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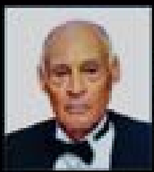

Dr. Funmi Coker

Financing Oil & Gas Projects

Engr. Dr. Wilson Dadet

Alarm Management & Process Safety

Engr. Olanrewaju Bamidele

Application of Failure Mode & Effect Analysis

COMPRESSED NATURAL GAS

...renewed focus in Nigeria

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NSChE VISION

"To be the Center of excellence for the Chemical Engineering Profession in Africa and the Prime Mover of Industrialization in Nigeria".

NSChE MISSION

"To organize the Nigerian Society of Chemical Engineers into a virile professional body capable of promoting the relevance and versatility of the profession, achieving better training and updating of Chemical Engineers through its activities. Fostering of relationships with the academia, research institutes, industries, other professional bodies and government will be the basis for stimulating accelerated industrialization of the country and improving the quality of life of the Nigerian people".

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FROM THE *Editorial* SUITE

The economic pulse in Nigeria is currently beating at uncomfortable level for most citizens. The buzzword is 'hardship' from the tongue of most Nigerians. Interestingly, this current challenging situation in the land presents opportunity for engineers to do what they know how to do best - that is problem solving to reverse the hardship. One of the sectors where thIS opportunity exists is the Energy Sector.

***Engr. Donatus Uweh**, MNSChE*
(Editor-in-Chief)

Engineers have the training and capacity to examine the energy sector and proffer solutions on how to achieve efficient and optional utilization of energy resources. In this edition of our widely read magazine, the advantage and practical way of utilizing an abundant energy resource, the compressed natural gas (CNG) in Nigeria are presented. The presentation is entitled

"Compressed Natural Gas: An Alternative Fuel for Internal Combustion Engine - Antidote to Premium Motor Spirit in Nigeria" by Engr Dr. AbdulrasheedBabalola, FNSE, FNSChE (Assoc Professor, Department of Chemical/Petrochemical Engineering,Akwa Ibom State University, Akwa Ibom State, Nigeria).

Already,we have noted the following actions and plans as far as CNG is concerned:

- Setting up of a training workshop by Ekiti State Government to train technicians on conversion of petrol vehicles to CNG vehicles
- Commencement of conversion of government vehicle in Kwara State to CNG vehicles
- Federal Government plan for a roll-out of 5,000 CNG tricycles in 3 months

All these enumerated actions point to renewed focus on CNG in Nigeria to reduce the huge expenditure in the use of petrol and diesel operated vehicles. All stakeholders should keep the momentum and ensure meaningful changes to the benefit of the entire economy in Nigeria.

This edition has also touched on a novel aspect of information in Communication Technology (ICT). That area is Artificial Intelligence (AI). It is presented by Engr. Anthony Ogheneovo, FNSChE, Executive Secretary of Nigerian Society of Chemical Engineers. Read about it and see how this electronically derived method of communication can be used to the benefit of man and processes. Engr. Ogheneovo has also presented memorable pictures of NSChE's 53rd Annual Conference/ Annual General Meeting held on the theme "Optimization of Nigeria's Oil & Gas Assets for Sustainable Energy Transition" held between 2nd and 4th November 2023 in Warri, Delta State.

The article on Financing Oil & Gas Projects in the Face of Sustainable Energy Developmentsby Dr. FunmiCoker, FNSChE is an eye-opener to those who wish to venture into investment in the oil & gas sector. Readers will learn some of the intricacies in this edition.

Other significant presentations in this edition are:

i. Alarm Management and Process Safety Intersection by

Engr. Dr.Wilson Dadet, FNSChE, FIGEM, CEng (Lead Process Engineer, Nigeria LNG Ltd)

ii. Application of Failure Mode & Effect Analysis (FMEA) in Chemical Process OperationsbyEngr. Olanrewaju, Adebayo BamideleMNSChE, MNSE, AMIChemE, AIChE, AMNIM

(Founder & Principal Consultant, Olanab Consults)

Readers will benefit immensely from the knowledge shared by Engr. Dadet and Engr. Bamidele. These articles underpin the significance of safety and efficiency of operating system.

Finally, we express our appreciation to all those who have contributed to the successful publication of this edition.

Engr. DonatusUweh, *MNSChE*
(Editor-in-Chief)

APPLICATION OF ARTIFICIAL INTELLIGENCE IN CHEMICAL ENGINEERING

Artificial Intelligence (AI) is revolutionizing various Industries, and chemical engineering is no exception. Here are several key areas where AI is making a significant impact in chemical engineering:

***Engr. Anthony Ogheneovo**, FNSChE*
(Executive Secretary, NSChE)

Process Optimization: AI algorithms can analyze vast amounts of data from sensors and process controls to optimize chemical processes. By identifying patterns and correlations in data, AI can enhance process efficiency, reduce energy consumption, and minimize waste generation.

Predictive Maintenance: AI-powered predictive maintenance systems can monitor equipment performance in process plants and predict potential failures before they occur. By analyzing historical data and real-time sensor readings, AI algorithms can detect anomalies and recommend maintenance actions to prevent costly downtime.

Product Development: AI can accelerate the product development process in chemical engineering by simulating and optimizing chemical reactions and formulations. AI algorithms can predict the properties of new materials, design optimal reaction conditions, and optimize formulations for desired performance characteristics.

Safety and Risk Management: AI can enhance safety and risk management in process plants by analyzing data from various sources, including process sensors, safety systems, and environmental monitoring networks. AI algorithms can detect potential safety hazards, identify abnormal operating conditions, and recommend preventive measures to mitigate risks. Supply Chain Optimization: AI-powered supply chain optimization systems can improve inventory management, production scheduling, and logistics in the process industries. By analyzing demand forecasts, production capacities, and transportation constraints, AI algorithms can optimize inventory levels, minimize transportation costs, and ensure timely delivery of raw materials and finished products.

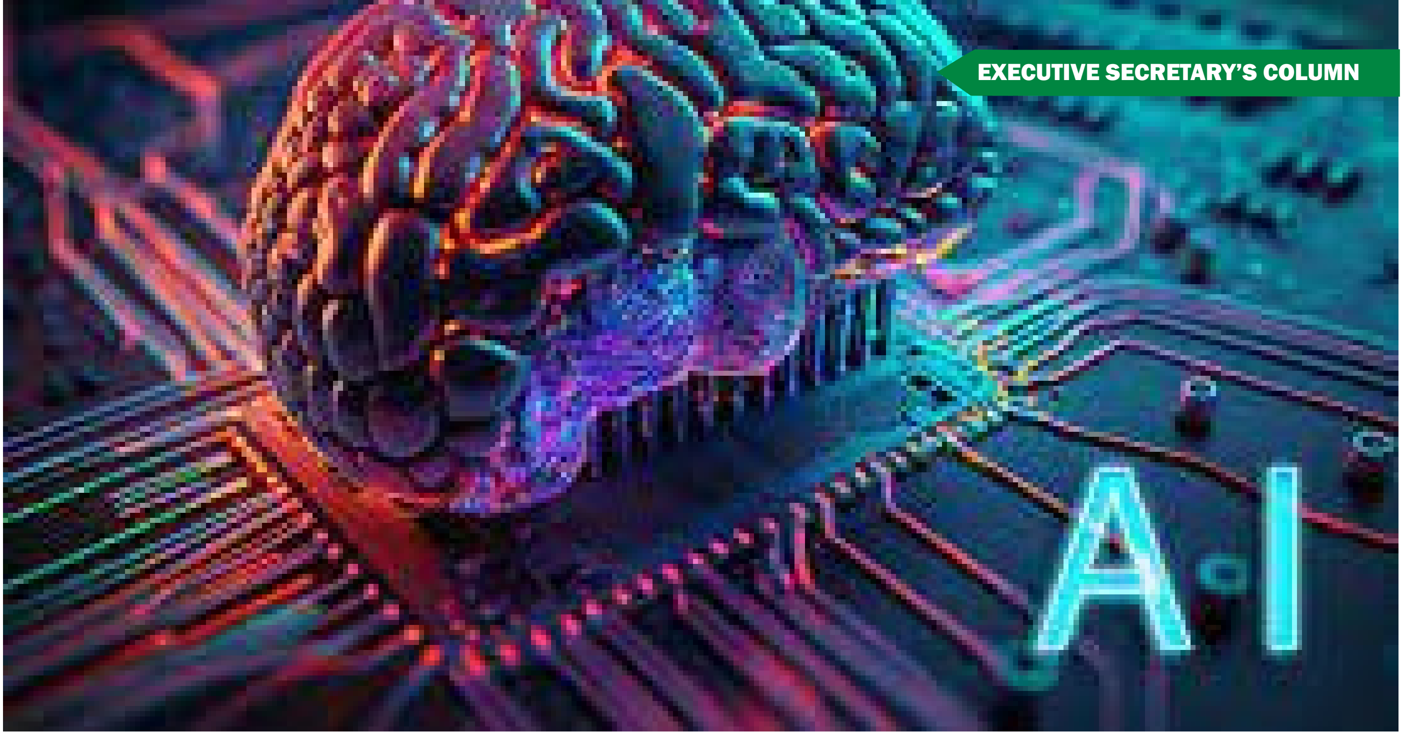
"Artificial Intelligence (AI) is revolutionizing various Industries, and chemical engineering is no exception."

Quality Control: AI can improve quality control processes inthe manufacturing industry by analyzing data from production processes and laboratory tests. AI algorithms can detect deviations from quality specifications, identify root causes of quality issues, and recommend corrective actions to maintain product quality and consistency.

Environmental Monitoring and Compliance: AI can support environmental monitoring and compliance efforts in process plants by analyzing data from environmental sensors, emissions monitoring systems, and regulatory databases. AI algorithms can detect environmental pollutants, assess compliance with regulatory requirements, and optimize environmental management practices to minimize environmental impact.

Energy Efficiency: AI algorithms can optimize energy consumption in different processes, by analyzing data from energy meters, process controls, and utility systems. By identifying opportunities for energy savings and optimizing operating parameters, AI can help reduce energy costs and minimize environmental impact.

Advanced Process Control: AI-based advanced process control systems can optimize the operation of complex processes in real time. By integrating data-driven models with control algorithms, AI can adjust process parameters dynamically to maintain optimal performance, even in the presence of disturbances and uncertainties.



Supply Chain Resilience: AI can enhance supply chain resilience in the industry by analyzing data from multiple sources, including supplier performance, market trends, and geopolitical risks. AI algorithms can identify potential disruptions, assess their impact on supply chain operations, and recommend strategies to mitigate risks and ensure continuity of supply.

Regulatory Compliance: AI-powered regulatory compliance systems can help process companies navigate complex regulatory requirements and ensure compliance with safety, environmental, and quality standards. By analyzing regulatory documents, historical compliance data, and expert knowledge, AI algorithms can identify relevant regulations, assess compliance risks, and recommend actions to maintain compliance.

Drug Discovery and Development: In the pharmaceutical and biotechnology sectors, AI is revolutionizing drug discovery and development processes. AI algorithms can analyze large datasets of chemical compounds, biological targets, and clinical data to identify potential drug candidates, optimize drug designs, and accelerate the drug development timeline.

Smart Manufacturing: AI-enabled smart manufacturing systems can improve efficiency, flexibility, and agility in chemical manufacturing operations. By integrating data from production processes, equipment sensors, and enterprise systems, AI can optimize production schedules, reduce downtime, and enable real-time decision-making to enhance overall manufacturing performance.

Carbon Capture and Utilization: AI can support the development of carbon capture and utilization technologies to mitigate greenhouse gas emissions from industrial processes. AI algorithms can optimize the design and operation of carbon capture systems, identify suitable CO2 utilization pathways, and assess the economic and environmental feasibility of carbon capture projects.

Continuous Improvement: AI-driven continuous improvement initiatives can help process companies optimize their operations and drive continuous improvement across all aspects of their business. By analyzing operational data, identifying areas for optimization, and recommending process improvements, AI can enable organizations to achieve higher levels of efficiency, productivity, and competitiveness.

Overall, AI has the potential to transform the chemical engineering industry by improving process efficiency, enhancing product quality, ensuring safety and compliance, and driving innovation across the entire value chain. As AI technologies continue to advance, chemical engineers can leverage these tools to address complex challenges and unlock new opportunities for sustainable growth and development
These are just a few examples of how AI is being applied in various domains within the field of chemical engineering. As AI technologies continue to evolve and mature, we can expect to see even greater advancements and innovations that will further transform the way chemical processes are designed, operated, and managed.

EVENTS

NSCHE'S 53RD ANNUAL CONFERENCE/AGM

Conference flyer

Press conference 1

Opening ceremony 1

Press conference 2

Opening ceremony 2

Opening ceremony 3

Exhibition

COMPRESSED NATURAL GAS AN ALTERNATIVE FUEL FOR INTERNAL COMBUSTION ENGINE: ANTIDOTE TO PREMIUM MOTOR SPIRIT

Engr. Dr. Abdulrasheed Babalola, FNSE, FNSChE;
Assoc Professor, Dept. of Chemical/Petrochemical Eng., Akwa Ibom State University, Nigeria

ABSTRACT:
The rapid increase in population and consequent rise in transportation demands have led to a significant increase in carbon dioxide emissions globally. Currently, the instability in the prices of fossil fuels has been a major challenge in the world energy sector. Therefore, there is need for an urgent intervention through the development of alternative transportation fuels. This study focuses on the viability of compressed natural gas (CNG) as an alternative to conventional fuels like gasoline and diesel for internal combustion engines. Compressed natural gas which is primarily composed of methane is abundant in Nigeria's natural gas reserves. Some of the benefits derived from the utilization of CNG range from energy source diversification, mitigation of climate change, reduced emissions and enhanced domestic energy security. The high octane rating and low carbon content of CNG, as compared to gasoline and diesel, makes CNG an attractive fuel option. This paper outlines the production, transportation and storage phases of CNG and highlights the safety measures and technological considerations for the utilization of CNG. The economic analyses showing the comparison between CNG with gasoline and liquefied petroleum gas (LPG) demonstrate potential cost savings and environmental benefits which have been considered in the course of the research. The establishment of CNG infrastructure across Nigeria including stations for refill and vehicle conversions can revolutionize the transportation sector.

KEYWORDS: *Compressed natural gas, Methane, Fuel, Internal Combustion Engine, Greenhouse gas.*

1.0 INTRODUCTION

The increase in population coupled with the growing demand for transportation have significantly resulted in the increase of carbon dioxide emission. The challenges in the world energy mix have made fossil fuel price to increase. With the unfolding challenges in the transportation sector, it is imperative that an alternative fuel for transportation be developed[1].
Natural gas (NG) has been discovered in several locations in Nigeria. Compressed natural gas (CNG) is a fuel that consists primarily of methane (CH4) and is used as an alternative to gasoline, diesel or propane for powering vehicles. CNG is a type of natural gas that is compressed under pressure of about 200 to 250 bar to reduce its volume, making it suitable for use in vehicles. CNG is one of the most viable alternatives to "Petrol", that is, premium motor spirit[2].

The benefit of gas fuels to Nigeria as a country with natural gas endowment include diversification of energy sources, reduction of petroleum product imports, promotion of local industry and increased domestic energy security. Mitigation of climate change, reduction of adverse environmental impact, improvement of engine life are some of the benefits of gas fuel on vehicle and the environment. CNG is formed when decaying plants and animals which are buried under the earth's surface interact with intense heat and pressure for millions of years. It is composed of methane (CH4) primarily, along with smaller amount of impurities. CNG is a lot greener than diesel and petrol. That means: it emits less carbon and other greenhouse gases. It reduces carbon monoxide emissions by 90% to 97%. It reduces environmental pollution significantly. That makes it very eco-friendly[3].

The octane rating of natural gas is about 130 which means that engines could operate at compression ratio of up to 16:1 without knocking. Natural gas significantly reduces carbon dioxide emissions by

20-25% when compared to gasoline because of the simple chemical structures. It is primarily methane that contains one carbon while diesel and gasoline have 15 carbon atoms and 8 carbon atomsrespectively. Methane and hydrogen can be blended to reduce vehicle emissions by an extra 50%.

2.0 NATURAL GAS COMPOSITION

The composition of natural gas varies from one location to another having a methane content between 70-90% with the remaining percentage consisting of components like ethane, propane, carbon dioxide. Natural gas exists as gas and has low density at atmospheric pressure and temperature. Natural gas is usually stored in a compressed state at high pressure in pressure vessels due to its low volumetric energy density[4]. See Table 1.

CNG Characteristics	Value
Vapor Density	0.68
Auto Ignition (oC)	700
Octane Rating	130
Boiling Point (oC)	-162
Air-Fuel Ratio (Weight)	17.24
Chemical Reaction with Rubber	No
Storage Pressure (MPa)	20.6
Fuel Air Mixture Quality	Good
Pollution CO-HC-NOx	Very Low
Flame Speed (m/s)	0.63
Combustion ability with air	4-14%

Table 1: CNG fuel characteristics [4]

Compressed natural gas can be easily used in a spark ignited internal combustion engine and it has a wider flammability range than gasoline and diesel oil. For natural gas to ignite it needs to be in a concentration of 5% to 15%. Vehicles that use natural gas emit substantially lesser number of pollutants than petrol/diesel powered vehicles. The physiochemical properties of CNG versus gasoline and diesel can be seen in Table 2.

Properties	CNG	Gasoline	Diesel
Octane/Centane Number	120-130	85-95	45-55
Molar Mass (g/mol)	17.3	109	204
Density at 15 OC	215	750-765	830-950
Stochiometric (Air/fuel ratio	17.2:1	14.7:1	14.6:1
L.H.V (MJ/Kg)	47.5	43.5	42.7
L.H.V of stochiometric Mixture (MJ/Kg)	2.62	2.85	2.75
Flammability Limit in air (Vol% in air)	4.3-15.2	1.4-7.6	1-6
Flame Propagation Speed (m/s)	0.41	0.5	-
Adiabatic Flame Temperature (OC)	1890	2150	2054
Auto-ignition Temperature (OC)	540	258	316

Table 2: Physiochemical properties of CNG versus gasoline and diesel [5]

Physical Properties of CNG

The state of the CNG is gaseous and it is an odorless, colorless, and tasteless gas. However, a chemical called methyl mercaptan is added to detect gas leaks.

It is a highly combustible gas and a fossil fuel. It has a low flammability range and high ignition temperature.

CNG is a mixture of simple hydrocarbon compounds especially methane (CH4) with small amounts of ethane, butane, pentane, and propane.

The gas has a high calorific value because it is free of any kind of toxicity.

The byproducts of CNG after burning are water vapor and carbon dioxide.

CNG and other natural gases are 60% lighter than air.

Chemical Composition of CNG

CNG is found in a gaseous state and consists of about 90% to 95% methane (CH4), the remaining 5% to 10% consists of nitrogen, carbon dioxide, helium or hydrogen sulfide. This is unlike liquified petroleum gas (LPG) which is a liquid composed of propane and butane.

CNG is a natural gas that is compressed under great pressure so that it occupies a lesser volume in the fuel tank or fuel storage. CNG is compressed to a pressure of 200 to 500 kg/cm2 or in other countries it can be 3600 pounds per square inch. In the compressed form, CNG occupies less than 1% of its volume at atmospheric pressure.

Vehicles can use natural gas in liquid as well as gaseous form. However, most vehicles use it in gaseous form compressed to 3000 psi. CNG has an energy density of 53.6 MJ/Kg or 9 MJ/L

“The composition of natural gas varies from one location to another having a methane content between 70-90% with the remaining percentage consisting of components...”

"It is 50% more cost-effective than electricity. CNG is also use for generating electricity. CNG is used for manufacturing a huge range of chemicals like acetic acid, ammonia, methanol, butane, propane, ethane, etc. Even fertilizers are made using CNG."

Uses of CNG

CNG is widely used by the transportation sector for powering cars, trains, ships and other vehicles.

The gas is used for cooking and heating. Dryers use CNG for drying clothes. It is 50% more cost-effective than electricity. CNG is also use for generating electricity. CNG is used for manufacturing a huge range of chemicals like acetic acid, ammonia, methanol, butane, propane, ethane, etc. Even fertilizers are made using CNG.

Some of the significant benefits of CNG include reduced fuel cost, high octane number as well as cleaner exhaust gas emissions. The number of vehicle engine powered by natural gas is growing rapidly. Nigerian Independent Petroleum Company which is a subsidiary of the Nigerian National Petroleum Company Limited converted 5,600 vehicles from using petrol to compressed natural gas (CNG). Over 11 million vehicles are still using liquid petroleum fuel of gasoline and diesel which in a way shows the proportion of carbon dioxide that is emitted into the environment.

Natural gas is safer than gasoline in various aspects. Natural gas has a higher ignition temperature than gasoline and diesel fuel; also natural gas is lighter than air. Due to the availability of natural gas, it will be imperative to apply natural gas asan alternative fuel to spark ignition engines as this will be a beneficial activity because fossil fuels may become scarce and expensive. As far as emissions in the environment is concerned, natural gas is environmentally cleaner than either diesel or gasoline. High octane number of natural gas makes natural gas suitable for spark ignition engines. The determination of the suitability of the engine to accommodate the newly introduced fuel is necessary when considering engine conversion. Spark ignition engines are easily converted to bi-fuel engines by retrofitting a natural gas vehicle kit to the engine system. Bi-fuel natural gas vehicles can use either gasoline or natural gas in the same internal combustion engine.

3.0 COMPRESSED NATURAL GAS PROCESSING

3.1 PHASES

Phase 1: Production

A typical CNG production facility depends upon the quality of the natural gas and reservoir pressure. The production process consists of compression, cooling, dehydration and most likely liquefied petroleum gas (LPG) separation. The extent of compression and cooling is going to differ from process to process.

Phase 2: Transportation

Coselle CNG Carrier – Creating a large but compact CNG storage with a pipe. It consists of several miles of small diameter pipes coiled into a carousel. Volume Optimized Transport and Storage – It consists of long and large diameter pipes encased in an insulated shell.

Phase 3: Receiving

In the receiving phase, the CNG ship unloads gas into the pipeline at the receiving terminal. The receiving terminal will have a dock with high-pressure pipeline connections and expansion to recover energy from the high-pressure gas.

Phase 4: Storage

Storage is required at the production and receiving terminal to maintain uninterrupted operation. The CNG can be stored in the ship docked at the port.

Fig. 1: CNG cylinder installed

PRACTICAL ASPECT OF STORAGE OF CNG IN VEHICLES

The compressed natural gas cylinder was mounted under the vehicle in the spare tire location. See Fig. 1. A rubber mat was used to wrap the clamp to avoid damage to cylinder surface.
A gas filter, manometer pressure gauge, MAP sensor were installed to monitor the pressure, temperature and quantity of CNG entering the engine.

During the conversion of the engines safety precautions such as selection of qualified technicians, compliance with connection standards and regulations, avoidance of enclosed spaces, use of regulators with flow shut-off valves, conduct regular system inspection and the gas cylinders need to be stored and handles properly.

4.0 THEORY/CALCULATION/ METHODOLOGY

VEHICLE CONVERSION

A privately owned petrol driven vehicle converted was converted into a natural gas driven vehicle. The average cost of conversion as obtained from secondary source was at a range of N200,000 to N250,000. An exchange rate of N420 to $1 was used for the study. To analyze the economics of using a vehicle running with CNG and LPG as an alternative fuel to gasoline, net present value and payback period were used as economic tools to carry out the cost analysis.

The formula for Net present value (NPV) is given as;

$$= \sum_{n=0}^{n=last\ year} (\frac{cashflow\ for\ year\ n - investment\ for\ year\ n}{(1+rr)^n} \qquad (1)$$

The initial conversion cost from gasoline-drive to natural gas driven, estimated annual maintenance cost, fueling cost and vehicle consumption rate were some of the factors considered during the analysis. a comparison of the fuel cost was conducted as well

"A privately owned petrol driven vehicle converted was converted into a natural gas driven vehicle. The average cost of conversion..."

Fuel Types	Distance Travelled per Day(k)	Fuel Consumption Rate/km	Unit Price of Fuel per Liter (N)	Fuel Price per Liter ($)	Fuel Cost per km (N)	Fuel Cost km ($)
CNG	100	0.100	230 -300	0.29	23.00	0.029
LPG	100	0.123	1000	1.25	123	0.154
PMS	100	0.144	700	0.81	93.6	0.117

Table 3: Results depicting fuel consumed for each gas fuel per kilometer travelled

"For this study, an estimated daily distance of 100km..."

Fuel Type	Monthly Fuel Consumption (L)	Monthly Fuel Cost (N)	Monthly Fuel Cost ($)
CNG	280	64,400.00	81.20
LPG	344.4	344,400.00	430.50
PMS	403.2	262,080.00	326.59

Table 4: Monthly fuel cost

as the price of gasoline with or without subsidy was compared with the price of natural gas. See Table 3.

For this study, an estimated daily distance of 100km for 28 days in month was considered which means a total of 2,800 km will be the distance covered for in a month. The monthly fuel consumption and cost were further obtained based on the information presented in Table 4.

The monthly fuel cost was calculated using equation 2.0 below (Emeke et. al, 2023)

monthly fuel cost=100km ×28 days×fuel consumption rate×fuel price

5.0 CONCLUSION

Embracing CNG engine in Nigeria will enhance a sustainable environment and reduce emission of greenhouse gas, cushion the effect of fuel subsidy. The investment in CNG plant would adequately address the high cost in petrol and diesel due to subsidy removal. The idea of CNG is increasingly becoming popular in Nigeria. CNG plant concept is a novel concept that could transform the Nigeria. The development of a CNG plant will eliminate unsafe illegal refineries which are dangerous to the environment. Establishment of CNG filling plant should be encouraged in cities and villages. Motorists are encouraged to change their generator and car PMS/ diesel systems to CNG fuel system.

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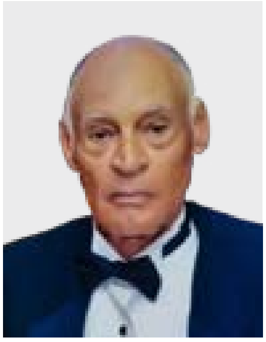
FINANCING OIL & GAS PROJECTS IN THE FACE OF SUSTAINABLE ENERGY DEVELOPMENTS



Dr. Funmi Coker, FNSChE

1.0 INTRODUCTION

Projects are evaluated on the following criteria:

- Technical
- Environmental
- Economic
- Financial

Financial evaluation is often done using lower oil prices compared to economic evaluation. Oil prices rise and fall but a project must have enough cash flow to service its loans throughout the duration of the loan, even during periods of low oil prices. For refinery projects, refinery profitability and cash flow are dependent on refinery margins, which also vary.

2.0 DIFFERENCES BETWEEN UPSTREAM, MIDSTREAM AND DOWNSTREAM ECONOMICS

- Exploration is high risk; consequently, upstream projects require high ROI >15%
- Refineries, petrochemicals and LNG have target ROI of circa 12%
- Pipelines are treated like utilities if revenue is based on tariffs and they have secure suppliers and off-takers. They can have low unfinanced economics and boost ROI through cheap financing

3.0 FUNDING UPSTREAM PROJECTS

The outcome of oil and gas exploration is uncertain; it is usually done without third party loans. Large, high cost exploration projects are normally implemented by joint ventures, with one of the parties acting as the Operator. Risk is thereby shared. It is common for companies with assets to invite others to farm-in and share the cost and risk. When reserves have been established, bank loans can be obtained for development. Creditworthy oil companies issue corporate bonds to help fund their overall activities.

4.0 UPSTREAM FUNDING IN NIGERIA

The industry developed as unincorporated joint ventures between NNPC and major international oil companies. NNPC was the major partner; each partner contributed its share to the budget. In recent years NNPC has not been able to fund and entered into agreements with JV partners to fund and recover.

International oil companies have been divesting blocks to local companies; they do not have the same funding capabilities. Deepwater projects are high cost and high risk; they are implemented under Production Sharing Contracts (PSC). NNPC is the concessionaire and a consortium of oil companies is the contractor. PSC contractor makes the investment; if exploration is successful, cost is recovered and production is shared with NNPC.

Marginal fields were designed to increase local participation. They are also sole risk operations

Deepwater is higher production cost than onshore/shallow water but it is where future potential is.

5.0 DOWNSTREAM/MIDSTREAM FUNDING IN NIGERIA

NNPC Warri and Kaduna Refineries were fully funded by government. The new Port-Harcourt Refinery, Eleme Petrochemicals and Escravos-Lagos Gas Pipeline were funded with loans obtained through Export Credit Agencies and with government guarantees. NNPC/Mobil Oso Condensate Project obtained loan finance. Dangote Refinery, a private sector project, has substantial loan funding, part of which is guaranteed by the Central Bank. Nigeria now has debt servicing problems and third party financing is difficult to obtain. Ajaokuta-Kaduna- Kano (AKK) Gas Pipeline does not have third party finance. Debt service/revenue is high although debt/GDP is moderate. Recent government

"Financial evaluation is often done using lower oil prices compared to economic evaluation."

reforms should improve financing environment. S&P credit rating is 'B-/B'; outlook is stable.

6.0 LNG FUNDING IN NIGERIA

NLNG acquired four ships in 1990, in advance of the main project; a loan was obtained to purchase the ships and was serviced by chartering the ships to third parties. NLNG Base Project (Trains 1&2) was funded fully by shareholders because Nigeria was off-cover during the Abacha regime (FID 1995). An Escrow Scheme was established in London for shareholder funding. NLNG Train 3 was also fully funded by shareholders (FID 1999). LNG ships were financed with non-recourse third party loans (1999). NLNGPlus(Trains 4&5) was financed with loans through Export Credit Agencies (FID 2002). Financing was also extended to NLNG Train 6 and the additional ships. NLNG Train 7 has not obtained third party loans.

OKLNG was lined up for Export Credit Agency loans with the foreign shareholders joining the loan consortium. The project did not proceed after Shell and Chevron withdrew in 2013.

"NLNG acquired four ships in 1990, in advance of the main project; a loan was obtained to..."

7.0 SUSTAINABLE DEVELOPMENT ISSUES FOR FINANCING

Critical issues which come into play in financing oil & gas projects in a sustainable manner are as follows:

- Environmental and Social Impact
- Negative reputation of Nigeria on environmental degradation and community issues
- Carbon intensity
- Project's minimization potential of greenhouse gas emissions as a condition to get international funding
- Declining Demand
- The projection by International Energy Agency that oil demand will peakpeak by 2030 and decline thereafter
- Gas demand is expected to peak later but will also decline
- Technological developments have resulted in new sources of oil and gas and are increasing competition for the market
- ISO Certification

Provides confidence that an organisation is compliant with standards and operates sustainably

- **ISO 29001, ISO 14001**
    i. Environmental and Social Impact: Lenders closely scrutinise environmental and social performance in Nigeria. There have been high profile international court cases and negative

publicity on pollution, environmental degradation and community issues. Projects require high quality environmental impact assessments to obtain international financing. Financing is subject to formal EIA approval by Federal Ministry of Environment. Major lenders and Export Credit Agencies assess projects on the basis of the Equator Principles – a financial industry benchmark for determining, assessing and managing environmental and social risk in projects. Lenders appoint independent consultants to assess the EIAs of projects. Lenders require projects to covenant Environmental and Social Management Plans (ESMP), which are binding. LA financial industry benchmark for determining, assessing and managing environmental and social risk in projects.

ii. **Carbon Intensity:** Major western countries have a Net Zero target of 2050; Nigeria has a 2060 target. Nigeria is a major emitter of methane, and has a target of reducing emissions by 30% by 2030 as compared to 2020 levels. Major oil companies report on their carbon intensity – the amount of carbon dioxide equivalent emissions per unit of energy produced .Oil and gas investment and lending is going preferentially to low carbon intensity projects.

iii. **Greenhouse Gax Emissions:** FC/World Bank, supported by the UK and Norway, is supporting Carbon Capture Utilisation and Storage in Nigeria. The Upstream Regulator has taken action to implement Nigeria's climate change commitments. There are some policies and guidelines to achieve the objectives as enumerated below:

- Guidelines for Management of Fugitive Methane and Greenhouse Gas Emissions in the Upstream Oil and Gas Operations in Nigeria, 2022
- Gas Flare, Venting and Methane Prevention of Waste and Pollution Regulations, 2023
- Regulations are international best practice
- Compliance is important for financing

Downstream/Midstream Regulator needs to do the same. Several major banks have policies of reducing lending to the oil and gas industry and some do not fund greenfield projects at all

There are issues to be addressed in Nigeria pertaining to climate change and the environment. Nigeria is seriously impacted by climate change • Extreme heat Some incidents and facts are:

- February heatwave in West Africa; temperatures 4 deg. C above average (11-15 Feb)
- Also, in mid-March NiMet reported extreme heat and 44 deg. C temperature in the North
- Drought in the North (followed by floods), floods

in central and southern areas and inland and coastal erosion
- Nigeria is the 9th largest emitter of methane (IEA)
- Nigeria has pledged to reduce methane emissions by 30% by 2030 from 2020 levels
- Nigeria is the 9th largest in gas flaring (World Bank)
- Nigeria has a target of 2030 for eliminating flares
- Nigeria has the highest number of child deaths from pollution in the world (UNICEF)

Nigeria is a big stakeholder in combatting climate change

iv. **Declining Demand:** IEA projects fossil fuel demand to peak by 2030. Oil demand will start to decline after 2030. Gas demand will remain close to the peak, sustained by power generation for the next two decades (no significant growth). Electric vehicles, data centres, 5G networks and AI will accelerate electricity demand. Oil demand for transportation is expected to decline after 2026 – growth in electric vehicles, biofuels and energy efficiency improvements. Petrochemicals demand is projected to increase, on the back of population growth and increases in living standards. Restrictions on single use plastics will constrain polymer demand growth. Green hydrogen for ammonia and urea will progressively replace brown hydrogen (from oil and gas. Large new sources of oil and gas are increasing market competition (shale, ultra deepwater, etc)

8.0 FINANCING PROSPECTS - UPSTREAM

Investment by international oil companies under PSCs is the best financing prospect for major projects, provided the fiscal and regulatory regime is attractive. The best growth prospects are in deep water, although production cost is higher than onshore. Projects will be designed to minimise carbon intensity. International lending will be scarce for increasing production but will be available for reducing carbon intensity and environmental impact, including flares out. Funding may be available for upgrading onshore infrastructure – pipelines, terminals, flow stations, etc. It will improve security from sabotage and theft, reduce spills, reduce GHG emissions, and increase efficiency. Nigerian banks will continue to be interested in lending to indigenous companies though lending capacity is limited because they were severely impacted by 2015 oil price crash. Borrowers need to demonstrate ability to service loans or provide non-oil asset collateral. Gas development for power generation is a good candidate for local financing but requires satisfactory economics – gas pricing and bankable gas sales agreements.

9.0 FINANCING PROSPECTS – DOWNSTREAM/MIDSTREAM

There is no case for additional greenfield refinery projects. Existing refineries can raise international finance for upgrading Actions required are:
- Installation in facilities to raise product quality to international specifications: reduce sulphur and benzene content, etc.
- Improving environmental performance by reducing refinery emissions
- Improving economics – modern instrumentation and control systems, etc
- Modifying configuration for changing market – addition of petrochemical units, etc
- Petrochemicals projects can obtain third party financing provided they meet technical, environmental, GHG emissions and economic criteria

It is worth noting that major gas pipelines are currently government owned and are impacted by the government debt crisis. Also, there are financing prospects for upgrading infrastructure and reducing methane emissions.

"IEA projects fossil fuel demand to peak by 2030. Oil demand will start to decline after 2030. Gas demand will remain close to the peak, sustained by power generation for the next two decades..."

10.0 FINANCING PROSPECTS - LNG

NLNG has had a good history of financing but has not financed Train 7. There was strong potential for OKLNG financing. Further financing for onshore LNG is unlikely. There are prospects for financing of Floating LNG (FLNG) in both shallow and deep water. FLNG technology has progressed in recent years and the industry has grown. Environmental and social impact is less than onshore. There is opportunity to utilise offshore associated gas and prevent flaring (also use reinjected gas); this is positive for climate change. There is opportunity to develop deepwater NAG fields. Fiscal regime for gas needs to be improved and PSC gas terms need to be resolvedThe recent Presidential Order has brought some improvement to the gas fiscal regime.

11.0 CONCLUSION

Climate change and technological developments have changed the oil and gas industry funding and financing landscape. Investment is being channelled to high value, quick return and low carbon intensity projects. Lenders are cutting back on oil and gas industry financing. Financing is available for combatting climate change and environmental impact. FC/World Bank supported by UK and Norway are supporting CCUS in Nigeria. Upstream financing will be by major oil companies under PSCs. Nigerian lenders can provide limited financing to local operators but require assurance that loans will be serviced. Gas for power generation requires financing but it needs robust economics. FLNG has potential for international financing. Petrochemicals, and refinery optimisation and upgrading can attract financing provided they satisfy environmental and economic criteria. The fiscal and regulatory regime is unfavourable and needs to be made more attractive for investment and financing. President issued Executive Order on Oil and Gas Reforms on 6th March 2024 to improve the investment climate • Areas addressed are gas taxation, contracting cycle and Nigerian Content.

As a way forward, the actions to achieve sustainability include:

- Encourage foreign direct investment in the petroleum industry • Nigeria needs both equity and loan financing
- Improve Nigeria's debt position; continue work towards higher credit rating
- Provide favourable environment
- Improve Fiscal and Regulatory Regime
- Address PIA and Nigerian Content Act obstacles (on-going)
- Security
- Reduce methane emissions and overall carbon footprint
- Reduce environmental and social impact
- Maintain high technical standards – ISO Certification
- Encourage gas export – Onshore and Floating
- Accelerate energy transition in Nigeria • Renewables, EVs, improved energy efficiency
- Reduce oil and gas production costs
- Focus on high value internationally competitive projects

Nigeria should strive to attract investment and financing for development andmodernisation of its oil and gas industry while participating actively in the energy transition

ALARM MANAGEMENT & PROCESS SAFETY INTERSECTION

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1.0 INTRODUCTION

Alarm management and process safety intersect at the critical juncture of ensuring operational integrity and personnel well-being within industrial environments. Alarm systems are pivotal components of process safety management, serving as early warning mechanisms for abnormal situations and potential hazards. The effectiveness of alarm systems heavily relies on their proper design, implementation and management.

Alarm management and process safety are closely intertwined. Alarm management system and associated operator intervention are often the last line of defence before a safety system trip.A good understanding of the role of alarms in process safety is necessary both for optimum operator effectiveness and plant safety.

2.0 THE CORE OF ALARM MANAGEMENT

At its core, alarm management involves the systematic design, deployment and maintenance of alarm systems to effectively notify operators about abnormal process conditions or equipment malfunctions promptly. In the context of process safety, alarms play a crucial role in preventing incidents by alerting operators about deviations from normal operating conditions that could lead to hazardous situations such as equipment failure, chemical leaks or process upsets.

Alarm management is the application of human factors (ergonomics) to design and maintain an alarm system to maximize its effectiveness. A common problem is having too many alarms annunciated during a plant upset, commonly referred to as an "alarm flood". However, other problems can exist with an alarm system, such as poor prioritization, improperly set alarm points, ineffective annunciation, unclear alarm meanings and so on. Improper alarm management is one of the leading causes of unplanned downtime, contributing to huge loses annually.

Alarm management is essentially the application of knowledge of human factors (scientifically) in the engineering of plant instrumentation and system information, for designing alarms to increase their usability for managing abnormal situations.

In most processes, maintaining asset parameter at a set value is not completely possible all the time. This is why identifying and establishing a 'Process Envelope' becomes very important. Most often, abnormal situations are caused by the process parameters running out of control, i.e. disturbances beyond the 'Process / Operating Envelope' (normal operating range), which may be of minimal or catastrophic consequence.

It is the responsibility of the operations team to identify the cause of the situation quickly and execute corrective actions in a timely and efficient manner. For this to be possible, they should have an idea of what could go wrong and an indication of when it does go wrong. This is the fundamental principle behind an alarm. The ultimate objective is to prevent or at least minimize, physical and economic loss through operator intervention in response to the condition that was alarmed. Alarms should be setup if and only if there are relevant operator actions connected to them but ultimate plant safety should not depend on operator response to an alarm.

3.0 PROCESS SAFETY MANAGEMENT

Process safety management (PSM) is a disciplined framework for managing the integrity of systems and processes that handle hazardous substances. It relies on good design principles, well-implemented automation systems and engineering, operating and maintenance practices. It deals with the prevention and control of events that have the potential to release hazardous materials and energy. For the process industry, emphasis is placed on process safety to prevent unplanned releases that could result in a major incident which typically is initiated by a hazardous release. It also may result from a structural failure or loss of stability that potentially escalates into a major incident.

4.0 CONSIDERATIONS IN ALARM MANAGEMENT & PROCESS SAFETY INTERSECTION

The intersection of alarm management and process safety encompasses several key considerations:

i. **Alarm Rationalization:** Effective alarm management begins with alarm rationalization

"...alarms must be rationalized to ensure that critical safety-related alarms are promptly identified..."

which involves evaluating and prioritizing alarms based on their relevance, urgency and potential impact on safety. In the realm of process safety, alarms must be rationalized to ensure that critical safety-related alarms are promptly identified and not masked by less important alarms, preventing alarm overload and ensuring operators can respond promptly to safety-critical situations.

ii. **Alarm Design and Configuration:** Alarm systems must be designed and configured to provide clear and actionable information to operators during abnormal situations. In the context of process safety, alarms should be designed to provide early warning of hazardous conditions, allowing operators to take corrective actions to prevent incidents or mitigate their consequences. Additionally, alarm design should consider human factors to minimize the likelihood of alarm fatigue or operator error.

iii. **Alarm Response and Management:** Effective alarm response and management are essential towards ensuring timely and appropriate operator actions in response to alarm activations. In the context of process safety, operators must be trained to recognize and respond to safety-critical alarms promptly in line with established procedures to mitigate the risk of incidents. Furthermore, alarm management practices such as alarm shelving, suppression and escalation can help prioritize alarms and prevent unnecessary distractions for operators during critical situations.

iv. **Continuous Improvement:** The intersection of alarm management and process safety requires a commitment to continuous improvement to enhance the effectiveness and reliability of alarm systems. This involves ongoing monitoring and optimization of alarm performance, leveraging data analytics and feedback from alarm handling experiences to identify opportunities for refinement and enhancement. Additionally, periodic reviews and audits of alarm systems are essential to ensure compliance with industry standards and best practices.

Ultimately, effective alarm management is integral to maintaining process safety and preventing incidents in industrial facilities. By ensuring that alarm systems are properly designed, implemented and managed, organizations can enhance operational integrity, protect personnel and minimize the risk of catastrophic events.

5.0 ALARM MANAGEMENT AND SAFETY INSTRUMENTED FUNCTIONS

i. Relationship: A good understanding of the role of alarms in process safety is necessary both for optimum operator effectiveness and plant safety. Many end users are undergoing alarm management projects at their respective plants or across their companies right now. In some cases, they are migrating from an old alarm management system. In others, they are initiating a new alarm management program. In either case, if a firm is undertaking such a project, it is a good idea to have a comprehensive understanding of where process alarms and safety intersect.

The implementation of a Process Safety Management (PSM) System revolves around the premise of preventing the Loss of Primary Containment (LOPC) of Highly Hazardous Chemicals (HHC) in a process. One of the key factors governing this is maintenance of the process within the intended operating envelope. Thus, the focus of alarms should be built around the identified safe operating process envelope.

Fig. 1 depicts the interactive layer between prevention and mitigation. It shows the alarm as the last layer of defence.

ii. Classes of alarm systems: In alarm management, there are many different classes of alarms, all with

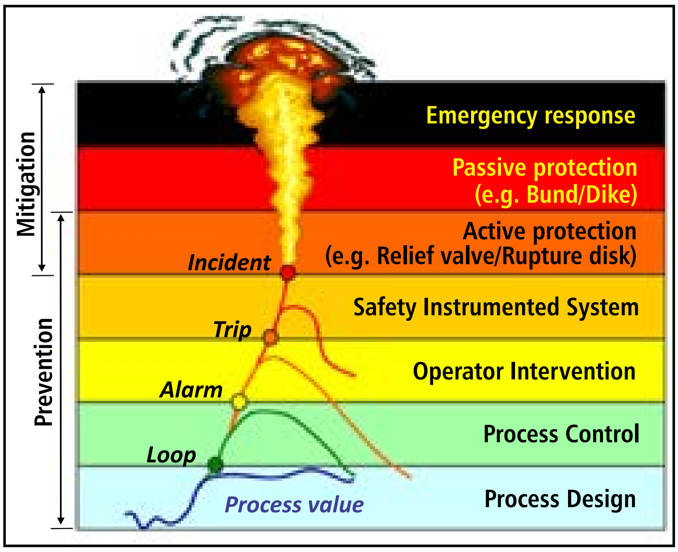

Fig. 1: Layers of protection - Courtesy of Exida

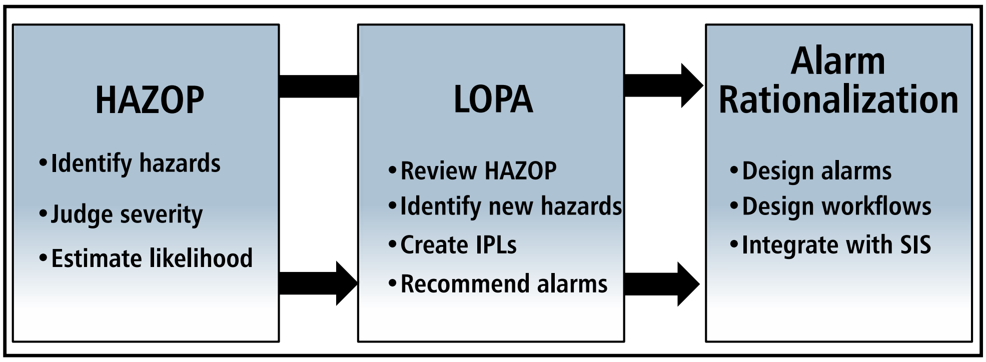

Fig. 2: Connection between HAZOP, LOPA and alarm rationalisation(Source: ISA's Flagship publications)

their own requirements. The same can be said for process interlocks. Process interlocks prevent incorrect operation and possible damage to process equipment. Safety interlocks prevent hazards to humans and are designed to prevent death, injury or a major process incident. A third classification of interlocks is also emerging that provide an independent protection layer (IPL). While these count as a layer of protection, they are not actual safety interlocks that address an abnormal situation. In other words, IPLs protect against abnormal situations or an "undesired consequence", while safety interlocks respond to undesired consequences and take the process to a safe state. The same logic can be applied to alarms.All alarms should require an operator response but not every operator response will be a critical safety-related response. A disruption in the process for a food plant, for example, must be documented in a certain way to satisfy regulatory requirements as a food safety alarm. This kind of alarm is not an everyday process alarm that you would find in a downstream petrochemical plant, nor is it a safety alarm. Instead, it falls into a class called "highly managed" alarms.

When alarms serve the safety system, analysis must be handled with care because the alarm gives the operator the last line of defence.

In a greenfield plant or process unit design, the hazard and operability (HAZOP) study is usually very early in the project before any concrete is poured or pipes are welded. Major hazards identified often trigger some equipment redesign. When the HAZOP is finished, a layer of protection analysis (LOPA) may be warranted to determine if a safety instrumentation system (SIS) is required (See Fig. 1). When the automation systems are finalized later, attention turns to alarm rationalization. An entirely new team of people, perhaps far removed from the HAZOP and LOPA efforts, may address rationalization. If a company is disciplined and fastidious about documentation, it is simple for the rationalization team to incorporate the results of the safety analysis, but this is not always the case.

The most important layer of protection in any process is effective process control. Short of an outright mechanical failure, operations within normal boundaries produce few, if any, incidents. But no basic process control system (BPCS) can handle every possible disruption because there will always be some process upsets.

The alarm system tells operators about disruptions that the BPCS cannot adequately handle automatically. An operator response is then required to fix or mitigate the problem before it escalates to the point where the SIS has to act. By definition, every alarm has an associated operator response and the operator needs to know the appropriate action. Fig. 2 shows the distinct phases linking HAZOP, LOPA and alarms.It shows what typically happens during sessions in each of the phases. As an example, if during the HAZOP exercise a deviation is noticed, alarms with operator action can be recommended. The alarm will thus prevent the consequence from leading to a top event. The alarm architecture is usually carried out via a process known as the ISU (Initial Set Up). During an ISU, a team with the relevant knowledge is constituted to determine the requirements for the alarm.

For most companies, the design of a safety system moves through distinct phases, each building on the previous effort. For this process to work correctly, each team must document its work thoroughly.

It is logical to perform a HAZOP before construction proceeds too far. For many companies, hazard analysis is tedious. A group spends many days hammering it out and might not want to extend the effort with discussions about alarm rationalization at this stage. Moreover, the automation system design may not be far enough to make such a discussion practical. This is not a problem if the results are thoroughly documented, but poor documentation can cause significant problems for subsequent design efforts. The HAZOP analysis identifies hazards in the process and determines the likelihood of a particular event actually happening. The LOPA considers ways to prevent the incident or at least mitigate the top event, with a preference for multiple layers of protection to prevent escalation to a full catastrophe. A LOPA study typically comes after the HAZOP, assuming a company uses it as its safety integrity level (SIL) assessment method. This is when IPLs are identified, including those defined as operator actions triggered by alarms. If the HAZOP team produced thorough documentation, this effort should be straightforward.

iii. Operator actions as layers of protection: When the LOPA team concludes that a particular operator action can eliminate or reduce a hazard identified in the HAZOP, an alarm may be defined as an IPL within the safety system strategy. As a result, that alarm is included in SIL calculations associated with the design of the SIS. SIL calculations can take credit from the alarm's presence and may permit less drastic action in subsequent layers\, as long as the operator appropriately addresses the situation.

For example, an interlock in a subsequent layer, which would have required a SIL 2-rated system, may only require a SIL 1 level of protection to achieve the same overall effectiveness when combined with the alarm. Of course, if the alarm does not cause the operator to take the designated action, the IPL fails, and the incident escalates until it encounters the next layer of protection.

With all this in mind, it is clear that the key information from these studies has to survive multiple team handoffs and be implemented properly to achieve the correct alarm response to a hazard. At each handoff and time lag, gaps can form in the chain and interfere with the desired outcome.

iv. Rationalization: Later after the other teams have done their work, the company will form an alarm rationalization team with a goal of determining the optimal set of alarms to include in the system. The idea is straightforward: deliver the right alarm to the right operator at the right time with the right importance and with the right guidance to correct or mitigate an undesirable situation. It sounds simple, but a team can become quickly intimidated by the scale and complexity of the challenge. The alarm rationalization team is supposed to review and evaluate the operation of the plant or unit, determine the undesirable things that might occur and subsequently determine which associated alarms are appropriate under the criteria set forth in the alarm philosophy document. The team may create a preliminary design that includes the priority, set point and other alarm attributes. The process is often long and tedious because it is usually multidisciplinary.

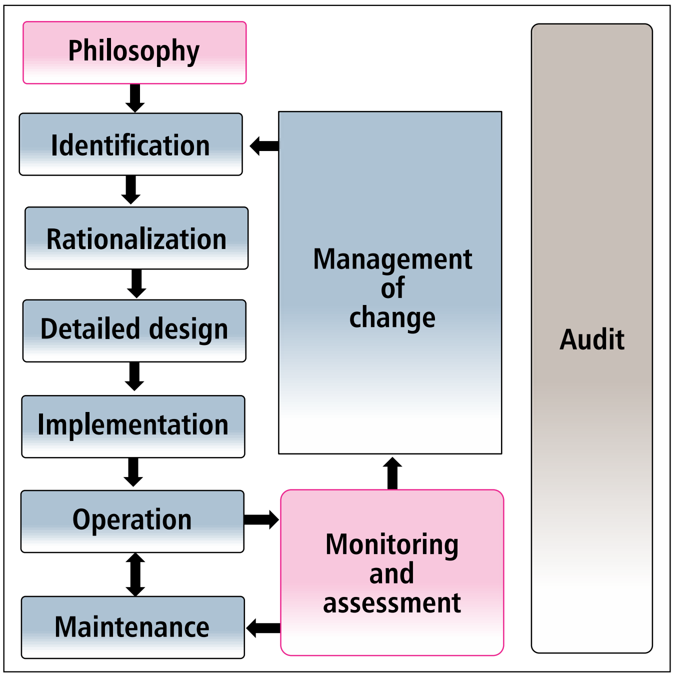

Fig. 3:The entire life cycle for a given alarm (Source: ISA's Flagship publications)

Most of the time, there are many more general process alarms than alarms related to safety conditions. So, within the massive undertaking of alarm rationalization, the team is supposed to give special consideration to perhaps 15 percent of the total. Any alarm intended to function as an IPL should be included as priority. There is no question about the validity of these alarms because they have already been figured into a broader safety strategy and definitely need to be there. Further, they must be implemented in a way that supports the intent defined in the safety analysis.

A team cannot be expected to review every hazard and to design the mitigation solution through layers of protection and alarming. Though ideal, it is impractical for most companies. In reality, it is common for each team-HAZOP, LOPA, alarm rationalization, implementation -to function independently, probably at different times and with different people.

When dealing with safety-related alarms, many of which qualify as IPLs and figure into the larger SIS calculations, many elements factor into the discussion, particularly when working with the safety-oriented alarms designed to perform as IPLs. The alarm rationalization team has to understand the methodology followed by earlier teams to recognize the hazards and generate the alarm requirements.

All alarms must have an associated operator action and this necessitates workflow management. Operators need to know alarm responses from memory or at least be able to retrieve them very quickly. Anyone auditing the system will likely quiz operators to make sure they can respond correctly and promptly. This means those individuals need to be trained. This is especially true for safety alarms where there is probably a very stringent time-of-response requirement. These alarms require the correct response within a specified time otherwise the opportunity to slow down or stop escalation of the problem will be lost.

Consequently, anyone on the alarm rationalization team must bring a variety of skills and a thorough understanding of all the implications of the team's actions. The relationship between the BPCS and alarms within the SIS calculations is complex. Not all alarms recommended to help mitigate SIS-related hazards qualify as IPLs, so determining where credit is taken requires a deep understanding of these mechanisms. If alarms being brought into the safety system are not implemented correctly, the IPL loses its validity, along with any credit in the larger SIS calculations.

Alarm rationalization requires an engineering review before implementation, so alarms can be identified correctly, with each resulting alarm providing the protection required to fulfil the HAZOP, IPL and the associated SIL calculations. Of course, this element of alarm rationalization is only one facet of a larger process.

6.0 HOW DOES ALARM MANAGEMENT IMPACT PROCESS SAFETY?

In addition to keeping a facility operating better, it comes into play when determining the risk, or more precisely the residual risk, in a given process. PSM risk analysis can be broken down into three steps:

Step 1: First, you must systematically evaluate the hazards (inherent risks) in operating a given process unit. This is typically done in a team setting performing a process hazard analysis (PHA) with the most common method being a hazard and operability (HAZOP) study. Hazards are identified and individually evaluated to determine the probability of occurrence along with the severity of consequences if the hazard is realized. In most companies, the overall risk is defined as the probability times the severity.

Step 2: For each identified hazard, the team must then evaluate any safeguards that mitigate those hazards (e.g., the alarm system) to determine how much residual risk remains after taking credit for the safeguards. The safeguards are called independent protection layers (IPLs). Independence is important because if one safeguard fails, it should not affect any other safeguard's ability to mitigate risk. Several methods are used to evaluate the safeguards with the most common being a layer of protection analysis (LOPA).

Step 3: After taking credit for the IPLs, the team will compare the residual risk to the company-defined tolerable risk level to determine if action needs to be taken. If residual risk is greater than tolerable, either the process needs to be redesigned or additional safeguards installed. A common safeguard is to install a safety instrumented system (SIS) to reduce the residual risk to acceptable levels. The size of the gap between the residual risk and the tolerable risk determines the safety integrity level (SIL), which is a measure of how "safe" the SIS needs to be.

Note the BPCS IPL is usually a credit for a safety alarm that triggers an operator response preventing the hazardous event, or some type of automated control, which keeps the process from reaching the hazardous condition. However, you can only count on the BPCS to provide credit for one IPL because the alarm and automated control functions are not truly independent. Certain BPCS failures could disable both functions.

7.0 REQUIREMENTS FOR SAFETY IPL ALARMS

Several requirements need to be met to use an alarm as a safety IPL:

i. The alarm must be designed to work for a specific initiating event that leads to the hazard one is trying to prevent.
ii. The alarmneeds to be tested, including associated instrumentation, at an appropriate frequency to verify that the alarm will work.
iii. The alarm must be independent from other IPLs and not disabled by the initiating event for the hazard.
iv. The likelihood that the alarm will annunciate and the operator will respond properly meets the requirements to be counted as an IPL. The overall alarm function (sensor + logic solver + HMI + operator response) needs to have a PFD of less than or equal to 0.1.

8.0 PHA TEAM RESPONSIBILITIES

When performing the PHA, it is essential that the team properly evaluates and documents every alarm that has been designated for IPL credit. This means meeting these requirements in positive response to these questions:

- Does the alarm meet the four requirements defined above for safety IPL alarms?
- Will the operator have adequate time to recognize the alarm and take necessary action before the hazard is realized?
- What should the alarm setpoint be?

"Process safety is paramount in industrial operations and an advanced DCS alarm management system is a critical tool for enhancing it."

- What does the test frequency need to be?
- What is the proper operator action required to mitigate the hazard?

All this information needs to be entered into the alarm management system with a designated class for safety IPL alarms to ensure they are not modified unless a PHA is conducted. Regardless of what sort of alarm management system is used, the IPL alarms need to be clearly designated because they require special handling.

9.0 IMPACT ON ALARM MANAGEMENT

Using alarms as safeguards for process safety hazards increases their importance and adds another dimension of importance for performing proper alarm management. Proper alarm management becomes more imperative than ever.
Maintaining the performance of the alarm system is critical to ensure that operator response is timely and accurate. Alarm floods, chattering or an excessive number of active alarms will reduce the chance that the safety IPL alarm will receive the attention needed. Alarm response procedures should be clear and easily accessible (ideally in the HMI) so operators can respond quickly and effectively.

10.0 AUDITING

This is a lifecycle requirement that requires a comprehensive assessment of the alarm system, including evaluation of the alarm system performance and work practices used to administer the alarm system. Periodic reviews of how frequently safety IPL alarms have been triggered along with the timing and accuracy of the associated operator response will reveal gaps not apparent from routine monitoring and will allow identification of necessary improvements.

11.0 SAFER PROCESSES

As can be deduced from aforementioned, there are many interactions between alarm management and process safety management. Each discipline requires a rigorous methodology to properly implement, yet understanding how they interact is equally important to ensure a safe and productive process.

12.0 SUSTAINABILITY

i. Using alarms as safeguards for process safety hazards increases their importance and adds another dimension of importance for performing proper alarm management.
ii. Maintaining the performance of the alarm system is critical to ensure that operator response is timely and accurate. Alarm floods, chattering or an excessive number of active alarms will reduce the chance that the safety IPL alarm will receive the attention needed.
iii. Alarm response procedures should be clear and easily accessible (ideally in the HMI) so operators can respond quickly and effectively.
iv. Auditing is lifecycle requirement that requires a comprehensive assessment of the alarm system, including evaluation of the alarm system performance and work practices used to administer the alarm system. Periodic reviews of how frequently safety IPL alarms have been triggered along with the timing and accuracy of the associated operator response will reveal gaps not apparent from routine monitoring and will allow identification of necessary improvements.

13.0 CONCLUSION

Process safety is paramount in industrial operations and an advanced DCS alarm management system is a critical tool for enhancing it. By providing early detection of abnormal conditions, reducing alarm overload, improving situational awareness, enabling root cause analysis and ensuring compliance with industry standards, a DCS alarm management system can significantly mitigate risks and enhance process safety.

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APPLICATION OF FAILURE MODE & EFFECT ANALYSIS (FMEA) IN CHEMICAL PROCESS OPERATIONS

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1.0 INTRODUCTION

Failure Mode & Effect Analysis (FMEA) is a systematic approach to identifying and preventing potential failures in chemical systems. Failure modes are the various ways in which a process can fail while effects are the ways in which these failures can result to waste, defects or harmful outcomes for the customer or end user of a product.

This article provides an in-depth understanding of FMEA principles and their application in ensuring safety, reliability and efficiency in chemical processes. The presentation covers how to identify potential failure modes, assess their effects, prioritize risks and develop strategies to mitigate them effectively to ensure optimal process operation.

2.0 IMPORTANCE OF FMEA IN CHEMICAL PROCESS OPERATIONS

In chemical process operations, FMEA is neededin assessing risks, enhancing safety, improving reliability and minimizing the likelihood of failures that could lead to safety hazards, environmental harm, production downtime or financial losses. It involves cross-functional collaboration and structured analysis to anticipate and address potential failures in chemical systems before they occur.

The following is a breakdown of the importance of FMEA in chemical process operations:

i. Risk Identification: FMEA helps identify potential failure modes within a chemical process, including equipment malfunction, human error or external factors such as natural disasters.

ii. Prioritization of Risks: By assessing the severity, occurrence probability and detection capability of each identified failure mode, FMEA allows for prioritizing risks based on their potential impact.

iii. Preventive Measures: FMEA enables the development of preventive measures to mitigate or eliminate identified failure modes. This could involve improving equipment design, implementing redundancy, enhancing operator training or establishing emergency response procedures.

iv. Safety Enhancement: Chemical processes often involve hazardous materials and conditions. FMEA aids in identifying safety-critical failure modes and implementing measures to minimize risks to personnel, the environment and surrounding communities.

v. Regulatory Compliance: Compliance with regulatory standards and requirements is paramount in chemical operations. FMEA ensures that processes meet or exceed safety and environmental regulations by systematically addressing potential failure modes and associated risks.

vi. Cost Reduction: Proactively addressing failure modes through FMEA can lead to cost savings by preventing costly downtime, equipment damage or environmental incidents. It also helps in optimizing maintenance schedules and resource allocation.

vii. Continuous Improvement: FMEA is not a one-time activity but rather an ongoing process. It fosters a culture of continuous improvement by encouraging regular review and refinement of risk assessment strategies based on new data, technological advancements or operational changes.

viii. Enhanced Reliability: By systematically analyzing failure modes and their effects, FMEA contributes to the development of more reliable and robust chemical processes. This reliability translates into increased operational efficiency and product quality.

“Failure modes are the various ways in which a process can fail while effects are the ways in which these failures can result to...”

Fig. 1: Process FMEA activity in a manufacturing facility (Photo Credit: Process Failure Mode Effect Analysis (PFMEA), Caroline Eisner, Oct 28, 2022. Getmaintainx.com/blog/what-is-pfmea/)

3.0 TYPES OF FMEA

In chemical engineering, FMEA is crucial towards identifying and addressing potential hazards and risks. The following highlights the different types of FMEA commonly used in chemical industries:

i. System FMEA (SFMEA): System FMEA focuses on analyzing potential failures within an entire system or subsystem. In the chemical industry, this could involve examining the overall process design, including the interactions among various components and equipment.SFMEA helps in identifying how failures in one part of the system could propagate and affect other components or the overall process.Common considerations in SFMEA might include process safety, environmental impact, reliabilityof instrumentation and the integrity of containment systems.

ii. Design FMEA (DFMEA): Design FMEA is used to evaluate potential failures and their effects during the design phase of a product or process. It aims at identifying and mitigating design weaknesses before implementation.In chemical industries, DFMEA involves analyzing the design of chemical processes, equipment and infrastructure to identify potential failure modes that could compromise safety, efficiency or regulatory compliance.Factors considered in DFMEA include material selection, component compatibility, design tolerances and adherence to industry standards and regulations (e.g., ASME, API, ISO).

iii. Process FMEA (PFMEA): Process FMEA focuses on analyzing potential failures within a specific manufacturing or operational process. It aims at identifying and mitigating risks associated with process variability, equipment malfunction, human error and external factors.In chemical industries, PFMEA are used in evaluating each step of the manufacturing process, from raw material handling to product distribution, to identify potential failure modes that could lead to safety incidents, product defects or process inefficiencies.Considerations in PFMEA include equipment reliability, process parameters, control systems, safety protocols and environmental factors (e.g., temperature, pressure, humidity). Fig. 1 shows Process FMEA activity in a manufacturing facility.

4.0 STEPS IN CONDUCTING FMEA

While Failure Modes and Effects Analysis (FMEA) is typically presented as a process rather than an equation, it can be conceptualized as a structured equation as follows:

FMEA = RPN × (S + O + D)

Where:

- FMEA represents the overall analysis or outcome of the process
- RPN (Risk Priority Number) is the product of Severity (S), Occurrence (O) and Detection (D) ratings assigned to each potential failure mode
- S represents the severity of the potential failure
- O represents the likelihood or occurrence of the potential failure
- D represents the likelihood of detecting the potential failure before it causes harm.

This equation encapsulates the core components of the FMEA process: identifying potential failure modes, assessing their severity, occurrence likelihood and detection capabilities and then prioritizing them based on their risk priority number.

The following is a more generalized step-by-step process of conductingfailure mode & effect analysis (FMEA) in the chemical industry:

i. **Select the Process or System:** Identify the specific process or system within the plant that you want to analyze. This could be a manufacturing process, a quality control procedure or any other critical operation.

ii. **Assemble the FMEA Team:** Form a multidisciplinary team including individuals with expertise in various aspects of the process or system. This may include engineers, chemists, operators, maintenance personnel and quality assurance specialists.

iii. **Define the Scope:** Clearly define the scope of the FMEA, including the boundaries and interfaces of the process or system under analysis.

iv. **Identify Failure Modes:** Brainstorm with the team to identify all possible failure modes that can occur within the process or system. This involves considering both internal failures (e.g., equipment malfunctions, process deviations) and external failures (e.g., environmental factors, supplier issues).

v. **Determine Potential Effects:** Assess the potential effects or consequences of each identified failure mode on the process, product quality, safety, environmental impact and regulatory compliance.

vi. **Assign Severity Ratings:** Assign a severity rating to each failure mode based on the potential impact of the failure. Severity ratings are typically placed in the rangerange from 1 to 10, with higher numbers indicating more severe consequences.

vii. **Identify Causes and Current Controls:** Determine the root causes of each failure mode and evaluate the effectiveness of current controls in place to prevent or detect the failure. This involves analyzing existing design features, process controls, maintenance procedures, and quality assurance measures.

viii. **Assign Occurrence Ratings:** Estimate the likelihood of each failure mode occurring based on historical data, process knowledge, and expert judgment. Occurrence ratings typically range from 1 to 10, with higher numbers indicating higher likelihood.

ix. **Assign Detection Ratings:** Assess the likelihood of detecting each failure mode before it reaches the customer or causes harm. Detection ratings reflect the effectiveness of current detection methods and range from 1 to 10, with higher numbers indicating lower detectability.

x. **Calculate Risk Priority Numbers (RPN):** Calculate the Risk Priority Number for each failure mode by multiplying the severity, occurrence and detection ratings together (RPN = Severity × Occurrence × Detection).

xi. **Prioritize Actions:** Prioritize the identified failure modes based on their RPN values. Focus on addressing the failure modes with the highest RPNs, as these represent the greatest potential risks to the process or system.

xii. **Develop Action Plans:** Develop action plans to mitigate or eliminate the highest priority failure modes. This may involve implementing engineering controls, process modifications, training programs or other preventive measures.

xiii. **Implement and Monitor:** Implement the recommended actions and monitor their effectiveness over time. Continuously review and update the FMEA as new data becomes available or changes occur in the process or system.

xiv. **Document Results:** Document the results of the FMEA, including the identified failure modes, risk assessments, action plans and outcomes. This documentation serves as a valuable reference for future audits, reviews and improvements.

xv. **Review and Improve:** Periodically review and update the FMEA to incorporate lessons learned, new technologies or changes in regulations. Continuous improvement is essential for ensuring the long-term effectiveness of FMEA in the chemical industry.

5.0 REGULATORY FRAMEWORKS GOVERNING FMEA

While there may not be specific regulatory frameworks governing FMEA in chemical processes, there are regulatory bodies and standards that often require or encourage its use in various industries, including chemical manufacturing and processing. Here are some relevant regulations and standards:

i. Occupational Safety and Health Administration (OSHA): In the United States, OSHA sets regulations and standards to ensure workplace safety. While OSHA may not specifically mandate the use of FMEA, its regulations often require employers to implement safety measures and risk assessments, of which FMEA could be a part.

ii. Environmental Protection Agency (EPA): EPA regulations may require risk assessments and management for chemical processes to prevent environmental pollution and hazards. FMEA could be used as part of these assessments.

iii. International Organization for Standardization (ISO): ISO standards such as ISO 9001 (Quality Management Systems) and ISO 14001 (Environmental Management Systems) often require risk assessment and management processes, which can include FMEA. Additionally, ISO 31000 provides guidance on risk management principles and guidelines.

iv. Process Safety Management (PSM): In the chemical industry, PSM regulations (such as OSHA's Process Safety Management Standard in the U.S.) require companies to implement measures to prevent or mitigate catastrophic incidents involving highly hazardous chemicals. FMEA is often used as part of PSM programs to identify and address potential hazards.

v. Good Manufacturing Practice (GMP): In pharmaceutical and chemical manufacturing, adherence to GMP regulations is crucial. While

"Future trends and emerging technologies in the application of Failure Mode...in chemical processes are likely to be driven by advancements in..."

GMP itself may not mandate FMEA, it emphasizes the importance of risk assessment and management to ensure product quality and safety.

vi. Industry-Specific Guidelines: Certain industries, such as pharmaceuticals, do have industry-specific guidelines or standards that recommend or require the use of FMEA in chemical processes. For example, the International Conference on Harmonisation (ICH) guidelines for pharmaceutical development may require risk assessment methodologies like FMEA.

vii. Chemical Safety Legislation: Depending on the country or region, there are specific legislations related to chemical safety that indirectly require risk assessments like FMEA to be conducted in chemical processes to protect workers, the public and the environment.

6.0 FUTURE TRENDS AND EMERGING TECHNOLOGIES IN FMEA

Future trends and emerging technologies in the application of Failure Mode and Effects Analysis (FMEA) in chemical processes are likely to be driven by advancements in several areas:

i. Advanced Data Analytics and AI: As data collection and processing capabilities improve, FMEA can benefit from advanced analytics and artificial intelligence (AI) techniques. Machine learning algorithms can analyze historical data to identify failure modes and predict potential failures before they occur. This predictive capability can significantly enhance risk management in chemical processes.

ii. Internet of Things and Sensor Technologies: The Internet of Things (IoT) enables the integration of sensors into various components of chemical processes, providing real-time data on operating conditions, equipment performance and environmental factors. By incorporating IoT data into FMEA, operators can better understand failure modes and implement proactive maintenance strategies.

iii. Digital Twins: Digital twins are virtual replicas of physical assets, processes or systems. By creating digital twins of chemical processes, operators can simulate various scenarios and conduct FMEA in a virtual environment. This allows for more comprehensive risk assessment and the optimization of process parameters to mitigate potential failures.

iv. Blockchain Technology: Blockchain technology offers a secure and transparent way to record and track data throughout the supply chain. In chemical processes, blockchain can enhance FMEA by providing a tamper-proof record of equipment maintenance, process changes and compliance with safety regulations. This ensures data integrity and enables effective traceability in risk management efforts.

v. Advanced Materials and Nanotechnology: Advances in materials science and nanotechnology are leading to the development of new materials with enhanced properties, such as increased durability, corrosion resistance and thermal stability. By leveraging these materials in chemical processes, operators can mitigate the risk of equipment failures and improve the reliability of their systems.

vi. Remote Monitoring and Control: Remote monitoring and control technologies allow operators to oversee chemical processes from a distance, providing flexibility and enhancing safety. By integrating remote monitoring capabilities with FMEA, operators can promptly identify abnormal conditions, diagnose potential failures and take corrective actions in real time.

vii. Human-Machine Interaction: Future trends in FMEA may also focus on improving human-machine interaction to enhance decision-making processes. User-friendly interfaces, augmented reality systems and wearable devices can facilitate communication between operators and automated systems, enabling more effective risk assessment and response strategies.

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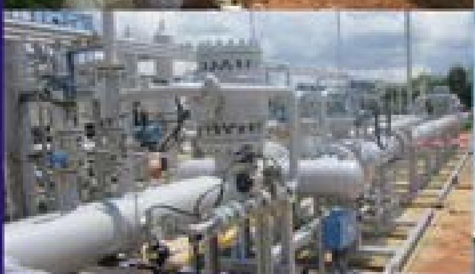

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