RESEARCH ARTICLE OPEN ACCESS

Corrosion Management and Control-Entrepreneurial Opportunities and Challenges in Nigeria

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ABSTRACT
Corrosion directly or indirectly affects everybody and the society at large in different ways to a major obstacle to maximization of technological and economic feats. Nigeria is a petroleum-producing maritimetropical nation with possibility of corrosion preponderances and unpredictability. The problem of corrosion is a majorchallenge she has been facing to utilize her economic potentials and develop to industrial status.Meaningfulentrepreneurship in corrosion managementand control in the country was seen to be a tangible way out of the problem. This was also regarded as a big job avenue of great financial rewards cum personal satisfaction for competent Nigerian graduates from tertiary institutions that had been in search of jobs that were non-existent and employees who had remained unsatisfied with their jobs and or take home pays for the past decades due to poverty, economic downturn, corruption and bad governance in the country. Some capital, good education and manpower in science and technology, and determination to succeed in the face of risks with sincere desire in solving corrosion problems were considered requisite for the entrepreneurship. The general principles of corrosion management and control were reviewed and issues at stake that can make greater entrepreneurial impact in the country highlighted.
Keywords: Nigerian economy, problems and cost of corrosion, management and control business, rewards and benefits, competent Nigerians.

Date of Submission: 06-10-2017 Date of acceptance: 31-10-2017

I. INTRODUCTION

Corrosion is a natural material degradation process that results by reaction of the material with its environment.Wherethe process remains unchecked for an applied material, it can result to various levels of costs in terms such as:

- Accidents and loss of lives.
- Repair or replacement of corroded parts or equipment.
- Overconsumption of materials by overdesign to allow for corrosion.
- Loss of production due to plantshutdownsduring corrosion maintenance or failures.
- Reduction of facility efficiency due to accumulation of corrosion products.
- Product contamination.
- Research on the science and methods of preventing corrosion.
- Loss of some expensive transportation assets such as aircraft or automobile in some accidents caused by corrosion failure as well as other valuable products that have irreparably corroded
- Limitationof applications ofdesirable materials for some services.
- Trauma and agonyand suffering by dependents arising from corrosion causes such as accidents involving lossor incapacitation of right-hand men or loved ones.
- Maintenance of standby facilities and workmen in readiness to operate when corrosion failure occurs or is anticipated.
- Jeopardy of human safety and environmental security by sudden failures that cause fire, chemical spillage, and explosion.
- Health problems associated with toxic corrosion products and chemicals or substances used to prevent corrosion.
- Depletion of natural resources, including metals and the fuels used to manufacture them.
- Loss of cherished aesthetics [1, 2, 3].

Today, the impact of corrosion on our global society and the associated degradation of materials are far reaching owing in part to the increased complexity and diversity of material systems, which include not only metallic materials but also ceramics, polymers, and composites which are subject as well to environmental extremes [4].

Most industrial or asset designs are made taking into consideration the effect of corrosion on the life span of the structures. Despite that, the most dangerous and costly of all corrosion still occurs in major industrial plants; such as electrical power, and chemical processing plants such as those of oil and gas industries as well as buildings and transportation systems and facilities. The oil industry with its complex and demanding production techniques and environmental threat should component fail takes an above average share of the consequences. The most important steps to hinder or reduce the extent of the consequences are sufficiently early detection, proper diagnosis and effective prevention measures of the imminent corrosion [5-8].The average corrosion cost for industrialized nations is put at about 5% of their GDPs. The cost for US industries alone was estimated at $170 billion per annum. The substantial cost has been putting strains on manufacturers, suppliers and users to invest in new opportunities or lose business to corrosion-related risks.In most developing countries, thesituation is worsened by general low level of corrosion-consciousness and counteractions with the deleterious phenomenon more or less silently taking its toll on their economies and people's lives [7-9].Nigeria is a maritime petroleum-producing tropical nation with possibility of corrosion preponderances and unpredictability. She is also a developing country that has been fervently searching for ways to become an industrialized nation. The country is endowed withabundant resources that can help her to easily develop to industrial status if managed properly. So far, the utilization of these resources as raw materials is dependent wholly on the industrialized economies. The country's economy especially the petroleum industry upon which it so much depends is prone to corrosion ravages. The costs of corrosion and its management and control are major challenges the country has been facing to utilize her economic potentials and develop to industrial status. About 80% of construction materials in the country are corrodible materials such as carbon steel and concretes. These materials are applied in industrial facilities, bridges, dams, commercial and residential buildings, pipelines, vehicle bodies, processing and storage facilities, etc. and are prone to high rates of corrosion in harsh operating environmental conditions and corrosive chemicals. Yet all the materials of construction in the country are imported, and an enormous amount of foreign exchange lost to corrosion.Effective corrosion control of such assetsor structures is not a simple regularly routine process because of various and unpredictable forms and levels of corrosion different materials experience as environmental factors vary from location to location for a given time. So, it needs to bemanagerially technologically accomplished with cost-justification for each different system or situation [7, 8, 9]. Plate I is a typical view of some different forms of industrial or utility corrosion that can also be encountered in Nigeria.

Plate I: Views of some typical forms of industrial or utility corrosion in Nigeria [10]

All forms of corrosion can however be dealt with through proper precautions and procedures, but only in corrosion management programs that contain them.Governments in Nigeria and their agencies alone have so far failed abysmally in tackling the general corrosion problem in the country because of lack of consistent corrosion policies and adherence to them [11]. There is therefore a lot which relevant competent professionals such as engineers can do on their own contributory to the country's efforts in tackling the general problem of corrosion in her domain.

An important avenue through which competent professionals can privately supplement governmental efforts to corrosion management and control whilst boosting economic and technological development as well as creating wealth and massive employment in Nigeria is through entrepreneurship. Entrepreneurship is the capacity and willingness to develop, organize and manage a business venture along with any of its risks in order to make a profit. Entrepreneurial spirit is characterized by innovation. It is an essential part of a nation's ability to succeed in an ever changing and increasingly competitive global marketplace. Entrepreneurial development is the bedrock of all economic evolution of any nation. It has played a vital role in the growth and development of the advanced nations[12-16].The key to successful entrepreneurship in the area of corrosion management and control should be competence and sincere desire for solving corrosion problems by persistent search for the problems and providing the requisite solutions to them. Aspiring entrepreneurs in this area should also be willing to take any idea, whether research and development, a product and/or service, and have the skillset, will, and courage to take extreme risk to do whatever it takes to turn that concept into reality and not only bring it to market but make it a viable product and/or service for beneficially solving corrosion problems [16].

The aim in this paper was to review the general principles of corrosion management and control and posit the basic areas ofneed, technological challenge, and opportunity that could make greater entrepreneurial impact in Nigeria. The specific objective was to make competent Nigerian graduates from tertiary institutions that had been in search of jobs and employees that had remained unsatisfied with their jobs and/or take home pays see the great contribution towards the country's industrialization aspirations cum personal rewards and benefits by entrepreneurship in corrosion management and control in their dear country and be motivated to embark on it.

II. BASICS OFCORROSION MANAGEMENT AND CONTROL

2.1 Corrosion Management

Invirtuallyall situations,metal corrosion can be managed, slowed, or even stopped by using the proper techniques. 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 the following benefits: statutory or corporate compliance with safety and health and environmental policies, reduction in leaks, increased plant availability, reduction in unplanned maintenance, and reduction in deferment costs [17, 18]. Fig.1 shows the basic corrosion management process.

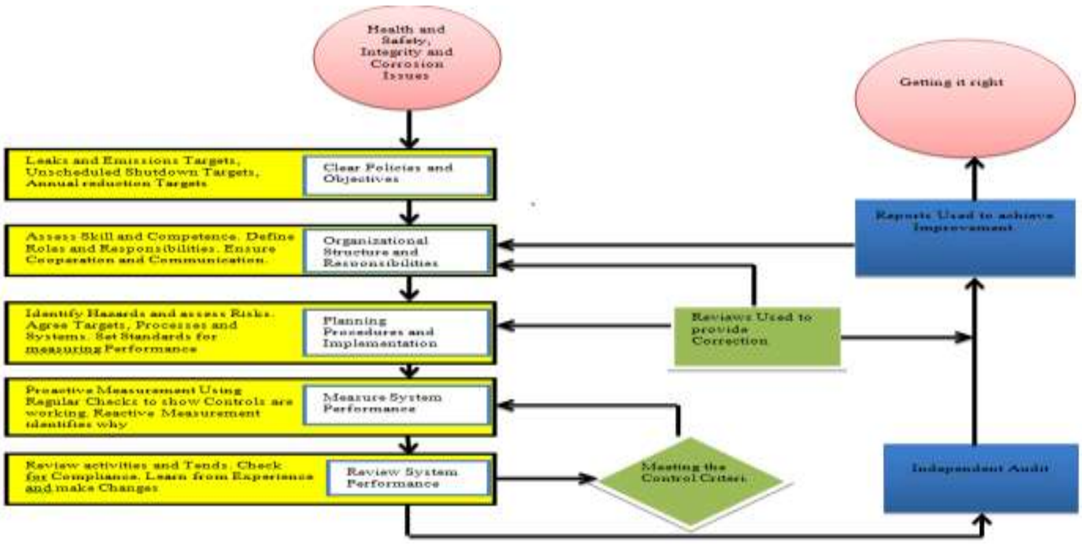

Fig. 1: Basic corrosion management process [17]

The corrosion management process provides the focus and action plandetails on how to optimally use human, capital and material resources to:

- Reduce corrosion maintenance and corroded-materials repair costs, amount of products lost due to corrosion damage and extend the useful life of manufactured products or assets through some action plan such as review of corrosion costs by processes, preventatives and packaging, and implementing a plan to reduce costs within the aforementioned areas.
- Examine liability and risk by metal materials, and review proper metal parts processing and handling regulations by evaluating current risks within processing, manufacturing, storage and shipping; determining consequences of failures in each area; and reducing risk through a change in corrosion protection and packaging technology.
- Investigate the possibility for new coatings, alloys and corrosion inhibitors by applying new corrosion protection and preventatives for more corrosion-resistant products and best practices.
- Get better corrosion protection by examining every process from manufacturing to delivery to cover the full scope of corrosion control [18].

Management activities such as corrosion monitoring, inspection etc. are utilized to support corrosion control throughout the lives of assets.

2.1.1 Corrosion monitoring:Corrosion monitoring is the practice of acquiring information on the progress of corrosion-induced damage to a material or on the corrosivity of the environment surrounding the material. It is one of the most important components in corrosion control. It can help in several ways by:

- Determining corrosion rates, identifying potentially hazardous conditions, locating structural defects and discovering material non-compliances.
- Providing an early warning that damaging process conditions exist.
- Diagnosing a particular corrosion problem and identifying its cause.
- Evaluating the effectiveness of a corrosion control or prevention technique.
- Determining optimal application of corrosion control or prevention technique.
- Providing management information relating to the maintenance requirements and ongoing condition of plant.
- Providing performance data and a basis for life prediction [20].

Corrosion monitoring is usually applied where:

- High pressure, high temperature, flammable, explosive, toxic processes exist.
- There is probability of high corrosivity in equipment.
- Corrosion rate may have changed due to changes in operating conditions.
- Corrosion inhibitors are in use.
- There is high concentration of corrosive constituents in process.
- Process feedstock is changed.
- Plant output or operating parameters are changed from design specifications.
- Evaluation of corrosion behavior of alloys is necessary.
- Induced potential shifts are used to protect systems and/or structures.
- There is a vital concern about product contamination due to corrosion [20].

The commonly used corrosion monitoring devices include: weight-loss coupons, spool pieces, electrical resistance probes, linear polarization probes, galvanic probes, hydrogen pressure probes, hydrogen electrochemical patch probes, electrochemical noise probes, field signature method, etc. [20, 21].

2.1.2 Inspection: Inspection is the means by which corrosion and any damage may be located in a structure, as well as gaining insight to the amount and severity of that damage. The main objective of periodic inspection is to determine whether the equipment 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. Inspection plays so important role in modern engineering that it is recommended to start even before the equipment is fabricated by checking materials selection, drawings, welding procedures, and capability of producers and suppliers. The fabrication and the acceptance of the finished product should also be inspected and quality-controlled. If the quality, periodicity, and extent of inspection or monitoring are carried out efficiently, the probability of detecting attacks before they cause serious failures is very high. To be able to perform the inspection in a systematic way, an inspection program has to be worked out. The program should specify the frequency of inspection, timing, and recording of service and equipment condition. To devise a proper inspection program, knowledge of the process and the material performance is needed. The inspection of various parts of the equipment or system and the type of inspection methods should be specified. Thefrequency of inspection should be evaluated based both on the risk of failure occurring and on the consequences if failure occurs. Most various inspection techniques available are typically used to give frequent, short time interval measurements, thereby allowing the day-to-day control of corrosion mitigation or prevention approaches such as corrosion inhibition. When the expected risk and/or consequences of corrosion failure of equipment are great, systematic periodic inspection or continuous corrosion monitoring has to be carried out. Inspection techniques and intervals for pressurized vessels and pipes are often defined by legal code requirements. Code regulations and specifications ensure that proper materials are selected, that a responsible design of the equipment is obtained, and that adequate fabrication methods are used. When the equipment has been installed on the site; operating procedures, maintenance procedures, inspection and control shall ensure safe performance and operation of the particular items. Advances in computer technologies and electronics have led to very efficient tools for monitoring and inspecting corrosion such as impedance spectroscopy, electrical field signatures, acoustic emissions, and radiographs [1, 21, 22]. Usually inspection tools are used less frequently than corrosion monitoring devices, often on an annual or even longer basis. The list of inspection techniques include: visual inspection, eye and magnifying glass, boroscopes, fiberscopes, robotic crawlers, cameras, caliper tools, ultrasonic thickness (UT) measurements, pulse-echo contact method, shear wave mode UTs, phased array, automated UT (both in compression and shear modes), long range UT or guided wave inspection (GWI), hardness measurement, radiography, dye penetrant, magnetic flux leakage such as in intelligent pigs, dry magnetic particle, wet magnetic particle, wet fluorescent magnetic particle testing (WFMT), magnetostrictive guided wave testing, eddy current, pulsed eddy current,tangential radioscopy, magnetic flux exclusion, acoustic emission, acoustics ultrasonic. The first six listed methods are however the most commonly used [20, 21]. Summarily, the purposes of corrosioninspection are, to:

- Find out the extent of corrosion.
- Promote the transition from a reactive to a proactive safety culture.
- Substantially reduce maintenance costs through making and implementing better decisions about critical asset life and reliability.
- Calculate the remaining life of assets.
- Implement cost-effective inspection and maintenance programs on items with a high probability of failure.
- Ensure the integrity and safety of assets, and contribute to a successful health, safety and environmental management program.
- Maximize asset performance management data and capabilities by providing real-time trending and robust visualizations to manage risk and proactively make disposition decisions [23].

2.2 Corrosion Control

Corrosion control refers to measures that are implemented in various fields to prevent or minimize corrosion in a specific metal, structure, part, equipment, system, environment, etc. With such measures in place, the harmful effects and negative consequences of corrosion can be avoided [19].Corrosion control starts at the top with proper design of assets or infrastructures by avoiding features that tend to promote corrosion and unnecessary maintenance costs. The most common and easiest way of controlling corrosion is by judiciously selecting optimally suitable materials that are resistant to corrosion in characterized environments and observance of important features such as: allowance of free circulation of air around the material structures, not exposing the structures in contact with water-absorbent material or wood, providing accessibility to the material structures for maintenance, selecting structural shapes which will have minimal exposed surfaces, avoiding shapes or details which catch dirt or debris, noting that large flat surfaces are easier to protect than more complicated shapes, ideally locating load-carrying members of the material structures in the least corrosive locations; and avoidance of pockets, low spots, sharp edges, sharp corners, cavities, crevices, lap joints, bolted joints, box sections which will trap moisture or water in all designs. Design also stipulates some standard protective and maintenance methods for the selected materials during their designed service lives. This is because design per se has some shortcomings because:

- It may not be feasible or economical for some practical situations and in most cases can only reduce but not completely prevent corrosion because.
- A change in design or materials for the purpose of corrosion control may have serious cost-incurred effects that are not related to corrosion per se or result in corrosion problems that were not previously present in the old system.
- Very often the effects of corrosion cannot be clarified at the early stage of design because information is lacking either on the precise environmental corrosivity levels or on the behaviours of materials in certain configurations or applications under these conditions [1,2, 3].

Due to the aforementioned shortcomings of the design method per se, other corrosion prevention or mitigation methods areusually specified for assets as part of the design. The method chosen depends mainly on comparative advantages in terms of feasibility, effectiveness, cost-affordability, durability, and ease of protection in a given environment [2, 24]. Various methods are used but the more known ones can generally classified into seven groups, namely: environmental modifications, metal selection, cathodic protection, use of corrosion inhibitors, metallic coatings, paint or organic coatings, and encasement [24, 25].

2.2.1Environmental modification: This involves removing the metal from an environment or changing the type of environment by changing its operating variables such as temperature and Ph or removal of its corrosive constituents such as oxygen, chlorides, moisture and carbon dioxide. For example, desiccants can be applied in closed spaces to remove moisture, and feed water for water boilers can be treated with softeners or other chemical media to adjust the hardness, alkalinity or oxygen content in order to reduce corrosion on the interior of the unit [1, 2,25].

2.2.2Metal selection: This requires the use of metal corrosion resistance and properties data in combination with information on environmental conditions to choose the metal that resists corrosion in an environment. The lists of suitable materials for various types of environments aregiven by some reputable national and international organizations such as, ISO, ASTM, NACE, and ANSI which can be consulted to make selections. However, corrosion resistance is not the only criterion to be considered when selecting a material. Availability and cost-justification of the material should ultimately dictate its selection [1-3].

2.2.3Cathodic protection: This is usually used to prevent or reduce the rate of corrosion of metal structures, immersed or imbedded in aqueous environmental electrolytes by impressing a counter current on the structures in a sufficient amount to neutralize their corrosion current, or making the structures cathodes. Cathodic protection is achieved either by using sacrificial anodes or by impressing a current (power impressed). It is usually the only economical method of protecting major buried or immersed metallic structures from corrosion.The main applications of cathodic protection include: buried pipelines, acid storage tanks, offshore steel structures such as platforms and oil rigs, ships and concrete structures exposed to sea water such as bridges. The method is simple and when absolutely correctly applied, corrosion is impossible. It can be applied to any buried metal item without fully excavating the system. The forms of corrosion which can be controlled by cathodic protection are wide including all forms of general corrosion, pitting corrosion, crevice corrosion, stress-corrosion cracking, corrosion fatigue, cavitation corrosion, and bacterial corrosion. At any time, the efficiency of the protection can be checked by measuring the potentials of the reference points, and making any required adjustment to compensate for any changes in local environment. Sacrificial cathodic protectionprovides uniform distribution of current without need for external power source. It is also cheap to accomplish and maintain and easy to install. The anodes used are metals that have the most negative potentials in the galvanic series. These include metals like magnesium, aluminium, copper, zinc, silver and their alloys. The impressed current cathodic protection has higher current and power outputs and adjustable protection levels. It can be used to protect works with large surface areas and poorly coated structures. The anodes used are the inert types and are lower in number compared to the sacrificial cathodic protection for the same work size. Such anodes include graphite, platinum, and niobium [1, 2, 24- 26].

2.2.4Corrosion inhibition: This is achieved principally by addition of certain chemicals or substances that can restrain corrosion of material in requisite environments. Corrosion inhibition is an economical method of protecting in-situ metals in certain environments such as boilers and pipe works of central heating systems, re-circulating systems such as internal combustion engines, cooling systems of road vehicles and railway locomotive; steam condensate lines, the oil industry at every stage of production from initial extraction to refining and storage prior to use, storage tanks, domestic and industrial water supplies, store rooms, and packages. Many inhibitors such as acetylenic alcohols, aromatic aldehydes, alkenyphenones, amines, nitrites, benzoates, toluylalanine, phenythiourea, sebacic acid, silicates, phosphates, imminium salts, triazole pyridine and its derivatives, thiourea derivatives, thiosemicarbazide, thiocyanates have been reportedly used to prevent steel corrosion. One major drawback of most synthetic organic inhibitors in use today is that they have various levels of toxicity to ecosystems and effluent disposal problem [1- 3, 24, 25, 27].

2.2.5 Metallic coatings:These are used to protect assets or structures from corrosion by acting as impervious interfaces between them and the environment or sacrificially by corroding at a higher rate than them. Metallic coating can be formed by a variety of methods; however there are four commonly used methods of applying protective metallic coatings. These are hot-dip galvanizing, metal spraying, electroplating, and sherardizing. The methods are used for coating metals mostly steel with zinc, aluminium, lead, and tin. The four metals are the most common and cheap non-ferrous metals that offer the most effective protection at economical costs

Hot-dip galvanizing is the most common method of applying a metal coating to structural steel works. It is the most economical method of zinc-coating steel.

The specification of hot-dip galvanized coatings is covered by the British Standard-BS729. Galvanizing provides a barrier as well as cathodic protection. It results in coatings that are highly resistant to corrosion and damage during transportation, storage and handling.

Metal spraying is the alternative method of applying either zinc or aluminium coatings to structural metal works. The main advantage of metal spraying compared to other metallic coating processes is cheapness. Metal spray coatings can be applied in shops or on site after a structure has been erected because of portability of spraying equipment and there is no limitation to the work size as there is with hot-dip galvanizing. The surface of the work remains cool during the process so there are no distortion problems. The main disadvantages of the coating process are; the tools are rather awkward to handle as they contain molten metal, the metal used for spraying must be easily fusible, the coatings are porous due to their structure of overlapping flakes after having solidified instantly on contact with the surface, and higher cost compared to hot-dip galvanizing.

Electroplating is electro-deposition that produces a thin, coherent and adherent coating of solid metal on a base one. The process is used to protect steel from corrosion by producing coatings of suitable metals on it with thicknesses from about 0.00762 to 0.001524mm. Deposit thicknesses appropriate for various conditions of service of the steel metal are specified by a number of organizations such as the ISO, BS, and ASTM. Metals that can be electroplated on steel and other metals for corrosion protection include those that offer sacrificial protection such as zinc, tin, aluminium, copper and bronze; and the noble metals such as lead, nickel, gold, chromium, titanium and platinum. The process requires high-quality surface pre-treatment of the base metal, good operator skills to control process variables such as electric current density. Protective coatings produced by the electroplating process are generally more adherent, smoother, cleaner, and thinner than those of other coating processes.

Sherardizing is zinc-coating steel by a diffusion process. By this process, the chemical composition of the steel surface is modified by diffusing zinc into it. This is accomplished by first cleaning the steelworks thoroughly, by pickling and sandblasting. The works are then placed in a suitable steel drum with zinc dust and heated to a temperature of about 260 to 315^{o}C, depending on their sizes and shapes whilst the drum is being rotated so as to promote tumbling of the contents. This results in coatings on the works that are not pure zinc, but an alloy of about 90% zinc and 10% iron; which is highly resistant to corrosion. The process is especially suited for screws, bolts and nuts, chains, pipe fittings, nails, and such other high strength articles that may conveniently be placed within the drum. The cost varies with character of the coated steelworks. The protective coatings that are produced by the process are the most adherent, thinnest, uniform in thickness, and damage-tolerant with long-term corrosion protection compared to those of galvanizing and spraying processes; but the cost involved is highest. Coating thickness usually varies from 0.012 to 0.04mm, and the coating is continuous and uniform even on threaded or irregular parts [1, 2, 24, 25].

2.2.6 Paint or organic coatings: This is commonest and most versatile method of protecting assets from environmental corrosion. About 90% of all steel assets are corrosion-protected by paint or organic coatings. There are laid down types of existingpaints or organic coatings for different soil, water, atmospheric, and high-temperature environments and procedures for applying them by different, industries, organizations and authorities such as the ISO, ASTM, NACE, BS, Army, Navy, etc. which must always be consulted and properly used [1, 3, 24, 27].

2.2.7 Encasement: This is often used to provide permanent or semi-permanent corrosion protection of structural metal works by encasing or sheathing the entire or part of the work with a suitable non-corrodible material. Concrete encasement, and reinforced bitumen coatings (wrappings) are the common encasements for the protection. Concrete encasement is used for protection of; waterfront structural works in the tide zone and below the waterline, buried pipe structures, lining pipes, structural elements which will be inaccessible in the final work and structures subjected to particular corrosive atmospheres such as those exposed to locomotive blasts or those in chemical plant. Reinforced bituminous coatings (wrappings) provide excellent protection against corrosion, and are widely used for the encasement of buried steel members in highly corrosive soils such as river bottoms, marshlands, cinder fills, fills containing organic debris such as garbage and in tidal regions. Wrappings are particularly used to protect, pipes, the tie rods and fittings that anchor retaining structures, and elsewhere where high-quality long-lasting protection is desired. They have the advantages of impermeability to water, high electrical resistance, good adhesion and resistance to bacteria. They are however, not commonly used for protecting metal works from atmospheric corrosion, because of higher costs involved compared to painting galvanizing and metal spraying and somewhat awkward appearance and infeasibility [2, 24].

III. ENTREPRENEURIAL CHALLENGES AND OPPORTUNITIES

Our surveys showed that management and control of corrosion in Nigerian economy is generally faced with cost, reliability, and safetyproblems and low level of corrosion-consciousness. This necessitates mass education on the subject and approaches that are based on the country's environmental peculiarities instead of general practicalities elsewhere. This creates need for

- Mass basic corrosion awareness.
- Cost-effective constructionand protective materials which do not create maintenance problems leading to safety problems in critical structures such as oil and gas wells and pipelines, high rise buildings, bridges, boilers, etc.
- Corrosion inhibitors which are benign to the country's ecosystems.
- Managing aging or complex or special infrastructures that can incur greater corrosion costs such as industrial systems, dams, bridges,big buildings, stadia, towers, aircrafts, ships and other critical transportation facilities.
- More competent Nigerians and their participation on the subject

The challenges imposed by the above needs are in the areas of establishing or running fully functional specialist centers as well as technical schools and tertiary institutions for corrosion education, advanced coatings including long-lasting paints and functional coatings, environmentally friendly corrosion inhibitors, safety improvement of built infrastructures,cutting the cost of materials for energy systems, advanced corrosion monitoring and inspection, and development and use of cost-effective corrosion-resistant materials.

The entrepreneurial opportunities created by the challenges include:

- Development or marketing of environmentally benign corrosion inhibitors.
- Development or marketing of; better protective coating materials, coating application methods and facilities.
- Development or marketing of highly accurate corrosion inspection and monitoring methods and facilities.
- Development or marketing of cost-effective corrosion-resistant structural materials using fundamental material understanding and combinatorial methods.
- Development of algorithms to better predict costs of maintenance and protection against corrosion of infrastructure which should enable effective up front decisions, for example, material selection.
- Development of new production methods that are benign to corrosion susceptibility ofcritical engineered surfaces.
- Sale or development of highly durable accurate corrosion sensors suitable for remote application.
- Development and evaluation of algorithms that use sensor information to determine the extent of corrosion degradation and predict when maintenance action will be necessary.
- Development of cost-justifiable methods of modifying surfaces of cheap but less-corrosion-resistant materials such as carbon steel to improve their corrosion resistances to required levels.

IV. OVERVIEW OFCORROSION PROBLEMS AND ENTREPRENEURIAL ISSUES AT STAKE IN NIGERIA

Nigeria is a maritime petroleum-producing tropical country with a large territorial area of about923,768 km^2 and population of about 186 million people [28]. She is a developing nation fervently searching for ways to becomean industrialized nation but antagonisticallyexperiencing a number of problems including high costs and management and control challenges of corrosion in her economy. Over 80% of construction materials in the country are corrodible materials such as carbon steel and concrete which are subjective to more rapid corrosion than advanced materials such as stainless, galvanizing, electro galvanizing, and weathering steels and corrosion resistant composite materials. Nigerian governments and their agencies alone have so far failed abysmally in tackling the general problem of corrosion in the country because of inconsistent corrosion policies in the country or non-adherence to them. The problem is accentuated by the general minimallevel of corrosion consciousness and counteraction by the country's populace.A measurable level of entrepreneurship in corrosion management and control is therefore a tangible way out to minimizing the costs of corrosion, improving life cycle assessment and optimizing operational budgets of assets in the country. It is the most feasibleway ofsupplementing the country's efforts to effectively address the generalproblem of corrosionin her domain. It is also seen as a big job avenue of great financial rewards cum personal satisfaction for competent Nigerian graduates from tertiary institutions that hadbeen in search of jobs that are non-existent and employees who had remained unsatisfied with their jobs and or take home pays for the past decades due to poverty, economic downturn, corruption and bad governance in the country.The concern for minimizing costs of corrosion creates challenges and opportunities for entrepreneurial corrosion management and control in the country. Good education and manpower in science and technology, some capital, determination tosucceed in the face of risks with sincere desire to solving corrosion problems by persistent search for them and providing the required solutions are considered requisite for embarking on the entrepreneurship. The capital to start with need not be great since entrepreneurial corrosion management and control can also be lucrative even at small scale level involving cheap affordable hand tools and fully manual processes like painting, sale and application of inhibitors and other protective materials in many cases. The range of professionals that can enterprise at various levels in corrosion management and control is wide. This is because corrosion management and control in all its ramifications is technologicallyencompassing involving professionals in various areas such as environmental analysis, administration,research and developments, engineering design, material selection and testing, chemical and physical and microbiological analyses, production and process control from fully manual to fully automated, economic and social issues,resource management, information gathering and processing, marketing, finance and accounting, cost analysis, algorithms and software developments, mathematical modeling, simulations, engineering law and standards, social and environmental security, environmental science,microelectronics and computers and robotics at the highest level, governance and political decisions, health issues and medication, history of engineering developments, etc. The sectors where entrepreneurs can find corrosion problems are also wide ranging from household and farm structures and machineries, domestic andcommercial building systems and facilities,dams and stadia structural systems, military gadgets and systems,organizational and public building structural systems and facilities,and transportation facilities or systems to major industrial plants such as electrical power generation and distribution or chemical processing plants such as oil and gas industries, etc.

Entrepreneurial services that can be provided are also wide and can include establishing and running of specialist centers, technical schools, tertiary institutions, and units for various levels of corrosion research and education. The bulk of the servicesare however control/support services such as cathodic protection and organic coating or painting, corrosion consultancy and studies, corrosion design basis memorandum, corrosion audit, corrosion assessment and management plan, corrosion risk and threat assessment and management, risk mitigation, cleaning of metal surfaces to required finishes by removing corrosion products and other undesirability, material development and selection, coating selection and development of corrosion-resistant coatings, corrosion product analysis, corrosion inhibitor evaluation and selection and development, corrosion monitoring and inspection, determining corrosion monitoring requirements by onsite and desktop studies such as proper monitoring locations, corrosion prediction and modeling, development and testing of corrosion-protective materials such as organic coatings, selling of corrosion protective materials such as paints or organic coatings and galvanic anodes as well as inhibitors, feasibility studies including site investigations, shop and field installations, repair and maintenance, infrastructure rehabilitation, development and manufacture or sale of surface cleaning equipment, development and manufacture or sale of corrosion testing equipment, automation of corrosion control processes including use of robots, development of algorithms and computer software that analyze laboratory or field corrosion problems, development and manufacture or sale of corrosion monitoring and inspection facilities, developing engineering specifications for tender, development of remote corrosion sensors, system and corrosion data analysis, equipment selection and testing, technical expertise and support, planning, inspection and maintenance program for potentially vulnerable items, etc[29].However, entrepreneurial services based on consideration of Nigeria's general environmental corrosivity peculiarities particularly research and developments are seen to be ofgreater entrepreneurial impact in the country compared to general practicalities elsewhere.

V. CONCLUDING REMARKS

Corrosion was re-examined as serious material degradation process that jeopardizes safety, reduces technological andeconomic development, and needs to be managerially technologically contended with cost-justifiably. The problem and cost of corrosion in Nigeria as a maritime petroleum-producing tropical country with possibility of corrosion preponderance and unpredictabilityin many quarters was highlighted. Entrepreneurial development as the bedrock of economic and technological evolution world over was also re-examined. It was seen to have played a vital role in the growth and development of manynations. Meaningful entrepreneurship in corrosion management and controlin Nigeria was seen to be crucial contribution to the country's efforts to effectively address the general costs of corrosion in her domain to properly utilize her economic potentials and develop to industrial status. This was also regarded as a big job avenue of great financial rewards cum personal satisfaction for competent Nigerian graduates from tertiary institutions that hadbeen in search of jobs that werenon-existent and employees who had remained unsatisfied with their jobs and or take home pays for the past decades due to poverty, production and economic downturn,corruption and bad governance in the country. A number of individuals, small and medium and large enterprises world over have been entrepreneurially contributing to technological and economic development of many nations and reaping their fortunes and rewards through corrosion management and control. Needs, challenges, and opportunities in this area also abound in Nigeria and call for meaningful level of participation in the country. The general principles of corrosion management and control were reviewed and an overview of applicable entrepreneurial issues that can kindle interest and make appreciable impact inNigeria presented for consideration.

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T. N. Guma. "Corrosion Management and Control-Entrepreneurial Opportunities and Challenges in Nigeria." International Journal of Engineering Research and Applications (IJERA) , vol. 7, no. 10, 2017, pp. 14–23.