fire protection systems. Particular attention is given to the sea-water fire-water system, hydrant network, foam systems, clean-agent protection, carbon-dioxide flooding, FM-200 protection, high-volume long-range monitors, LPG protection and emergency response equipment. The study also documents design calculations for cooling water, foam solution, supplementary hose streams and simultaneous major-fire scenarios. The source study reports design fire-water requirements of 1,595 m³/hr for floating-roof tank protection, 1,947 m³/hr for cone-roof tank protection, 2,255 m³/hr for LPG sphere protection, 948 m³/hr for an LPG rail-wagon loading gantry and 1,200 m³/hr for process-unit protection. The two highest simultaneous cases lead to a design fire-water rate of approximately 4,200 m³/hr, while a full-surface floating-roof tank fire calculation gives approximately 3,800 m³/hr. The paper consolidates these source-derived findings into a research-paper format without introducing external measured results.*

Keywords: Oil and gas safety; fire protection; hazard identification; risk assessment; HAZOP; hydrant system; foam system; LPG protection; fire-water demand; refinery safety.

I. INTRODUCTION

Petroleum refineries and oil/gas processing facilities store and process large quantities of flammable materials. The submitted study emphasizes that, even when installations are located away from populated areas, residential and industrial development can progressively occur nearby. Consequently, a major fire, explosion or loss-of-containment event can affect both the installation and surrounding areas. The central purpose of an effective fire protection system is therefore not only extinguishment but also prevention of escalation from an initiating emergency to a major event.

The source document frames fire protection as part of a broader loss-prevention philosophy. It identifies design and construction failures, operating errors, equipment failures, maintenance weaknesses, inadequate supervision and training, natural phenomena and external interference as important incident contributors. It also stresses that emergency procedures, communications, firefighting, evacuation and regular drills are essential elements of risk control.

The research scope stated in the source study includes accident-pattern analysis in the oil and gas industry, comparison of accident causation with established models, investigation of inherent risk factors and modernization of methods used for accident prevention. The methodology recognizes simple linear, complex linear, complex non-linear and human-

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factors models. The study subsequently moves from general accident causation to practical refinery hazard management and fire protection-system evaluation.

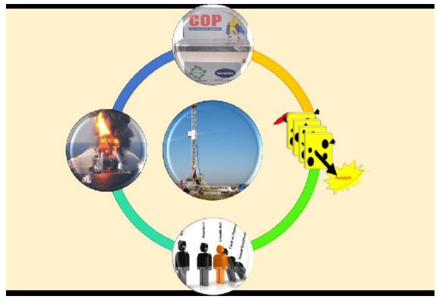

Figure 1. Research-work representation reproduced from the submitted study

II. LITERATURE REVIEW AND RESEARCH FRAMEWORK

The literature summarized in the source document shows that storage-tank fires require robust cooling and extinguishment arrangements because their consequences can be severe. Alimohammadi et al. examined water-spray cooling for floating-roof storage tanks and compared an average-method design with a linear-density approach. The source reports that the linear-density design used 3.55% more water but addressed limitations associated with assuming a uniform flow distribution.

Dogan's refinery HAZOP study is cited as evidence that equipment failure, design defects, maintenance problems, material defects, corrosion, welding defects and human failure can contribute to major process accidents. The study identified deviations, causes, consequences, safeguards and recommendations through semi-quantitative HAZOP. Other cited work combines HAZOP and fault-tree analysis to prioritize preventive and corrective measures and highlights the importance of human factors in loading and unloading risks.

The source document also discusses the Dow Fire and Explosion Index as an empirical hazard-index technique and notes that HAZOP is primarily qualitative, while FTA and FMEA provide more structured quantitative or semi-quantitative approaches. The research framework therefore uses multiple layers: hazard identification, frequency consideration, consequence analysis, risk evaluation, risk assessment and selection of risk-reduction measures.

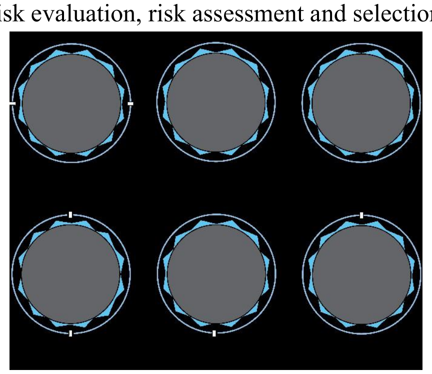

Figure 2. Cooling-system piping layout reproduced from the literature-review section of the submitted study.

Research gap identified from the source material: the submitted study contains a broad risk-assessment objective and extensive fire-protection calculations, but it does not present a single consolidated statistical comparison of accident-causation models. Accordingly, this paper treats the documented fire-protection design and risk-management evidence as the principal results rather than inventing a numerical accident-frequency dataset.

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III. METHODOLOGY

The methodology in the submitted study is structured around systematic hazard identification and risk assessment. The risk-management chapter describes quantitative risk assessment as a sequence of hazard identification, hazard-event frequency analysis, consequence analysis, risk evaluation and risk assessment. The intent is to identify major accident hazards, estimate their likelihood and consequences where appropriate, evaluate the resulting risk and identify practical risk-reduction measures.

The source study also proposes a bow-tie-type approach to screen a large number of potential hazards and focus detailed effort on those contributing most to risk. HAZOP is used to consider operational and human-error aspects. In addition, the study discusses accident-causation theories and recognizes that oil and gas operations may contain low-probability, high-impact events.

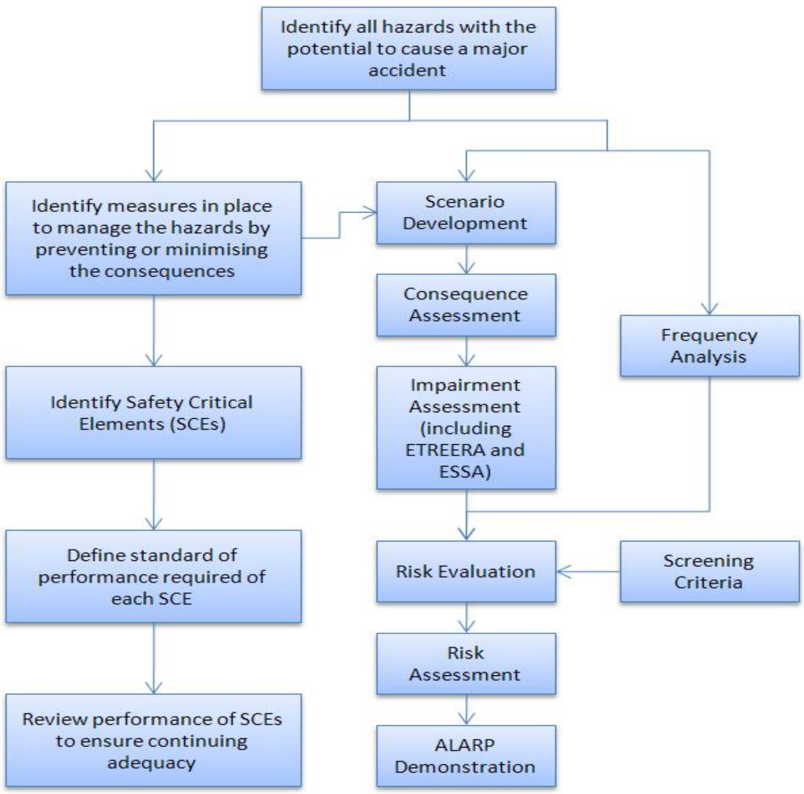

Figure 3. Risk-management process reproduced from the submitted study

3.1 Analytical sequence adopted

Stage	Purpose documented in the source study
1. Hazard identification	Identify hazardous conditions and major accident scenarios.
2. Frequency analysis	Estimate expected frequency of identified hazardous events using historical information and installation-specific considerations.
3. Consequence analysis	Evaluate physical effects, escalation mechanisms and potential impacts on personnel.
4. Risk evaluation	Combine event frequency and consequence to express overall risk.
5. Risk assessment	Compare risk with criteria and identify risk-reduction measures / ALARP considerations.

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The practical fire-protection part of the study then evaluates the adequacy and operating characteristics of fire-water, hydrant, foam, clean-agent, CO_2, FM-200, LPG spray, monitor and emergency-response systems. Design calculations in the annexures are used to establish water and foam requirements for representative major-fire scenarios.

IV. FACILITY PROFILE AND PROCESS CONTEXT

The company-domain section of the submitted study describes a large integrated refinery environment with crude-oil processing, petrochemical integration and extensive utility and emergency-response infrastructure. The documented process environment includes units such as the Fluidized Catalytic Cracker, coker, alkylation, paraxylene, polypropylene, refinery off-gas cracker and petroleum-coke gasification facilities. The source also describes refinery activity at Jamnagar and an oil-and-gas business environment with large-scale engineering, construction, logistics and operational requirements.

The refinery products listed in the source include LPG, propylene, naphtha, gasoline, jet/aviation turbine fuel, superior kerosene oil, high-speed diesel, sulphur and petroleum coke. These products create different fire and explosion scenarios because their flash points, boiling ranges, storage conditions and handling requirements vary.

Product	Application / use reported in source
LPG	Domestic and industrial fuel
Propylene	Feedstock for polypropylene
Naphtha	Feedstock for petrochemicals
Gasoline	Transport fuel
Jet / aviation turbine fuel	Aviation fuel
Superior kerosene oil	Domestic fuel
High-speed diesel	Transport fuel
Sulphur	Feedstock for fertilizers and pharmaceuticals
Petroleum coke	Fuel for power plants and cement plants

The source describes the fire station as a two-floor facility with fire-vehicle parking, crisis and central control rooms, an extinguisher/hydrant maintenance workshop, foam-solution tanks, a store room and a 12 m drill tower. An occupational health centre is located adjacent to the fire station for stabilization and initial treatment of casualties.

V. HAZARD IDENTIFICATION AND RISK PROFILE

The refinery hazard profile documented in the source includes flammable products, high-temperature products, hydrogen sulfide, nitrogen, health/environmental hazards, slips and trips, falling objects and process-related fire and explosion hazards. The study emphasizes that the most significant safety hazards are associated with handling and storage of liquid and gaseous substances, where releases can expose workers and potentially affect surrounding communities.

5.1 Major incident contributors

Contributor	Safety implication described in source
Design / construction failure	Can initiate loss of containment or create inadequate protection.
Operating error	May produce unsafe process conditions or incorrect response.
Equipment failure	Can cause leakage, loss of containment or loss of protective function.
Maintenance weakness	May allow degradation, corrosion or latent failures to remain.
Insufficient supervision / training	Can increase human and organizational error.
Natural phenomena	Can initiate or aggravate hazardous events.
External interference	Can create initiating conditions outside normal process control.

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The study also recognizes hazardous wastes and environmental hazards. Spent catalysts, oily sludge, solvents, used filters, spent amines and other process wastes require controlled storage, handling and disposal. Chemical hazards identified include potential releases of hydrogen fluoride, carbon monoxide, methanol and hydrogen sulfide. Noise sources include rotating machinery, compressors, turbines, pumps, motors, air coolers and emergency depressurization.

5.2 Human factors and emergency preparedness

Human factors are treated as an important part of accident causation. The source identifies overload, work beyond worker capability, environmental distractions, personal/internal factors and unclear instructions or risk levels. The practical safety system therefore includes training, work permits, emergency drills, communication, access control, PPE and coordination among operations, projects, maintenance and contractors.

VI. FIRE-WATER SYSTEM AND HYDRANT NETWORK

The fire-water system is described as the backbone of the fixed firefighting arrangement. The sea-water pump house supplies pressurized water to the hydrant network. The source reports two basins with a combined capacity of 13,000 m³ and a normal hydrant-line pressure of about 8 kg/cm². Water circulation through cooling and fire-fighting services helps maintain the water system, while treatment chemicals are used for microbial growth, scaling and corrosion control.

Parameter	Electric-drive pump	Diesel-engine-drive pump
Number / configuration	5 pumps	Capacity 800 m³; diesel-driven arrangement
Working pressure	10 kg/cm²	10 kg/cm²
Speed	1500 rpm	1500 rpm
Total head	103.35 m	103.35 m
Pump input	305.99 kW	305.99 kW
Pump size	350 mm	350 mm
Prime mover	340 kW / 456 HP motor	Recommended 540 HP

Automatic pump settings in the source are 6.0, 5.5 and 5.0 kg/cm² for the respective switch stages. A control valve is provided because the electric pumps can generate pressure above 11 kg/cm²; the valve helps maintain approximately 8 bar in the hydrant line by returning excess water to the sump.

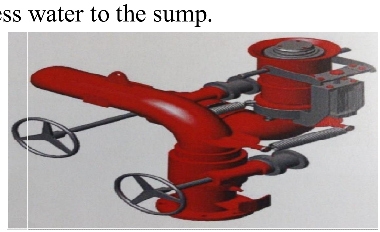

Figure 4. Hydrant / monitor valve assembly reproduced from the fire-protection section of the submitted study.

VII. STORAGE-TANK FIRE PROTECTION

The study considers fixed water-spray, semi-fixed foam and automatic rim-seal protection for hydrocarbon storage tanks. The source states that fixed water spray is used for specified petroleum storage tanks and that semi-fixed foam systems are provided for floating-roof and fixed-roof tanks storing Class A and Class B products. For large floating-roof tanks, automatic rim-seal protection may be based on foam flooding or clean-agent flooding, in addition to water spray and semi-fixed foam protection.

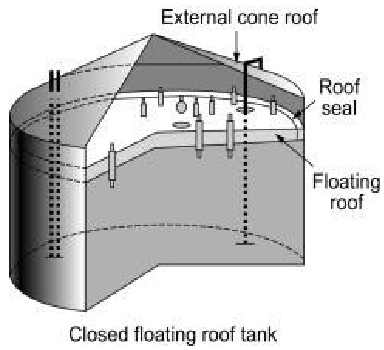

Figure 5. Floating-roof tank protection concept reproduced from the submitted study.

7.1 Foam application criteria documented in the source

Tank / case	Foam application rate
Cone-roof tank	5 LPM/m²
Floating-roof tank	12 LPM/m² of seal area
Floating-roof sinking / full-surface case	8.1 LPM/m²

The source also gives minimum numbers of foam chambers/makers by tank diameter: two up to 20 m; three for more than 20 m up to 25 m; four for more than 25 m up to 30 m; five for more than 30 m up to 35 m; six for more than 35 m up to 40 m; eight for more than 40 m up to 45 m; and ten for more than 45 m up to 50 m.

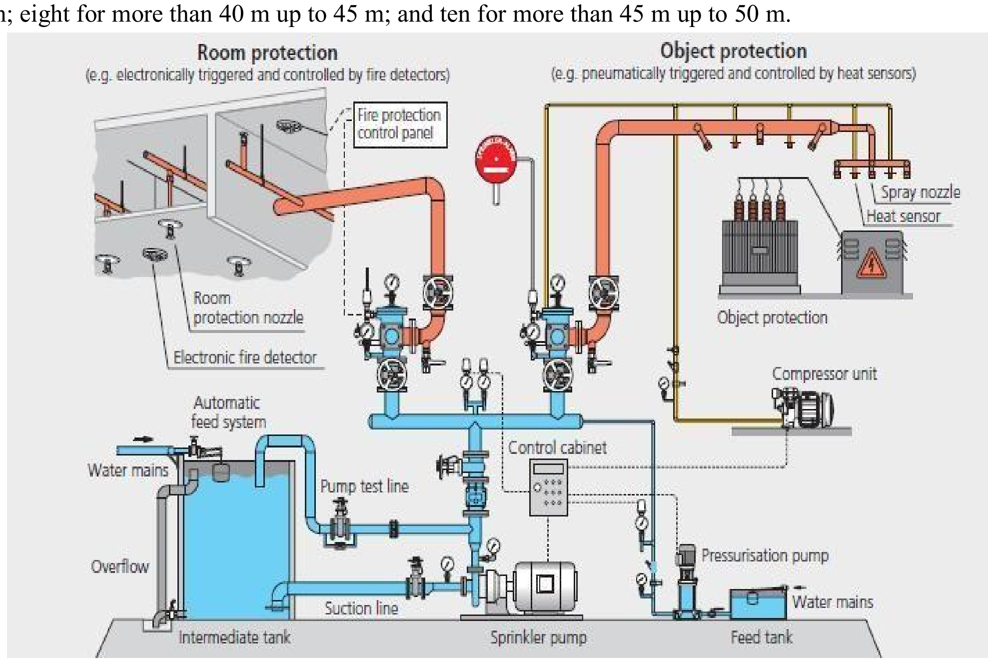

Figure 6. Fixed foam-system arrangement reproduced from the submitted study.

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VIII. CLEAN-AGENT, CO_2 AND FM-200 PROTECTION

The source documents several special extinguishing systems for equipment where water is unsuitable or where rapid gaseous extinguishment is required. The clean-agent arrangement uses CF3I-based detection/spraying in the described equipment-protection application. A heat-induced glass bulb release activates the extinguishing agent, while pressure and level switches provide alarm indication.

The captive power plant gas turbines are protected by CO_2 total-flooding systems. GT1, GT2 and GT3 are divided into zones, with multiple CO_2 cylinder banks. The source reports 45 kg CO_2 cylinders and a two-stage discharge philosophy: an initial discharge for extinguishment followed by an extended discharge to maintain a CO_2 atmosphere and reduce the possibility of reignition.

GT1 / GT2 protected area	Master cylinders	Slave cylinders
Accessories and turbine compartment	2	13
Generator compartment	2	6
Naphtha skid	2	4

The FM-200 system is described for the data-center and server-room environment. The system contains eight FM-200 cylinders and is actuated using a combination of fire and photoelectric smoke detection, with manual override. The source lists NFPA 2001 as the application standard, a 21°C room-temperature consideration, 25 bar system pressure, 7% minimum concentration and 4.8 bar minimum nozzle pressure.

Figure 7. Clean-agent / pressure-vessel illustration reproduced from the submitted study.

IX. LPG PROTECTION AND HIGH-VOLUME LONG-RANGE MONITORS

LPG is identified as a flammable hydrocarbon requiring dedicated protection. The LPG system described in the source is protected by medium-velocity water spray and a fresh-water hydrant network. Two raw-water tanks of 12,000 m³ each supply the system. The LPG fire pump house contains five diesel pumps, two jockey pumps and two compressors; three diesel pumps are dedicated to LPG protection and two can support both LPG protection and refinery services.

LPG protected location	Number / coverage	Application rate
LPG bottling plant shed	21	10.2 LPM/m²
LPG pump house	1	20.2 LPM/m²
LPG mounted tanks	3	10.2 LPM/m²
LPG bulk loading gantries	1	10.2 LPM/m²
LPG train-wagon gantry	1	10.2 LPM/m²

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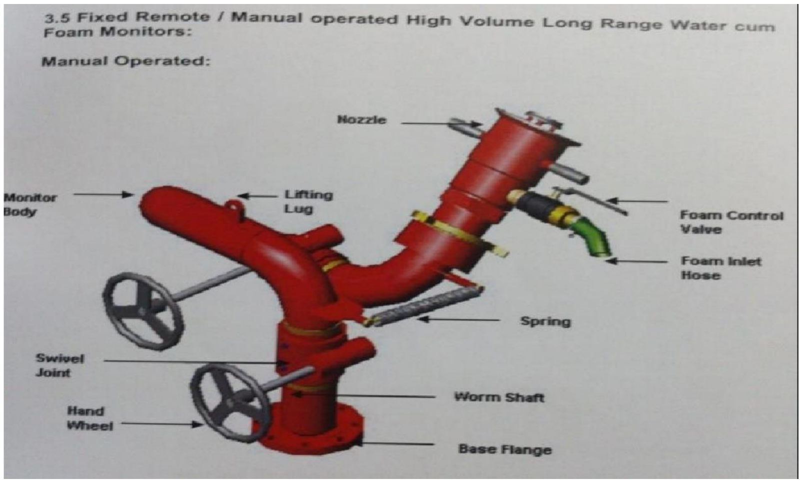

Figure 8. High-volume long-range / monitor assembly reproduced from the submitted study.

The high-volume long-range monitors are self-inducting, non-aspirating devices with capacities of 1,000, 2,000 and 4,000 US GPM at about 7 bar inlet pressure, with a horizontal range of approximately 70–75 m. The source notes that monitor placement is selected so tank areas fall within the foam-throw range and the required application rate is achieved.

X. QUANTITATIVE FIRE-WATER DEMAND

The annexure of the source study calculates fire-water demand for representative major-fire cases. The design basis states that the fire-water system should be capable of fighting two major fires simultaneously. The individual scenario calculations combine tank cooling, foam application and supplementary hose/monitor streams.

Scenario	Design fire-water rate (m^3/hr)
Floating roof tank	1595
Cone roof tank	1947
LPG sphere	2255
LPG rail wagon gantry	948
Process unit	1200

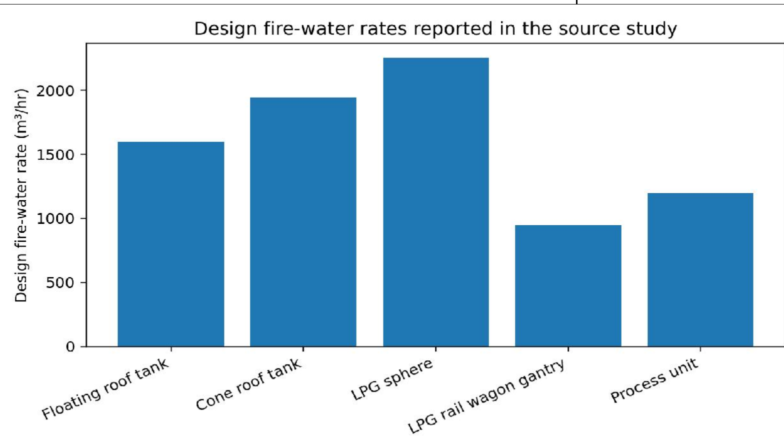

Figure 9. Fire-water demand comparison calculated from the five scenario values reported in the source document.

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The two highest individual demands are the LPG sphere case at 2,255 m³/hr and the cone-roof tank case at 1,947 m³/hr. Their sum is 4,202 m³/hr, rounded in the source to approximately 4,200 m³/hr as the design rate for two simultaneous major fires.

The source also considers a full-surface fire of the largest floating-roof tank under a roof-sinking contingency. The calculation gives 858 m³/hr for cooling water, 2,330 m³/hr for water associated with foam application and 600 m³/hr for supplementary streams, producing 3,788 m³/hr and a rounded requirement of 3,800 m³/hr.

XI. DETAILED DESIGN CALCULATIONS

11.1 Floating-roof tank protection

For the largest floating-roof tank case, the source considers two tanks with total storage capacity of 120,000 m³, each tank having a capacity of 60,000 m³, diameter 79 m and height 14.4 m. Cooling water is calculated at 3 LPM/m² of tank-shell area for the tank on fire and 1 LPM/m² for the adjacent tank when it is beyond the stated distance criterion. The resulting total cooling-water requirement is 858 m³/hr.

The rim-seal area is calculated using a 79 m tank diameter and a 0.8 m foam-dam offset. The source obtains a rim-seal area of approximately 196.4 m² and a foam-solution flow of approximately 2,356.8 LPM at 12 LPM/m². The foam compound requirement is then combined with the foam-monitor and hose-stream requirements.

11.2 Cone-roof tank protection

For the cone-roof tank case, the source considers a dyke area with 50,000 m³ total storage, four tanks of 37.5 m diameter and 12 m height. Cooling demand is calculated from a 3 LPM/m² shell rate, while foam solution is based on 5 LPM/m² of the liquid surface. The source reports 1,016 m³/hr for cooling, 331 m³/hr for foam application and 600 m³/hr for supplementary streams, giving a total of 1,947 m³/hr.

11.3 LPG sphere protection

For three LPG spheres of 17 m diameter, the source calculates a cooling requirement of approximately 545 m³/hr per sphere and considers three spheres within the specified influence distance, giving 1,655 m³/hr. Addition of 600 m³/hr for hose streams produces a total of 2,255 m³/hr.

XII. FOAM-COMPOUND REQUIREMENT

The source's second annexure calculates foam compound demand for cone-roof and floating-roof tank cases. For a 37.5 m diameter cone-roof tank, a foam solution application rate of 5 LPM/m² produces a solution rate of 5,522 LPM. At 3% concentration, the calculated foam-compound flow is approximately 166 LPM; for a 65-minute duration, the source reports 10,790 L of compound for the tank itself.

A portable foam monitor with 4,500 LPM solution capacity requires approximately 8,775 L of 3% compound for 65 minutes. Two foam hose streams contribute approximately 4,446 L. The source totals these requirements at about 23,971 L and rounds the requirement to 24,000 L for the cone-roof tank protection case.

For the 79 m floating-roof tank, the source calculates a rim-seal foam requirement of approximately 4,596 L for 65 minutes. Adding 8,775 L for one foam monitor and 4,446 L for two hose streams gives a total of 17,817 L, rounded to 18,000 L.

Case	Tank foam compound	Monitor	Hose streams	Total rounded
Cone roof	10,790 L	8,775 L	4,446 L	24,000 L
Floating roof	4,596 L	8,775 L	4,446 L	18,000 L

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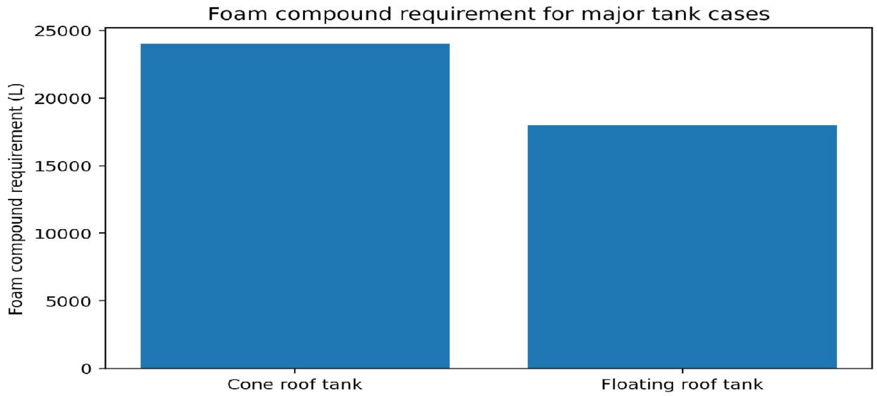

Figure 10. Foam-compound requirements based directly on the source annexure calculations.

The source further states that requirements for two major dyke areas should be combined. It gives examples of 48,000 L for two cone-roof dyke areas and 36,000 L for two floating-roof dyke areas.

XIII. EMERGENCY RESPONSE, MOBILE EQUIPMENT AND MODERNIZATION

The fire station and emergency-response inventory form an important part of the modernization approach. The source lists foam tenders, foam-cum-DCP tenders, DCP tenders, emergency-rescue tenders, rescue vehicles, foam nurse trucks and associated emergency equipment. The documented equipment includes breathing apparatus, gas meters, hydraulic cutters and spreaders, electric chain saws, rescue equipment, fire and chemical suits, fire proximity suits and fire-entry suits.

The source describes regular testing and maintenance practices for fire pumps, jockey pumps, sump pumps, compressors, bore-well pumps, hydrant valves, monitors and extinguishers. Daily, monthly and six-monthly test intervals are described for different equipment. These maintenance practices are important because the performance of a fixed fire-protection system depends not only on design capacity but also on availability and readiness.

Figure 11. Communication hand-set reproduced from the emergency-response section of the submitted study.

Figure 12. Manual call point reproduced from the submitted study.

13.1 Modernization priorities

Based strictly on the documented study, modernization priorities include maintaining automatic detection and alarm systems, ensuring the availability of fire-water capacity for simultaneous major-fire scenarios, maintaining foam systems and monitors, improving LPG spray protection, maintaining clean-agent and CO_2 systems, strengthening inspection routines and continuing emergency drills. The source also emphasizes training, communication, work-permit compliance, access control and contractor coordination.

XIV. DISCUSSION

The combined evidence in the submitted study shows that refinery fire protection must be treated as a layered safety system. Hazard identification and risk assessment provide the basis for recognizing major scenarios; engineering safeguards reduce the likelihood or severity of initiating events; fixed firefighting systems provide cooling and extinguishment; mobile equipment supports incident control; and emergency management limits escalation and protects personnel.

The quantitative calculations demonstrate the importance of scenario selection. The largest individual fire-water demand in the documented five-case set is the LPG sphere case at 2,255 m^3/hr, while the cone-roof tank case is 1,947 m^3/hr. Because the design basis considers two simultaneous major fires, the required system capacity is governed by the two highest scenarios, yielding approximately 4,200 m^3/hr. This is materially higher than any single scenario and illustrates why fire-water systems should not be sized only for an average or isolated event.

The full-surface floating-roof tank calculation provides a second design check. Although its total requirement is approximately 3,800 m^3/hr, the source states that the final design fire-water rate should be the higher of the simultaneous-major-fire requirement and the full-surface tank contingency. This scenario-based approach provides a rational basis for selecting the governing design case.

The study also shows that fire protection is not limited to water. Foam is required where blanketing and rapid suppression of hydrocarbon liquid surfaces are necessary; CO_2 is used for enclosed gas-turbine equipment; FM-200 is used for sensitive electrical/data-room spaces; LPG areas require water-spray cooling; and HVLR monitors provide long-range application capability. This multi-agent architecture is consistent with the different hazard characteristics documented in the source.

14.1 Study limitations

The submitted document states accident-pattern and accident-causation comparison as research objectives, but it does not provide a consolidated numerical accident database or a statistical model output in the material reviewed for this paper. Therefore, no new accident-frequency percentages, statistical significance values or risk-reduction percentages are introduced here. The principal quantitative findings reported in this paper are the fire-water and foam calculations explicitly contained in the source document.

XV. CONCLUSIONS AND RECOMMENDATIONS

The submitted study provides a practical framework for assessing and modernizing fire protection in a large oil and gas installation. Its main strength is the integration of hazard identification and risk-management concepts with detailed engineering information on fire-water, hydrant, foam, LPG, clean-agent, CO_2, FM-200, HVLR and emergency-response systems.

The principal quantitative result is a design fire-water rate of approximately 4,200 m^3/hr when the two highest major-fire scenarios are considered simultaneously. The full-surface floating-roof tank contingency produces a calculated requirement of approximately 3,800 m^3/hr. Foam compound requirements are approximately 24,000 L for the documented cone-roof case and 18,000 L for the documented floating-roof case. These values provide clear engineering benchmarks within the context of the source study.

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Recommendations

• Maintain the fire-water system and pumping capacity so that the governing simultaneous-fire demand remains available.

• Continue scheduled inspection, lubrication, testing and performance verification of hydrant valves, monitors, pumps and deluge equipment.

• Maintain foam concentrate inventories against the governing dyke-area scenarios and verify proportioning performance.

• Continue automatic detection, alarm and suppression testing for LPG, turbine, control-room and other protected areas.

• Strengthen periodic HAZOP/HAZID review and management-of-change processes so that modifications do not introduce unrecognized hazards.

• Continue emergency drills, communication checks, access-control checks and coordination between operations, maintenance, projects and contractors.

• Use the documented fire-water and foam calculations as design-basis checks and update them whenever tank sizes, process configuration or protection philosophy changes.

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