

Corrosion Management and Control in the Petroleum Industry-A Case Study of Practicalities at Kaduna Refinery

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Abstract: Corrosion is preponderant in the petroleum environment because most known factors that can cause to extreme various types of corrosion of a wide range of materials are abundantly present in the physicochemical composition of crudes. Every crude oil has about the same kinds of constituent chemical types but in different proportions, so different types of crudes coupled with their processing, transportation and storage conditions can have different corrosivities to materials in different refineries. Kaduna refinery uses Nigerian crudes sometimes blended with foreign crudes to produce some fuels and chemical industrial raw feedstock. The refinery has however been experiencing maintenance problems over its years of existence. This paper is a report of field and literature surveys that attempted to lay bare the basis of the problems. The study found that the entire refinery structures or systems were well designed with corrosion consideration, and corrosion management and control institutionalized therein. Corrosion is managed and controlled in the refinery through many methods including corrosion monitoring and inspections, corrosion audit, and maintenances of all designed controls. The study nevertheless found that corrosion had been a serious problem in the refinery by contributing greatly to its costly maintenance needs, shutdowns and downtime, low production and profitability, and time to time non-availability of its products to the public. Shoddy and lack of proactive corrosion management and control of the refinery have been attributed to its maintenance needs at expensive costs. Possible ways of improving corrosion management and control in the refinery are suggested for enhancing its productivity, profitability and service delivery.

Key words: Refinery products, daily needs, low production, non-availability, maintenance costs, corrosion, and ways out.

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I. Introduction

Back ground to the Study: Corrosion is a destructive attack on an engineering material especially metal as a result of either chemical or electrochemical reaction between the material and its environment [1]. Material corrosion can result to serious impediments of economic and industrial developments and safety depending on how it is controlled. Not all environments are equally corrosive; some are far more corrosive than others. Also, not all materials have the same rate of corrosion deterioration in the same environment; some deteriorate at far greater rates than others [2]. Corrosion generally occurs at a greater degree in the petroleum and water environments than most other types of environments, because most factors that are known to cause different types of corrosion of a wide range of materials to extreme are abundantly present in the two environments. The total global cost of corrosion in the petroleum sector alone is huge and estimated at 3.5% of the Gross Global Domestic Product [3]. A refinery is the type of industry that uses petroleum to produce fuels and wide range of chemical raw materials for the public and other different types of industries. Like all petroleum industries corrosion in refineries is very common and can be very serious with its resultant effects depending on how it is managed and controlled. The level of corrosion in refineries stems from the corrosive nature of crude oils coupled with their processing conditions involving heating to high temperatures and cooling to ambient temperature under various pressures [3, 4]. The combination of all these and other factors influences corrosion in different ways at the preparation, transportation, storage and processing stages of crude oils in refineries. Corrosion in refineries is therefore a serious problem and must be managerially and economically technologically controlled to avert its consequences. Corrosion management is that part of the overall management system which is concerned with the development, implementation, review and maintenance of the corrosion policy. The corrosion policy provides a structured framework for identification of risks associated with corrosion, and the development and operation of suitable risk control measure. Effective management of corrosion will contribute towards achieving statutory or corporate compliance with safety and health and environmental policies, reduction in leaks, increased plant availability, reduction in unplanned maintenance and deferment costs. Management activities such as corrosion monitoring, inspection etc. are utilized to support

corrosion control throughout the lives of assets. Corrosion control refers to the actual technological methods used to control corrosion. The first step to control corrosion is proper design of assets or infrastructures by avoiding features that tend to promote corrosion and unnecessary maintenance costs [4-9]. Design method of controlling corrosion also includes judicious selection of materials that are resistant to corrosion in characterized environments. Various other control methods such as environmental modification, cathodic protection, use of chemical corrosion inhibitors, paint or organic coatings, bituminous wrappings and concrete encasements, metallic coatings by methods such as hot-dip galvanizing, metal spraying, electroplating, and sherardizing, etc. are also specified in the design and implemented based on their levels of effectiveness, cost-justification, and feasibility. No corrosion protection has infinite durability, so effective life of all corrosion protections by any method is limited in most environments and various levels of corrosion maintenances such as change or replacement of parts and renewal of protection are required from time to time to keep averting corrosion problems [9].

Statement of the Problem: Kaduna refinery was built in 1976 at the cost of \$525 million. The refinery has a production capacity of 100,000 barrels per stream day. The refinery uses Nigerian crudes sometimes blended with foreign crudes like Venezuelan, Saudi Arabian, Kuwaiti and Basra crudes and processes them under peculiar refining conditions to produce a wide range of products which include: kerosene, automotive gas oil, lube oil, low pour and high pour fuel oils, liquefied petroleum gas, premium motor spirit, hydro-finished wax, bitumen, linear alkyl benzene, benzene, sulfur flakes, aromatic solvent, toluene, normal and heavy paraffin, heavy alkylate, and kero-solvent. The custodian of the refinery, Nigerian National Petroleum Corporation (NNPC) had on a number of occasions shut it down and other refineries in the country due to increase in their operation costs and maintenance interventions. The effects of such shut downs include low production output from the refinery and scarcity of its products like gasoline, kerosene, diesel, liquefied petroleum gas needed daily by the Nigerian populace and industrial feed stocks like linear alkyl benzene, toluene, and bitumen. The end results are great national economic loss and hard ship on the Nigerian populace and low production by secondary industries that depend on the refinery's products for feed stocking. The last time a comprehensive turn around maintenance was conducted on refinery was in 1992. In recent years, lots of money was voted for maintenance of the refinery. For example, by the end of 2014, a whopping \$1.6billion (about N251 billion) was voted for turnaround maintenance of the refinery and other refineries across Nigeria. By 2017, the total cost of turnaround maintenances of Nigerian refineries was nearly double the cost of building them [10]. Unresolved issues in the refinery maintenance over its years of existence are greatly attributed to time to time occurrence of the problems such as intermittent production with resultant scarcity of its highly valuable products much desired daily and used greatly in Nigeria. 60-70% of maintenance needs and costs were attributed to corrosion causes. Corrosion is therefore recognized as an inevitable serious phenomenon in the refinery and contributor to many of its problems. These problems have made many Nigerians who have no clear knowledge of production problems at the refinery keep complaining with desire to know what is wrong to merit their hardship due to increased cost or non-availability of products they need and are sure the refinery is capable of producing in sufficient quantities to meet needs at reasonable affordable rates in the country.

Aim and Objectives: The aim of this paper is to present a conducted study on how corrosion is managed and controlled in Kaduna refinery. The specific objectives are:

- i. To lay bare some fundamental facts that the general Nigerian public may need to know pertaining to shutdowns, low production and other problems with the refinery which directly or indirectly affect them.
- ii. To know whether there are any lapses in corrosion management and control in the refinery that should be corrected to reduce corrosion problems and costs to improve the refinery's productivity, profitability and service delivery.

Significance of the Study: It is unarguable that Kaduna refinery and other refineries in Nigeria have continued to produce grossly beneath their capacity levels. A well known cause of the problem is time to time non-availability of crudes to the refinery [10, 11]. Apart from this, it is thinkable that production and maintenance problems at Kaduna refinery will be minimal if there is no corrosion. But corrosion inevitably causes problems in the whole Nigerian petroleum industry including the refinery and needs to be controlled to the barest level at minimal cost [9]. The paper has outlined the paradigms of the basic problem as well as managerial pitfalls that need to be tackled to holistically prevent or minimize production problems at Kaduna refinery for any possible rethinking by NNPC and the refinery managements for the general interest of the public and relevant researchers.

Scope of the Study: The scope of the paper is:

- i. Finding out peculiarities of corrosion causative factors at the refinery.
- ii. Understanding the level of corrosion problem and identification of possible types of corrosion within the refinery and their causes.
- iii. Finding out how the management of the refinery tackles corrosion within the domain of the company and how much the cost is yearly.
- iv. Finding out ways of averting ineffective corrosion management and control in the refinery

II. Methodology

The method of study was through field surveys at Kaduna refinery and official and private discussions with some competent staff of the refinery and NNPC on the subject. Also, various related technical articles on the refinery within and outside the company in libraries offices and INTERNET were sought for and consulted. In addition some competent academics and workers in oil companies in Nigeria with good knowledge of inner domains of the refinery or petroleum sector in Nigeria were consulted for their views on the topic.

III. Study Results

Peculiarities of Corrosion Causative Factors at Kaduna Refinery: The chemistry of crude oils is very complex with many factors that influence its corrosiveness. These factors make it difficult and in most cases impossible to predict corrosiveness of crude oils according to their physicochemical composition. Crude oil is a mixture of numerous liquid hydrocarbons containing dissolved gases, water, and salts. Crude oils vary widely from almost solid and heavy that sink in water up to light materials that float on water. Crude oils are, in fact, emulsions or drops of aqueous solution dispersed throughout the continuous hydrocarbon phase [3]. Interstitial or connate water is always present in crudes. These water drops vary from almost fresh to saturated aqueous solutions of salts and are the main cause of crude corrosiveness. The general components of crude oils that determine their corrosiveness are given in Table 1.

Table1:The general components of crude oils that determine their corrosiveness[12, 13]

Hydrocarbons	Constituent chemical type
Naphthenic	Alkyl cyclopentanes, and alkyl cyclohexane
Aromatic	Alkyl benzenes, aromatic naphthenic fluorenes, polynuclear aromatics
Sulfur compounds	Elemental sulfur (S ₈), hydrogen sulfide (H ₂ S), mercaptans; organicsulfides, disulfides and polysulfides; thiophenes and benzothiophenes; sulfones
Dissolved gases	Nitrogen (N ₂); carbon dioxide (CO ₂)
Organic nitrogen compounds	Pyridine, quinolone
Organic oxygen compounds	Carboxylic acids (including naphthenic acids), alcohols, phenols, ldehydes, ketones, esters, ethers, oxyacids
Organic metallic compounds	Pyridine, quinolone
Colloidal particles	Asphaltenes; resins; paraffin waxes
Surfactants	Sulfonic acids, sulfonates, sodium naphthenates
Metals	Vanadium, nickel, iron, aluminum, sodium, potassium, calcium, copper
Sediment and Water	Fresh or saline
Solids	Sand, dirt, silt, soil dust, mud, corrosion products (metals' oxides, sulfides, salts)

In addition to the hydrocarbons shown in Table 1, composition of crude oil can also include compounds containing sulfur, nitrogen, oxygen, and metals. All these contaminants influence corrosion in different ways and may be present in crude oils as dissolved gases, liquids and solids or distinctive phases. Microorganisms also influence corrosion and can be present in crudes in active or dormant state. Every crude oil contains about the same kinds of compounds, but in different proportions. As a result, crude oils differ by their corrosiveness. Usually, corrosiveness of petroleum is determined by the total acid number, sulfur content, water and salt content and levels of microorganisms present [3].

Problems of Corrosion at Kaduna Refinery: Results of the study show that Kaduna refinery incurs many corrosion problems from time to time that manifest in the forms of:

- i. Blockage of pipes by corrosion products.
- ii. Mechanical damage to valves, pumps and pipes resulting to fluid leakages.
- iii. Production losses due to allowance of time for maintenance.
- iv. Increased production cost as a result of corrosion maintenances.
- v. Environmental contamination due to perforated vessels and pipes allowing escape of their content which could cause harm to the surrounding.
- vi. Contamination and reduced value of products.
- vii. Safety risk to staff.

- viii. Reduced efficiency of equipment or facilities.
- ix. Reduced life and aesthetics of facilities or systems.

Types of corrosion possible at Kaduna Refinery

Different types of corrosion that can occur in the refinery were documented since they may require different management and control approaches to prevent or remediate all of them. The study found that the complexity of physicochemical compositions of crudes coupled with high temperatures during refining also make it possible for different types of corrosion to occur in the refinery. This type of environment was found to be capable of making it possible for any type of corrosion to occur either at the preparation, transportation, storage and processing stages of crude oils in the refinery. The corrosion types can include microbiologically influenced corrosion, uniform or nearly uniform corrosion, pitting corrosion, stress corrosion cracking, erosion corrosion, fretting corrosion, fouling and tarnishing, etc.

Corrosion Management and Control: The study found that corrosion management is institutionalized at Kaduna refinery. Management activities such as corrosion monitoring, inspection etc. are utilized to support corrosion control of the refinery systems, structures and equipment. Corrosion monitoring is used to acquire information on the progress of corrosion-induced damages of the refinery structures or systems or how corrosive the environments surrounding them are. Regular inspections are also conducted at the refinery to locate and gain insight into the amount and severity of corrosion damages in the material structures of the refinery systems, or equipment. The main objective of the inspection is to determine whether everything is still conforming to the safe design parameters by establishing whether corrosion, erosion or abrasion has consumed the corrosion allowance in the equipment or if there are indications of mechanical or corrosion-influenced cracking that can lead to failure. These activities if properly carried out can help in controlling corrosion in the refinery in several ways by [4-9]:

- i. Determining corrosion rates, identifying potentially hazardous conditions, locating structural defects and discovering material non-compliances.
- ii. Providing an early warning that damaging process conditions exist.
- iii. Diagnosing a particular corrosion problem and identifying its cause.
- iv. Evaluating the effectiveness of a corrosion control or prevention technique.
- v. Determining optimal application of corrosion control or prevention technique.
- vi. Providing management information relating to the maintenance requirements and ongoing condition of plant.
- vii. Providing performance data and a basis for life prediction.
- viii. Promoting the transition from a reactive to a proactive safety culture.
- ix. Substantially reducing maintenance costs through making and implementation of better decisions about critical component or system life and reliability.
- x. Calculating the remaining life of assets.
- xi. Implementing cost-effective inspection and maintenance programs on items with a high probability of failure.
- xii. Ensuring the integrity and safety of all the refinery components and system make up, and contributing to a successful health, safety and environmental management program.
- xiii. Maximizing the refinery asset performance management data and capabilities by providing real-time trending and robust visualizations to manage risk and proactively make disposition decisions.

Every methodical corrosion protection of a structure or system has limited life. The refinery structures or systems are protected from corrosion by maintaining protections provided by a number of methods that have been in place as part of its design or by replacement of corroded component, systems, machineries, etc. The various methods used to control corrosion in the refinery include:

- i. Coating systems such as coal tar enamel coatings, plant-applied tape systems, polyolefin(cross head extruded) with butyl adhesive, polyolefin(dual-side extruded) with butyl adhesive, epoxy (fusion-bonded), paint and organic coatings,
- ii. Sheathing methods such as concrete encasements.
- iii. Corrosion inhibition by use of chemical inhibitors.
- iv. Cathodic protection using galvanic anodes or impressed current.
- v. Feasible use of more corrosion resistant materials.

Cost of corrosion management and control at Kaduna Refinery

The cost of corrosion management and control at Kaduna refinery stems from all its activities. These include costs of corrosion monitoring and inspections, cost of acquiring protective materials some of which have

to be imported, cost of actual maintenance work, cost of consultancy, etc. The average annual estimated cost by this study for effective corrosion management and control of the refinery as worked out with knowledge of moneys voted for its rehabilitations or repairs over its years of existence is about 10-15 billion Naira per annum [11].

Level of effectiveness of corrosion management and control at Kaduna refinery

In spite of strategies laid down for controlling corrosion at the refining company, corrosion related problems persist therein. Some reasons attributable to these include possibilities of: lapses in the corrosion management and control, incompetence of some staff involved, shoddy or lack of proactive corrosion maintenances of the refinery, endemic corruption in NNPC due to moneys voted for maintenances of the refinery ending in futility.

Ways of averting ineffective corrosion management and control at Kaduna Refinery.

The following suggestions are made among other things for improving the present corrosion control status in the refinery [11]:

- i. NNPC and Kaduna refinery managements should recognize corrosion as a serious causative factor of problems in the refinery and be proactive in dealing with it.
- ii. Corrosion monitoring and inspections should be regularly conducted on all equipment or facilities within the refinery using the state-of-art techniques.
- iii. The corrosion management and control unit of the refinery should have monthly record of any intolerable corrosion rates and other abnormalities within the refinery for analysis to know the trend with time.
- iv. Sufficient money should always be voted timely for all repairs in the refinery and the repairs timely and properly effectuated.
- v. All moneys voted for maintenances of the refinery should be judiciously used for the purpose.
- vi. All contracts for repairs in the refinery should be awarded only to reputable companies that know the detailed design of the refinery.
- vii. There should be no lapses in corrosion management and control in the refinery.
- viii. NNPC should set up a standing reputable committee consisting of experts in corrosion engineering for advising it on corrosion issues in the refinery and monitoring all contracts and contractors for maintenance works in the refinery.
- ix. The refinery and NNPC managements should be ensuring that all their employees or contractors involved in corrosion management and control are competent and resourceful.
- x. Possibility of privatizing the refinery for better performance should be considered.

IV. Conclusion

Kaduna refinery is a critical component of the Nigerian industry and economy. This study was undertaken to find out how corrosion is managed and controlled in the refinery with the aim of laying bare any lapses or defaults that need to be improved by all concerned for perpetually keeping corrosion and its effects abey in the refinery. The study found that corrosion is a serious problem in the refinery in spite well protective design of the company and laid down strategies by the company and NNPC managements to keep corrosion to benign level in its domain. The effects of corrosion sometimes manifest in shut downs of the refinery, low production output from it, and scarcity of its products needed daily by Nigerian populace for fuelling and feed stocking some other industries. The end results of the effects are great national economic loss with attendant hard ship on the Nigerian populace and low production by secondary industries that depend on the refinery's products as their feed stocks. The study attributed these to, lapses in corrosion management and control in the refinery, incompetence of some staff involved, shoddy or lack of proactive corrosion counteractions in terms of repairs or maintenances, and money sometimes voted for maintenances or repair purpose ending in futility because of endemic corruption in NNPC. Possible ways of averting ineffective corrosion management and control in the refinery have been suggested to alleviate its problems for greater productivity, profitability and service delivery.

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