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Bitumen in Coating Corrosion Protection of Steel-The Position and Prognosis of Nigerian Bitumen

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ABSTRACT: *The paper discusses bitumen as an important cheap technological material that is supplied in a variety of grades that are not all good for specific wide range of its applications. Various grades of bitumen and their sources as well as conditions that govern their selection for corrosion protection services are reviewed. Problem of corrosion of carbon steel as a prime structural material in relation to Nigeria's solely petroleum dependent economy which is bedeviled by effects and costly management of corrosion is revisited. Benefits of using bitumen in coating corrosion protection of steel works and potentials of exploiting the country's vast reserves of natural bitumen, the second largest in the world whose compositional contents and quality vary from location to location; to sustainably and profitably combat her corrosion problem are explored. The exploration exposes Nigerian bitumen as generally undeveloped, uncharacterized and ungraded at various resource locations for proper exploitation due to a number of problems. The paper concludes that for engineering utilization of Nigerian bitumen, impediments to development of her bitumen resources must be sincerely and radically addressed to make her bitumen readily available. Extensive test-evaluation of relevant properties and performances as well as standard grading of the country's bitumen from various resource locations, and documentation of overall applicable coating codes of practice also needs to be properly undertaken beforehand.*

Key words: *Bitumen grades, selection, corrosion coat-protection of steel, Nigerian bitumen, development and exploitation, scarcity of relevant applicable information*

I. INTRODUCTION

Corrosion is an insidious material degradation process that jeopardizes safety and hinders technological progress to maximal attainments [1]. Corrosion is preponderant in the oil and gas industry. The cost of corrosion to the industry worldwide is huge and staggering. A figure of $300 billion was mentioned in the United States alone in 1998. It was estimated that only 15% of the amount was economically justifiable using the existing technologies of corrosion prevention. Several millions of American dollars are spent worldwide annually on researches on the science and methods of preventing steel corrosion, yet the up-to-date efforts and technological sophistication on the subject are far from utopian achievement[2-7]. The practicable technological achievements have been by various levels of cost-incurring control of corrosion. It is thus apparent that corrosion control is primarily an economic problem. Whether or not to apply a control method is usually determined by the cost savings involved. The method or methods utilized must be the optimum economic choice. Companies, business groups and individuals are not into business primarily to make any product-they are in business to make profit [8]. On this basis, paint or organic coatings have been the most important, versatile and widely used method for combating corrosion of steel-the most important, versatile, widely used available and cheap structural material in our engineering technological era. Corrosion of steel accounts to about 90% of all corrosion problems and make it critical to contend with technologically in all spheres. About 90% of all steel are corrosion-remediated by paints or organic coatings. The area of organic materials and coatings is wide and inexhaustible and engineers have been searching for better materials and various ways and levels of combining them to combat corrosion. It is the duty of the engineer to bring the idea and designs into reality by proper selection of the coating material and technology. To keep the challenges imposed on the engineer, it is desirable for them to have thorough knowledge of coating materials and processes for particular applications [9-12]. Organic coating materials vary greatly and include bitumen, epoxy resin, amino resins, polyamides, polyurethanes, cellulose derivatives, casein, polyolefin, acrylic polymers, drying oils, fossil resins and polyvinyl [13]. Bitumen is a generally common, cheap and versatile material in today's technological world. It is widely used for roofing, pipe coating for corrosion protection; construction of roads, bridge decks, parking lots, airport pavements, reservoirs, canals, tunnels, and hydraulics; etc. It is however available in a variety of grades that are not equally good in terms of adhesive properties, effectiveness, availability, service performance and reliability, handling and processing, etc for coating and other specific engineering applications [14, 15 and 16]. Nigeria's economy is about 85% petroleum-dependent. The country is a developing nation that is searching for ways to catapult her to the status of an industrialized nation without necessarily preparing for it. No government in Nigeria has yet come to grips with the reality of the devastating effect of corrosion on the country's economy. The country is endowed with abundant critical and strategic resources that can help her to easily attain industrial status if managed properly but so far, the utilization of these resources as raw materials is dependent wholly on the industrialized economies. The petroleum industry upon which the Nigerian economy is so dependent is prone to effects of corrosion. About 80% of her refinery equipment and transmission pipelines are made of carbon steel particularly of the low carbon type. These pipelines pass through the sea, rivers, underground or surface water in urban and rural areas. Deterioration of these pipelines and other aspects of plants in the economy as a result of corrosion is a huge cost to the country in terms of subsequent wastages from oil leakage and spillage, product contamination, replacement of parts, protection and maintenance, contravention of environmental and safety laws due to pollution, fire and general losses. Yet all the materials of construction in the country are imported, and an enormous amount of foreign exchange is lost to corrosion in the country [12, 17 and 18]. There is therefore strong need for concern posed by professional, technological and economic challenges on how best to mitigate the problem.

Nigeria is however blessed with abundant bitumen from her resources that should be sustainably available at economical rate for exploitation for corrosion coat-protection of transmission pipelines and other aspects of plants in her petroleum industry compared to imported materials in the country. Bitumen was discovered in Nigeria over 110 years ago. The country has proven reserve of about 42.47 billion tonnes of bitumen, the second largest in the world, covering about 120 x 4.3km on the onshore areas of Eastern Dahomey (Benin) basin [19, 20, 21 and 22]. This is spread along the bitumen belt stretching from the country's Lagos and Ogun to Ondo and Edo States. Five distinct hydrocarbon types of occurrence have been identified within the Nigerian tar sands belt as; outcrop, rich sands, lean sands, shale and deep seated heavy crude. The bitumen content of the tar sands varies from location to location. Very rich natural bitumen deposits are found in Ondo State around the region of Idiobilayo, Foriku, Agbabu, Okitipupa, and Aiyibi. Generally tar sands are composed of bitumen, water and some mineral accessories. Tar sands with 5-10% by weight bitumen content are designated as good or medium grades. The average bitumen content of Nigerian tar sand is about 20%. Between 1904 and 1970, close to 40 wells, bore holes and exploration wells had been drilled within some areas of surface occurrence in the country [20, 21, 23 and 24]. The clay content of Nigerian bitumen deposit is very low averaging about 5% and heavy oil extracted from the area has API gravity between 5.00 and 14.6^{O}. Physical properties reported include softening point (44-52^{O}C), ductility (0.1-1.3), penetration (80-100mm), hydrocarbon content (7.2-18.2% by weight), resins (32.12-34% by weight), and sulphur (5.00-10.00ppm). Furthermore, the Nigerian bitumen possesses relatively large quantity of naphthalene aromatics and asphaltenes that are similar to the conventional oil. This makes Nigerian bitumen a very useful alternative source of petroleum hydrocarbon and a potential feedstock for petro-chemical industries [22 and 25]. On the other hand, Kaduna Refining and Petrochemical Company (KRPC), Kaduna, is the most important source of synthetic bitumen in Nigeria. The KRPC bitumen is produced by blending imported suitable crudes such as Lagomar from Venezuela, Light Arabian from Saudi Arabia, Basra from Iran, and from Kuwait with Nigerian crude which per se is predominantly light, nearly sulphur-free and poor in bitumen content as feedstock [26]. The objectives of this paper are:

i. To revisit the problem of corrosion of carbon steel as a prime structural material in relationship to the Nigerian economy.
ii. To review the benefits, main sources, grades, and applications of bitumen as an engineering material in relation to corrosion mitigation.
iii. To extract the position of Nigerian bitumen in combating corrosion in the country, any contending issues and approaches.

II. METHODOLOGY

Information presented in the paper was obtained from various literature sources, field surveys, discussions with professional colleagues and other competent workers in the field and refined with several years of teamwork experience as engineering professionals, academics, researchers and fieldworkers.

III. REVIEW OF BITUMEN AS A COATING MATERIAL

3.1 Desirable qualities of coating materials

It is not every material that can be used for coating treatment on metal or other substrates, either for protective, aesthetic, or test purposes. This is because some materials are generally known to posit unwanted effects that make the treatments economically wasteful and vain exercises. Economy demands that before coating treatment on any substrate is carried out for test or application purposes, the coating material should be satisfactorily indicative of suitable properties and performances, as may be determined from knowledge of its established properties and general service performance, or some appropriate preliminary tests. To ensure the integrity of coating during application, handling and in service, it is essential that the coating material meets a number of key requirements which ideally include the following [12, 27, 28, 229 and 30]:

i. It should be sustainably available at minimal cost.
ii. It should provide good adhesion to the substrate and completely inhibit any corrosion of the substrate to be protected with minimal coating thickness and surface preparation of the substrate.
iii. Its coating must have maximal resistance to disbondment and chemical degradation
iv. It should not pose any undesirable effects to the substrate under protection.
v. Coatings produced with it must be flexible to withstand deformations that can occur in bending, testing or lying, as well as any expansion or contraction due to changes in temperature. The coatings must also not develop cracks during and after application or curing.
vi. Its coating should be easy to repair at minimal cost.
vii. It must be possible to produce desired coating formulations with the material, and use the formulations to apply coatings in the factory or in the field at a reasonable rate and ease and handle the work reasonably quickly after the coating has been applied without damaging the coating.
viii. Its coating must be an electrical insulator and must not contain any conducting material, so as to prevent any corrosion due to electrical contact between it and environmental electrolytes.
ix. Its coating must be chemically and physically stable. In line with this, it must not develop aging effects such as denaturing due to absorption of lower-molecular weight constituents or hardening with resultant cracking from any cause such as temperature changes.
x. Its coating must be impervious, sound and of high integrity.
xi. It should always be in either proper liquid, solid, powdered, or gaseous states to facilitate its coat-application with various available methods; or it should easily be modified or changed to such state with minimal additives to it at minimal costs.
xii. It should have and maintain any desired aesthetic finishing and integrity.
xiii. The coating itself should be non-corrodible or have very high resistance to weathering.
xiv. Its coating should provide infinite protection of the substrate with minimal thickness in any service environment.
xv. Its coating should also have maximal resistance to abrasion, wear and environmental contamination.
xvi. It must be non-toxic or pose any health hazards to personnel handling it.
xvii. It must have chemical and physical compatibilities with a wide range of cheap and easily obtainable additives that can be used to enhance its properties.
xviii. It should be easy to get satisfactory coating from it using cheap available coating methods.
xix. It must be non-flammable or pose any other hazards to personnel.
xx. Its coating must be resistant to attack by environmental bacteria and other organisms.

It can be appreciated that no coating material has been found to possess all these and other ideal requirements. The level of performance of a coating material can be judged relative to the requirements. In practice, the choice of any coating material for a protective treatment on a given part, component, or structure, for a particular application is determined basically by the material's comparative degree of effectiveness and service life, initial and maintenance costs, method of coating and degree of automation involved, availability, aesthetics, feasibility of maintenance, applicability to mass treatment, minimum effective thickness, chemical composition and other properties of the substrate, and corrosivity level of the service environment [31 and 32]. Performance and economic factors have however been found to be of prime importance when choosing a coating material for protective application. The area of organic coatings is very wide and complex, and is one of the most important areas that engineers have been searching for optimal ways of preventing or controlling corrosion of steel in its service environments. The search can only be measurable if appropriate procedures and corrosion tests involving treatments of a considerable number of wide ranges of organic materials singly or in various combinations on the metal, are conducted and results properly established through the respective collation and data analyses [12 and 33].

3.2 General Record of Bitumen in Service Performance

Valuation of bitumen as a coating material can be made from its general record in usage in relation to the ideal requirements of coating material. Bitumen has been in use since ancient times as back as over 3,500 years before Christ. Documented accounts of the material show the following qualities which measure the level of its suitability as protective coating material and make any meaningful relevant research result on it applicable beneficial supplementary information [34, 35 and 36]:

i. Bitumen was used in ancient Egypt for mummification of Pharaohs-a form of corpse preservation that used to be effective for hundreds of years. This shows that it has preservative capabilities against bacteria or microbes, fungi and other organisms.
ii. It has been in use for satisfactory waterproofing and soundproofing. This is indicative that it is a sealant and can protect an underlying material from corrosion if applied atop its surface, by excluding the surface from environmental moisture, oxygen, chemicals, fungi, insects, dirt, leaves, paper, etc.
iii. It is a generally cheap material with average cost of about 25 Nigerian Naira per kilogramme (N25/kg) which is about 0.125 US dollars. It is also supplied in various standard grades around the world.
iv. Bitumen of different grades or physicochemical properties performs differently in service. It is important that the most suitable or convenient grade or quality of bitumen be selected for particular technological services.
v. It has been used either singly or in various combinations with some organic or inorganic products to improve its properties and performance to various levels.
vi. Improvement in service performance and durability is apparent where bitumen forms the main proportion of an applied material such as asphalt used in the construction of roads, airport and park pavements and buildings.
vii. Compared to some paints and other coatings, it has very minimal health problems to personnel during handling.
viii. It is also being widely used today to build vapour-proof and flexible bituminous or asphalt protective coat in accordance with its formulation and polymerization grade, for corrosion protection of structural steel, concrete, etc.
ix. Generally, bitumen is an abundant and cheap material with large proven reserve of over three metric giga tonnes worldwide.
x. Bitumen coatings are heavy bodied materials and have excellent resistance to industrial pollution. Bitumen of properly established properties and performances is used today in various coating forms such as enamels, bituminous wrappings, bituminous tapes, bituminous paints, etc to protect steel and other structural materials in corrosion-preponderant industries such as petroleum or other chemical and water industries.
xi. Different methods of bitumen coat-application ranging from jobbing to fully automated are exploitable.
xii. It is not every grade of bitumen that is good for coating protection and other specific engineering applications. For corrosion protection services; availability, hardness, consistency with respect to changes in temperature, adhesion and knowledge of minimum effective coating thickness are of paramount importance in choosing bitumen. It is contrary to engineering principles to harvest or obtain uncharacterized or ungraded bitumen and use it on the basis of general or average performance of bitumen for specific applications. Moreover, even graded and supplied bitumen can be contaminated during transportation or laying by even small amount of solvent, petrol, fuel oil or diesel and considerably alter their properties and service performances. Engineering principle therefore demands proper test information on any bitumen whose grade or quality is not certain before critical service applications.

3.3 Sources of Bitumen

Bitumen exists naturally in a number of locations worldwide. Bitumen obtained from different regional sources can have wide variation in chemical composition and other properties so can be widely different in grades and service performances. This is due to variations in geological factors and chemistry; hence sand and water contents, mineral accessories of bitumen, etc. It is also synthesized in different grades or qualities from crude of even the same source or properties by various manufacturing processes. This is because the types and levels of mineral accessories, sand and water contents, etc removable from crude by a particular manufacturing process in producing bitumen differ from different process so resulting in bitumen with different chemical and other properties [2].

Synthetic bitumen

A bulk of bitumen in most modern applications is produced by fractional distillation of crude oil; only a small amount comes from natural sources like Trinidad lake asphalt in Canada. Usually the distillation is done in two steps. First, the crude oil is heated up to 300-350^{o}C and introduced into an atmospheric distillation column. Lighter fractions like naphta, kerosene and gas oil are separated from the crude oil at different heights in the column. The heaviest fractions left at the bottom of the column are called long residue. The long residue is heated up to 350-400°C and introduced into a distillation column with reduced pressure called vacuum column. By using reduced pressure, it is then possible to further distillate lighter products from the residue because the equivalent temperature that is temperature under atmospheric conditions is much higher. By carrying out a second distillation under atmospheric conditions with increment in the temperature above 400°C, thermal decomposition of the long residue occurs. The residue at the bottom of the column is called short residue and is the feedstock for manufacture of other bitumen. The viscosity and other properties of the short residue depend on the origin of the crude oil, the temperature of the long residue, the temperature and the pressure in the vacuum column and the residue time. Usually, the conditions are such that short residue is produced with a penetration between 100 and 300mm. Bitumen manufactured from short residue is called straight run bitumen or asphalt [14, 15 and 37]. Of the wide variety of crude oils that are commercially available only a limited number are considered suitable for producing bitumen of the required quality in commercial quantities. In general, these are heavy crude oils with high sulphur content. In modern integrated refineries, it is common practice to blend multiple crude oils to produce consistent quality high grade bitumen that meets precise engineering specifications. Synthetic bitumen is available in variety of grades around the world. Specifications vary to meet the needs of the consuming industries and are based on physical tests that define the safety, solubility, physical properties and durability of bitumen. The physical properties are designed to define performance characteristics that are required under climatic and loading conditions that the bitumen will experience. Although bitumen is produced and supplied in various grades around the world; each grade has particular uses, distinct handling and service performances [15].

Natural bitumen

Natural bitumen exploitation is very energy and capital-intensive and controversial because it causes considerable pollution and environmental damage. It devastates the forest and destroys wildlife habitat and causes deaths of birds, uses very large quantities of water that are not returned to the natural cycle and gas to heat the water into steam to heat the bitumen into extractable condition, causes acid rains that spread into nearby provinces and produces large amount of tailings that are toxic which keep on building up and are stored indefinitely and pollute rivers downstream. Also, producing a unit measurement of bitumen produces three times more greenhouse gases than a unit of conventional petroleum. Technologies of extracting bitumen from the ground vary widely, but basically two methods are used. The strip-mining technique (traditional extraction method) which is more familiar to the general public but can only be used for shallow bitumen deposits and insitu processes. The insitu processes are available with varying technologies and advantages and disadvantages which can be selected to extract bitumen. The more recent technique is the steam-assisted gravity drainage (SAGID). SAGID is enhanced recovery technology for producing heavy crude oil and bitumen. It is better suited to the much larger deep bitumen deposits that surround the shallow ones. It has the ability to extract bitumen deposits up to 200m beneath the surface. In the SAGID process, steam at about 232°C is forced through injection wells which heats up the surrounding, making the bitumen less viscous and eventually cause the bitumen to flow freely via gravity to a production well below. The advantage of the insitu process is that only a small fraction of the land is used compared to surface exploration such as the strip mining technique. Some insitu processes do not use water but off the grid electricity to power its air compressors [38].

3.4 Grades of Bitumen

Since all bitumen grades are not good or used for coating, it is imperative to know the basic characteristics of various grades of bitumen for selecting the most suitable for specific applications. Generally, hardness and consistency determine the suitability of a grade for coating and are greatly correlated to the physicochemical properties of the bitumen. The principal grades of bitumen are [16]:

i. Penetration or paving grade bitumen. This is the most commonly and widely used bitumen for road engineering and industrial applications. It is essentially the parent bitumen or original form of bitumen from which the other forms of bitumen are produced by further processing to meet better service requirements that take into account different climatic conditions. The penetration grade bitumen is divided into Pen 40-50, 60-70, 80-100, 120-150 and 200-300 grades based on bitumen penetration test procedure in accordance with ASTM D5. Each of grade bitumen has other distinct properties such as viscosity, flash point, specific gravity, elasticity and/or plasticity, adhesion and cohesion, softening point, weather or oxidation resistance, breaking point, etc; so, their performances are different under the same service application. The differences in properties between high and low penetration grade bitumen are mainly caused by different amounts of molecule structures with strong interaction. Low penetration grade bitumen contains more of these molecule structures. This is the main reason why their properties are much higher than for the high penetration grade bitumen (Pen). Pen 40-50 is the hardest grade and is most suitable for application in hotter climates while the Pen 200-300 in cold climates. The hardness of bitumen decreases with increase in its penetration, so the Pen 200-300 is the softest. For service performance by any parent bitumen of unknown grade, its properties need to be established for optimally using it according to engineering principles. Specifications of properties of penetration grade bitumen are documented in a number of standards such as the international standard IS-73:2006.

ii. Cut back bitumen. This consists of short residue (original form of bitumen) that has been diluted in solvent oil such as white spirit, diesel, kerosene, gasoline and gasoil to make it more fluid to reduce its viscosity for applications at ambient temperatures. Cutbacks are classified according to the time it takes for them to cure, or become solid due to evaporation of the diluents. Classifications are rapid curing (RC), medium curing (MC) and slow curing (SC).

iii. Bitumen emulsions. These are dispersions of about 30-80% by bitumen volume in water. Hot bitumen, water and emulsifier are processed in a high speed colloid mill that disperses the bitumen in water in the form of small droplets. The droplets are normally 5-10µm in size range but may be even smaller.

iv. Modified bitumen. These are formulated with additives to the original form of bitumen to improve their service performances by changing such properties as their durability, resistance to ageing, adhesive or cohesive strength, elasticity and/or plasticity.

v. Industrial or oxidized bitumen. This is made by blowing air through hot paving grade bitumen. The process results in bitumen that is technically more advantageous for applications in terms of durability, flexibility, chemical stability, water resistance, hardness, consistency and higher softening temperature than penetration grade bitumen. Industrial bitumen also has more rubber-like properties and their viscosities are much less affected by changes in temperature than is the case with penetration or paving grade bitumen.

vi. Multi-grade bitumen. This is chemically modified bitumen that has the properties of hard paving grade bitumen at high service temperatures coupled with the properties of soft paving grade bitumen at low temperatures. In other words, it has properties that span at least two grades. Multi-grade bitumen provide improved resistance to deformation and reduce the detrimental effects of high service temperatures, whilst providing reduced stiffness at low service temperatures than exhibited by a similar normal paving grade bitumen.

3.5 Bitumen in Coating Protection of Steel

Bitumen coatings have been in use for protecting steel and other structural materials from corrosion, and coatings based on suitable bitumen show excellent resistance to industrial pollution. Whilst bitumen itself does not possess any inherent corrosion inhibiting properties, it is effective because of its impermeability preventing water, oxygen, and other agents of corrosion reaching the metal surface. Bitumen is not totally impermeable to the agents for every thickness, but any desired degree of impermeability can be achieved by applying a sufficiently thick layer of hard grade bitumen. Proper engineering principles demands that such a layer must be applied with the understanding of the minimum thickness that is sufficient to completely inhibit corrosion of the substrate. When using available bitumen of known grade, such thickness may be obtained or worked out from documented standards such as the BS 4147(4). Proper engineering principle however demands series of relevant tests and standardization to establish the grade, minimum effective thickness, properties and service performance in using bitumen whose grade is not known for specific applications such as corrosion protection. Such information is also necessary to serve as control where the bitumen does not meet the required specifications but requires modification before using it [14, 15 and 16]. Because of its high viscosity, bitumen cannot be efficiently and economically coat applied at room temperature; so it is usually heated to 150 to 250^{o}C to lower its viscosity for industrial applications to metalwork by spraying, rolling and mopping methods [32, 34 and 39]. By adjusting the proportions of the various constituents of bitumen, it is often prepared with sufficient plasticity to prevent cracking under cold weather and a sufficiently low melting point; that it may also be applied to metalwork by hot-dipping at about 150-200^{O}C. As bitumen is not mechanically tough enough itself to withstand much wear or stress, it is usually applied by ‘hot wrapping’ in which a fiberglass swathe is passed through the cauldron of molten bitumen and then wound round the steel or other material to be protected. Inorganic or polymer weaves are not used for wrapping, ordinary sacking or hessian is subject to decay and in so doing creates conditions suitable for both direct acidic attack and bacteria corrosion. This mode of protection is particularly suited to exterior pipelines both above and below ground level, and by it much thicker coatings can be achieved than is possible with unsupported bitumen. A second technique that is used for producing thick coatings is by the addition of about 30% of inorganic filler such as powdered limestone or asbestos to the bitumen, the resulting composition is known as mastic coatings [33 and 34].

Bitumen used in the coating industry is coal tar and asphalt. Although these materials are distinctly different physically and chemically, in appearance they are identical black tar materials. Coal tar enamels or pitches are derived from coking of coal. Asphaltic coatings generally have much greater ultraviolet resistance than coal tar, so, they are suitable for above-grade, atmospheric weathering applications. However, coal tar coatings are vastly superior to asphaltic coatings in moisture and chemical resistance, so they are used most commonly below grade or in water immersion services [34]. Thermoplastic bituminous coatings are applied as hot melts, solvent cutbacks, or water emulsions as follows [39]:

i. The hot melt method involves heating the bitumen to a temperature of approximately 177-246^{O}C to reduce viscosity for application. The hot melt can then be applied by mop or swap by brush, roller or spray, or by flow coating of the interiors of pipes and small vessel. In general hot melt applications provide the best moisture and chemical resistance, followed in order by solvent cutback and water emulsions.
ii. Solvent cutback method involves dissolving asphaltic or coal tar bitumen in a suitable aliphatic or aromatic hydrocarbon solvent to lower viscosity for application by spray, brush or roller. The solvent then volatizes and the bitumen re-solidify into a film. The coating thickness and moisture resistance of a solvent cutback generally are less than that achieved by hot melt application, but the convenience of not having to heat the bitumen at the job site immediately before application is a major advantage.
iii. Water emulsions are prepared by suspending minute particles of the bitumen in water using emulsifying agents together with inert fillers, such as coal dust, powdered silica, mica, and limestone dust. After application, the water evaporates and coalescence occurs to form a protective film. Emulsions of both asphalt and coal tar can be applied by brush, roller or spray.

Bitumen water emulsions are volatile organic compounds (VOC)-complaint. However some solvent cutback applications may not be VOC-complaint due to the use of solvents. While hot-melt bitumen generally is VOC-complaint, it may release volatile organic compounds into the atmosphere during heating and application. This depends on the type of bitumen and the heating temperature. Furthermore, volatile phenol-containing compounds produced during the heating of bitumen are considered carcinogenic and skin irritants. Therefore, suitable protective clothing and appropriate respirators must be used. Because of their chemical make-up, coal tar and asphalt coatings generally are incompatible and are not be used as mixtures or applied one over the other [39].

Problems in using bitumen for coating protection

Bitumen is a thermo-visco-elastic material where temperature and load application have a great influence on its behaviour. It is classified as rheological material since its viscosity; stress and strain response is both time and temperature dependent. The binder consistency and hence ability to sustain and hold its fundamental cementing mechanism changes depending on its viscosity. In most cases, bitumen is not used in its original form but modified or supported because of certain undesirable characteristics of the material [32 and 33]. These characteristics include [33 and 40]:

i. It's ability to exist in solid, semisolid, or very high and low viscous liquid state; and change its hardness or consistency with temperature. At 20^{O}C, the viscosities of some types of bitumen range from 10^{3} to 10^{8} Poise depending on the type; compared to water 10^{-2} Poise, diesel 10^{-1} Poise and engine oil 10 Poise.
ii. It's not being mechanically tough enough to withstand much wear or stress.
iii. It's ability to crack under cold weather.
iv. It's poor resistance to organic solvents.
v. The engineering properties of bitumen are dependent on temperatures, duration or time of loading, and the stress applied. In contrast to many traditional structural materials, such as steel, whose properties are for practical purposes constant, the behaviour of the material under stress varies from elastic to viscous according to the condition of stressing. Under stresses of short duration and at low temperatures, bitumen behaves purely elastically, whereas, under conditions when the stress is applied for long periods and/or at high temperatures, the behaviour is purely viscous. Between these two extremes, and this is the range of practical interest for most applications, the behaviour is intermediate or visco-elastic..
vi. The principal limitation of bitumen as a coating material is its vulnerability to heat; many will soften and creep on inclined surfaces if exposed to strong sunshine so are unsuitable for applying to pipes carrying hot liquids. They should also be used with caution in conjunction with oil paints, as for example, when bituminous coating might be applied on top of a red lead primer. The reason for this is that chemicals in the bitumen can have the effect of preventing hardening in oil-bound paints and the result may be a failure in adhesion of the combined coating. It should also be noted that bitumen is unlovely in appearance, which often restricts its use to buried metalwork and industrial protection systems in which aesthetic values are not a high priority.

One reason that is attributed to all these above characteristics is that bitumen is not a well-characterized chemical, despites its wide use. The material is a complex mixture of organic and inorganic compounds and their complexes [33 and 36].

Modification of bitumen to enhance its shortcomings in coat-protective applications

To mitigate temperature dependence and other shortcomings of bitumen, it is often formulated with additives to improve its service performance by changing such properties as its durability, resistance to ageing, elasticity and plasticity. The most important modifiers are polymers such as thermoplastics, thermo sets, and rubber. Because of cost consideration, polypropylene and styrene-butadiene-styrene (SBS) modifications find applications in paving and coating. Amorphous polypropylene (APP), a waste by-product in the manufacture of isotactic polypropylene (IPP), was initially used in Europe to modify asphalt for roofing membranes and other applications. The technology is now applied in many countries such as United States of America. Copolymer polypropylene containing 2-10% ethylene has been found to increase clarity, toughness, flexibility, and lower melting points of bitumen. Thermoplastic block copolymers with styrene end-blocks and rubber mid-blocks, for example, butadiene (SBS), isoprene (SIS), and their hydrogenated versions (SEB, SEPS) are common modifiers of asphalt [36]. Polymer modification of bitumen is achieved by poly-blending with rubber polymers, for example, SBS, SEBS, SIS, and ethylene/vinyl acetate/carbon monoxide (E/VA/Co) at 2-5% by weight polymer level in paving applications. For coatings, both rubber and polypropylene modifications are used but at a much higher polymer loading. Typically 11-15% by weight SBS rubber polymer (linear, radial, or combination) or 20-25% by weight polypropylene (APP/IPP or copolymer PP/FPP) based on bitumen is used for coating. Bitumen is also often coordinated with resins such as phenolics, alkyds, urea formaldehyde or polystyrene to increase the strength of bituminous finishes. Such finishes are used for treating the external surfaces of pipelines employed to carry water, gas or oil [36 and 41].

3.6 Health Question of Bitumen

Bitumen is usually handled and coat-applied at high temperatures, which can be above their flash points so this presents potential hazard from skin burns and inhalation of substances such as sulphur compounds from hot storage tanks. Skin burns can however be alleviated by plunging into cold water and once cooled; no further harm will be done as the bitumen provides a sterile covering until it becomes detached [35]. Bitumen contain compounds which are potentially carcinogenic but the concentrations of these compounds in the bitumen have been found to be negligibly very minute and thus do not necessarily constitute a health risk in practice, although appropriate precaution should always be taken [35 and 42].

The unmistakable odour of bitumen, which can be carried over great distances, may result in a variety of complaints ranging from slight discomfort to mild nausea or feeling ill. The pungency of the odour varies with a number of factors, including the source of bitumen (composition), temperature of the bitumen, ambient temperature, prevailing winds, and the type and condition of the melting equipment. The fumes emitted by bitumen tend to be concentrated at the locations where it is being heated, discharged into carriers, and applied. Unfortunately, current technology for heating bitumen, relying on external heating sources and exhausting fumes into the air, makes its aroma an unavoidable eternality that must be taken into consideration each time they are heated and applied. Complaints from individuals regarding the noxiousness of the fumes, particularly on such sensitive projects as schools and health care facilities, have, in some instances, led to costly interruptions, severe restriction to work schedules, and in extreme cases the complete cessation of the activities [42].

Odour emissions are one of the key concerns for manufacturers of asphalt and bitumen coating industries. The industry has implemented several measures for reducing odour output. Examples are the placement of higher stack, the implementation of fine dust filters, scrubbers, and the covering of storage areas. In some cases these measures are not sufficient and neighbours continue complaining about the odour emissions even after the initial odour removal measures. Due to reported complaints and high costs imposed by them on contractors involved in the use of bitumen, a research project was designed to investigate potential ways of mitigating adverse effects with respects to the odour produced while heating the material. The project consisted of laboratory testing and field trials of commercial fragrant compounds to determine their effectiveness in masking the odours associated with heated bitumen. The results of this research indicated that these compounds can be successfully employed to screen the aroma of hot bitumen and reduce the discomfort of individuals who find it offensive. The compounds include natural and synthetic oil or extract fragrances such as lemon oil, orange oil, peppermint, spearmint, cinnamon and bubble gum. Others are fragrances that consist of natural and synthetic materials having glycol ether, alcohols, esters, adehydes, ketones, etc [42].

IV. POSITION OF NIGERIAN BITUMEN

Nigeria's natural bitumen from various locations is yet to be developed, properly graded, supplied and exploited for economic and technological development. Yet, there is scarcity of comprehensive information on codes of practice with the Nigerian bitumen by standards organizations. Agbabu, a village of about 400 inhabitants with location coordinates of E004^{O}48-49^{1} and N06^{O}34-36^{1} is where bitumen was first spotted in Nigeria in 1910 and the first bitumen well NBC-7 was drilled. NBC-7 has remained open to the surface and periodically flow heavy oil. The bitumen deposit within the region of the village is ranked as one of the first five major bitumen deposits in the world but is still equally undeveloped and unexploited [20, 21, 23 and 24]. Problems that impede natural bitumen development in Nigeria include policy inconsistency and lack of adequate legislation, high risk and health hazards in exploitation, weak regulation, lack of well equipped laboratories, unwholesome practices of stakeholders and inadequate number of trained personnel, lack of access to capital, lack of appropriate technology and machinery, and environmental degradation and pollution. Bitumen produced from crudes at KRPC is grossly inadequate for the needs of consumers even in Nigeria alone. At a news conference on Tuesday, July 22, 2014, in Kaduna, the Association of Bitumen Marketers and Distribution of Nigeria (ABIMD) reported that Nigeria loses about, 300 billion Naira on bitumen importation annually. The amount, the union said, could be used for other meaningful projects if the government had stopped importation of the product and encouraged its local production at KRPC. Fred Nyabam, the national vice chairman of the association described the massive importation of bitumen in the country as a serious threat to the economic development of the nation. He raised alarm over activities of some few individuals who he described as 'selfish individuals' and 'economic saboteurs', who he said had truncated all efforts made in the past to stop importation of bitumen in Nigeria and encourage local production. The brazen act of sabotage against the nation is that over 60% of all the bitumen imported into Nigeria was from a refinery in Iran whose bitumen production capacity is not bigger than that of KRPC; he stated [14, 43 and 44]. As earlier stated in this paper, it is contrary to engineering principles to harvest bitumen of unknown grade and characteristic performances from any source and coat a metal to any thickness or use it on the basis of general or average performances of bitumen for corrosion protection or other critical engineering applications. Proper engineering principles demands all necessary test evaluations of such bitumen to establish their grades, suitability levels, capability and handling properties before considering them for applications or further processing to meet the required service properties or standards [14 and 45]. Guma *et al* [2-7] contributed research efforts towards engineering coat-utilization of Nigeria's abundant bitumen resources for corrosion protection of steel works but a lot more still has to be done.

V. APPROACHES TOWARDS UTILIZATION OF NIGERIAN BITUMEN FOR CORROSION PROTECTION

For engineering utilization of Nigerian bitumen to optimally reduce the cost and effects of corrosion in her economy, the following approaches need to be followed among other things**.**

i. Problems that impede bitumen development in Nigeria such as lack of affordable optimal technology, adverse effects on the environment, and lack of the wherewithal should seriously be re-examined and addressed by all stakeholders especially the Nigerian engineering community and Government.

ii. Proper laboratory tests with coatings of various thicknesses of bitumen from the different resource locations in Nigeria on corrosion inhibition of important structural materials such as steel and concretes should be extensively conducted and cross-checked by field and service tests to optimize applicable data.

iii. An active research unit as part of Nigerian Bitumen Development Project or a different research centre equipped with laboratories and enough good facilities should be established and based in the Nigerian bitumen belt. The unit or centre should have on its employment, relevant professors, lecturers, higher degree holders, competent technical staff and management staff charged with the responsibility of conducting extensive and detailed applicable researches on specific engineering applications of Nigerian bitumen from several sources. All such researches should be properly collated, documented and made available to the public. All employers of the unit or centre should be on the salary scale of oil companies in Nigeria and paid higher than their counterparts on the same levels in Nigerian universities as incentive.

iv. Basic technical information on design coating-treatments; and by extension formulation of corrosion-resistant coatings such as paints, bituminous wrappings, admixtures in concrete encasements etc, of Nigerian bitumen for corrosion protection of structural steel works such as pipelines, surface and underground tanks in water, petroleum and other chemical industries should be properly conducted.

v. Researches on optimal modifications of bitumen from various Nigerian sources to mitigate poor characteristics that are associated with all bitumen such as temperature-dependence of properties should be conducted using affordable materials in Nigeria.

vi. The Standards Organization of Nigeria should collate and understudy all corrosion coat-inhibition research information on Nigerian bitumen in conjunction with existing standards worldwide on coating usage of bitumen and issue coating codes of practice with the country's bitumen.

V. CONCLUDING REMARK

Corrosion of carbon steel as prime structural material in relation to Nigerian economy, and coating use of bitumen in protective applications are reviewed. The review exposes corrosion as an outstanding material degrading mechanism that pose direct threat, cost and management challenges in the country's petroleum-dependent economy. Moreover, it exposes bitumen as an important widely used technological material that is available in a variety of grades that are not all good for specific engineering applications. For corrosion protection services; availability, hardness, consistency with respect to changes in temperature, adhesion and knowledge of minimum effective coating thickness are of paramount importance in choice and use of bitumen. Nigeria is blessed with vast sustainable reserves of natural bitumen; the second largest in the world whose compositional contents and quality vary from location to location. The potentials of exploiting the resources for the country's economic and technological developments are wide and great. In particular, the country's bitumen can be a source of sustainable coating material that can be more beneficially used to tackle her corrosion problems compared to imported materials if well planned, established, and laid down. Findings from the paper have however shown that, so far, Nigerian bitumen is generally undeveloped, uncharacterized and ungraded at various resource locations for proper exploitation due to a number of problems. For engineering coat-utilization of Nigerian bitumen for corrosion protection: impediments to development of her bitumen resources must be sincerely and radically addressed to make her bitumen readily available, extensive test-evaluation of relevant properties and performances as well as standard grading of the country's bitumen from various resource locations should be properly undertaken beforehand, and provision of documented overall applicable codes of practice with her bitumen is needful.

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