

Design and Safety of Petroleum Products Storage Depot in Compliance with Local and International Standards

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Abstract- *Petroleum product storage depots are critical downstream facilities that pose significant operational and safety challenges due to flammability, environmental risk, and high inventory volumes. This study presents a process engineering design and safety analysis of a petroleum products storage depot comprising Premium Motor Spirit (PMS), Dual Purpose Kerosene (DPK), and Automotive Gas Oil (AGO), each stored in a 2,500 m³ atmospheric tank. The work covers tank sizing, pump selection, pipeline hydraulic calculations, hazard area classification, and a systematic Hazard and Operability (HAZOP) study. Design calculations are carried out using established engineering correlations, local and international standards such as API 650, API RP 500, NFPA 30, ASME B31.3, Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) guidelines and Mineral Oil Safety Regulations (MOSR). Results show that appropriate pump sizing, conservative pipe diameters, and adequate safety systems significantly reduce operational risk. Recommendations are made for safer depot operation, instrumentation improvements, and regulatory compliance. Minimum Industry Safety Training for Downstream Operators (MISTDO) is made mandatory by NMDPRA for all operators and managers in the Nigerian Midstream/Downstream Petroleum Sector.*

Keywords: *Petroleum depot design, pump sizing, pipeline hydraulics, hazardous area classification, HAZOP, storage tanks, MISTDO*

I. INTRODUCTION

In Nigeria, the demand for petroleum products are on the increase and the need for reliable and safe storage facilities is on increasing demand. Regulators of the oil and gas sector promote local content in design and operations (NUPRC 2023). This has called for indigenous design and development of these facilities to augment the existing ones, and hence, to conserve foreign exchange and enhance job creation (Enarevba et al, 2016). Establishment, construction, installation, and operation of PMS, AGO or DPK storage and sales facilities has to be in line with established

guidelines by the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) (NMDPRA, 2022). Products from the oil industry are very important, especially in modern society because of their versatility and position in the energy scene (Nomor et al, 2023). Key petroleum products consumed in Nigeria (PMS, DPK, AGO, Heavy fuels, LPG, CNG, Bitumen & Lubricants) while the Regulatory Agencies include NMDPRA, SON & NESREA (Lamorde, 2025). Generally, most of the liquid hydrocarbons such as Gasoline (PMS), ATK, AGO, DPK are obtained from the fractional distillation of crude oil (EPCM, 2025). This work brings together Nigerian oil and gas guidelines and international standards to perform tank sizing, pump selection, pipeline hydraulic calculations, hazard area classification, and a systematic Hazard and Operability (HAZOP) study for petroleum products depot.

II. LITERATURE REVIEW

2.1 Overview of depots

Aboveground Petroleum Storage Facility or Bulk Depot means a tank or tanks that has/have the individual capacity to store 150 m³ or more of petroleum products and that is substantially or totally above the surface of the ground (Sanyang, 2017). A depot is defined as any location where refined or unrefined petroleum hydrocarbon is being stored in bulk, by individuals, organizations, government or any of its agencies, for the purpose of transferring the product later, for further processing in a refinery or associated plants, sales to the public in bulk or for consumption (DPR, 2009). Oil storage keeps petroleum products and other oils in large, specialized containers for long periods (Paredes, 2025). In setting up petroleum products storage depots preference is given to vertical tanks. A storage tank shall be used for the storage of petroleum (products) when its material and construction are

compatible with the products stored and conditions of storage such as pressure and temperature. All bulk storage tank installations shall be constructed so a secondary means of containment is provided for the entire capacity of the largest single tank and sufficient freeboard to contain precipitation. Diked areas shall be sufficiently impervious to contain discharged oil (Sanyang, 2017).

A typical tank is between 50 and 15,000 cubic meters (m³). In general, tanks are separated to avoid damaging other tanks should they catch fire. The separation distance is dependent on the particular type and amount of fuel product. Individual secondary containment for tanks is used to further minimize the risk of heating adjacent tanks in the event of a fire. Storage of petroleum products takes place in various sized tanks, typically installed above ground (World Bank Group, 2007).

Tanks are classified based on their roof design. Normally, atmospheric tanks are of fixed roof or cone roof or floating roof or fixed cum floating roof (with or without Nitrogen blanketing) type tanks and low pressure Nitrogen blanketed tanks (KLM 2013). Fixed roof storage tanks are typically cylindrical in shape and can be either horizontal or vertical in orientation (World Bank Group, 2007). Floating roof tanks may have external and internal floating roofs. The roof rises and falls with the liquid level in the tank to minimize VOC emissions (World Bank Group, 2007).

2.2 Guidelines for design of depots

Plans for storage facilities shall be signed by a professional engineer (Sanyang, 2017). Copies of equipment layout including all Piping & Instrumentation drawings (P&IDs) of the proposed depot or modifications must be stamped by A COREN registered engineer. The detailed engineering and equipment specifications must conform to acceptable national and international standards, so as to guarantee the safety and operability of the depot and equipment and detailed HAZOP report shall make up a key part of process safety consideration. There shall be a detailed Environmental Impact Assessment (EIA) study of the area as provided for in the National Environmental Guidelines and Standards for the Petroleum Industries in Nigeria (EGASPIN) (DPR, 2009). The design parameters of petroleum products depot shall

generally follow but not limited to the specifications outlined in the current editions of (DPR, 2009):

- Standards Organization of Nigeria (SON) specifications of petroleum products (for domestic market).
- API Standard 2510 Design and Construction of LP Gas Installation at Marine and Pipeline Terminals, Natural Gas Processing Plants, Refineries, Petrochemical Plants and Tank Farm.
- API Recommended Practices 520 and 521 for pressure relieving and depressurizing systems.
- National Fire Protection Association Standards No. 59A
- Liquefied Petroleum Gas Safety Code of Safety Practice.
- Electrical Safety Code: Part 1 of the Institute of Petroleum Model Code of Safe Practice
- American Society of Mechanical Engineers – ASME – Boiler Pressure Vessel Code, American Society of Mechanical Engineers (ASME) Mechanical Standards Class “B” Heat Exchangers Section 7.
- API 550 Manuals of Refinery Instruments and Control Systems
- ASME B31.3 for Plant Piping
- ASME B31.3 for Liquids Transmission and Distribution System

Design pumps to deliver the full range of operating conditions anticipated at any facility with flow rates required. Ensure pumps develop sufficient head to overcome the friction and static head losses in the system at the rated flow. Consider the specific gravity, temperature, viscosity, vapor pressure, corrosive, and solvent properties of the fuel. If a range is given for the specific gravity, etc., use the larger value for the purpose of calculations. For any single grade of fuel, connect pumps in parallel. Select according to the type most suitable for the particular application. Do not use positive displacement or reciprocating pumps for product issue or pipeline transfer. Provide enough pumps to allow the system to operate at full capacity with the largest pump out-of-service (Guyer, 2014).

Use API Std 610 centrifugal pumps to pump from aboveground tanks with continuously flooded suction. Use API Std 610 vertical turbine pumps to pump from underground tanks. Do not use horizontal transfer pumps in a pit alongside the underground tank as an alternative. Use sliding vane positive displacement pumps or self-priming centrifugal pumps for applications such as stripping pipelines or

similar service where the pump may frequently lose its prime (Guyer, 2014).

2.3 Operations of depots

Typical activities during the operations of terminal facilities include receiving and unloading of products from ships, rail tankers, trucks, and pipelines; storage and handling of product in on-site tanks; mixing or product blending activities; and loading products to transportation vehicles and other links, such as pipelines, rail tankers, trucks, and ships, for distribution to customers (World Bank Group, 2007).

The operation of depots and installations demand diligence to avoid spills, explosions and fire. This implies among others that a competent person must always be available during all the operations particularly during the discharge or loading at the installations or depots. Furthermore, frequent observations should be made on ship-to-shore connections and pressure gauges. Appropriate warning signs must be displayed where necessary. Highlights of the key activities in the operations of depots and installations include:

- i. Receiving and or delivering bulk cargoes.
- ii. Receiving and delivering packed petroleum cargoes from or to ships.
- iii. Loading and unloading road tank vehicles
- iv. Storage tank operations, pumps/general facilities and maintenance

Operational activities mainly consist of unloading / loading the product from supply links (e.g. vessels, pipelines, rail, and truck tankers) to storage tanks, and onward to distribution links, typically rail and truck tankers. Petroleum product terminals generally employ above ground piping systems, consisting of pipelines, hoses / loading arms, valves, instrumentation connections, meters, and pump stations, to transfer the product between tanks and transport links. Other equipment includes vapor recovery systems and components of secondary containment zones in the loading bays for rail / tank trucks. Depending on the product, handling systems involving gravity, pump, compressor, and inert gas techniques are employed to move the product in and out of tanks. The design, construction, and operation of these systems are subject to international standards. Terminals involving tanker ships have distinct loading and unloading considerations and equipment (World Bank Group, 2007)

2.4 Hazards in depot operation

The storage and transfer of liquid materials in crude oil and petroleum product terminals creates the potential for leaks or accidentally releases from tanks, pipes, hoses, and pumps during loading and unloading of products. The storage and transfer of these materials also poses a risk of fire and explosion due to the flammable and combustible nature of the materials stored (World Bank Group, 2007).

Occupational health and safety issues associated with petroleum product terminals primarily include the following (World Bank Group, 2007):

- Chemical hazards
- Fire and explosions
- Confined spaces

Chemicals Hazards

Occupational exposures may be most likely related to the dermal contact with fuels and inhalation of fuel vapors during fuel loading and unloading (World Bank Group, 2007).

Fire and Explosions

Fire and explosion hazards at crude oil and petroleum product terminals may result from the presence of combustible gases and liquids, oxygen, and ignition sources during loading and unloading activities, and / or leaks and spills of flammable products (World Bank Group, 2007)

Confined Spaces

Confined space hazards, as in any other industry sector, can, in the worse case scenario, potentially lead to fatalities if not properly managed. Confined space entry by workers and the potential for accidents may vary among terminal facilities depending on design, on-site equipment, and infrastructure. Confined spaces in crude oil and petroleum product terminals may include storage tanks, some secondary containment areas, and stormwater / wastewater management infrastructure (World Bank Group, 2007)

Crude oil and petroleum product terminals are designed to receive and dispatch bulk shipments of gasoline, middle distillates, aviation gas, lube oil, compressed natural gas (CNG), liquid petroleum gas (LPG), and specialty products from pipelines, ships, railcars, and trucks. Crude oil and petroleum product terminals are often located at the sea coast but may also be situated inland (World Bank Group, 2007).



Figure 1: 3D Model of Petroleum Products Storage Depot

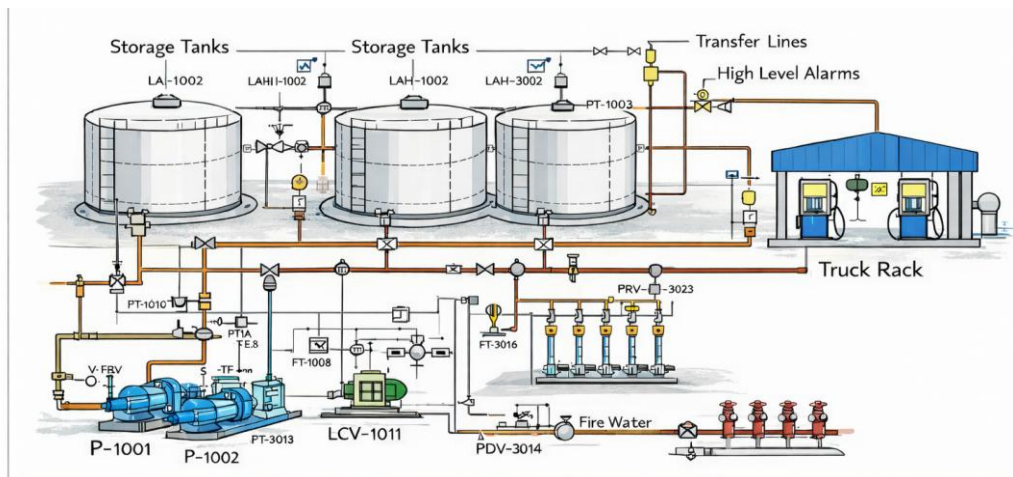


Figure 2: P & ID of Petroleum Products Storage Depot

This design focused on a depot with 3 storage tanks, each 2,500 m³, connected to a truck loading rack, with pumping, piping, instrumentation, and safety systems as shown in figures 1 and 2.

Design followed API 650 for tanks, NFPA 30 for safety, and standard chemical engineering principles.

3.2 Storage Tank Design

Tank Capacity

Each tank: $V=2,500 \text{ m}^3$

Material: Carbon steel (API 650)

Tank Dimensions

A height/diameter ratio $H/D = 1$

$$V = \pi \frac{D}{4} H \quad (1)$$

$H = D = 14.7 \text{ m}$

Tank dimension was specified as 15 m diameter x 15 m height

3.3 Pump Design

Pump Sizing

Objective: Fill tank truck in 30 minutes (t), truck capacity, V_{truck} is 40 m³

Flow rate, Q:

$$Q = \frac{V_{truck}}{t} = 80 \text{ m}^3/\text{h} \quad (2)$$

For 2 simultaneous trucks, total flow, $Q_{total} = 160 \text{ m}^3/\text{h}$

Pump Head, H, Calculation:

$$H_{total} = H_{static} + H_{friction} \quad (3)$$

Static head: 15 m (tank height)

Friction head (pipe 50 mm dia, 50 m length, rough steel):

Darcy–Weisbach equation:

$$H_f = f \frac{L}{D} \frac{v^2}{2g} = 9.18 \text{ m} \quad (4)$$

Friction factor, f of 0.02 was assumed, fluid velocity, v of 3 m/s was specified.

$H_{total} = 24.2 \text{ m}$

Pump Power

$$P = \frac{\rho g Q H}{\eta} = 12.1 \text{ kW} \quad (5)$$

Products density, $\rho = 800 \text{ kg/m}^3$

Pump efficiency, $\eta = 0.7$

15 kW Centrifugal pump was specified for margin

3.4 Piping Design

Pipeline Diameter

Maximum velocity of 3 m/s was used

$$Q = A \times v \quad (6)$$

$D = 150 \text{ mm}$

150 mm diameter pipe was specified for main line.

Piping Material

Carbon steel ASTM A106 or API 5L, welded, with corrosion allowance 2–3 mm

Valves: Gate valves for isolation, check valves for backflow prevention, ESD valves at truck rack

3.5 General Design

Truck Loading Rack Design

Two bays, bottom-loading

Design Summary Table

Parameter	Design Value / Example
Tank volume	2,500 m ³ × 3 tanks

Flow meters: Coriolis type, ±0.5% accuracy

Cycle time: 30 minutes/truck

Emergency shutdown interlock with high-level tank alarms

Safety Systems

Fire Protection

Firewater tank: 1,000 m³ (≈100% of largest tank + 25% redundancy)

Monitors, hydrants, foam systems per NFPA 30

Overfill Protection

High-level alarms, automatic ESD valves

API 2350 compliance

Hazardous Zones

Zone 0: Inside tank roof

Zone 1: Near truck rack, pump area

Zone 2: Peripheral areas

Bund Wall

Volume ≥ 110% of largest tank: $2,500 \times 1.1 = 2,750 \text{ m}^3$

Height ~2.5 m around tank

Instrumentation and Automation

Instrument	Purpose
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Radar level gauge	Tank level monitoring
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Pressure sensor	Pump and tank line pressure
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Flow meter	Truck load measurement
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High-level alarm	Overfill prevention
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SCADA	Monitoring, logging, automation
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Environmental Protection

Oil-water separator at drainage

Spill kits near truck racks

Vapor recovery system on tanks to reduce emissions

Process Flow Summary

Road Tanker → Inlet Strainer → Flow Meter → Tank → Circulation Pump → Filter → Truck Loading Rack → Dispatch

Tank level alarms prevent overfilling

Pumps sized for simultaneous truck loading

Firewater and ESD systems integrated with SCADA

Tank diameter/height	14.7 m × 14.7 m
Pump	15 kW centrifugal, 160 m ³ /h
Main pipeline	150 mm, carbon steel
Truck loading	2 bays, bottom-loading, 40 m ³ /truck
Firewater system	1,000 m ³ , hydrants, monitors, foam
Bund walls	2.5 m height, 2,750 m ³ volume
Instrumentation	Radar level, pressure, flow, SCADA

3.6 HAZOP Study

HAZOP Node: Transfer Pump

Deviation	Cause	Consequence	Safeguard	Recommendation
No flow	Pump failure	Loading stoppage	Standby pump	Preventive maintenance
High pressure	Blocked line	Line rupture	PRV	Add pressure trip
Leak	Seal failure	Fire hazard	Firewater, ESD	Double mechanical seal

HAZOP Node: Storage Tank

Deviation	Cause	Consequence	Safeguard
Overfill	Operator error	Tank overflow, fire	High-level alarm
Vacuum	Rapid draining	Tank collapse	Vacuum breaker
Vapor ignition	Static	Explosion	Earthing & bonding

IV. RESULTS AND DISCUSSION

The design calculations demonstrate that relatively small storage volumes (2,500 m³) still require rigorous engineering and safety analysis. Pump sizing shows that modest power ratings are sufficient, but safety margins are essential due to product volatility. Hazard classification highlights that most depot areas fall under Zone 1, necessitating explosion-proof equipment. The HAZOP study identifies overfilling and seal failure as the most critical risks, aligning with historical depot accident data. The HAZOP study confirms that the highest risks are associated with PMS storage, primarily due to flammability and vapor cloud formation. With proper overfill protection, venting, fire systems, and operational discipline, the depot can be operated safely in compliance with local and international standards. Results obtained agreed with similar studies conducted by Enarevba et al, 2016.

V. CONCLUSION

This study presents a comprehensive design and safety analysis of a petroleum products storage depot handling PMS, DPK, and AGO. Through detailed numerical calculations, hazard classification, and HAZOP analysis, the work demonstrates that safe depot operation depends not only on correct sizing of

equipment but also on robust safety systems and operational discipline.

VI. RECOMMENDATIONS

Automatic tank gauging and independent high-high level shutdowns should be installed. Double mechanical seals should be used on all transfer pumps. Strict earthing and bonding procedures should be enforced. Periodic HAZOP revalidation should be conducted. Depot operations should align with NFPA 30, API safety and NMDPRA safety guideline. Minimum Industry Safety Training for Downstream Operators (MISTDO) is made mandatory by NMDPRA for all operators and managers in the Nigerian Downstream Petroleum Sector.

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