Journal of Research in Engineering and Computer Sciences
April 2023, Vol. 1, No. 1, pp. 43-54

Oil and Gas Pipeline Corrosion Monitoring and Prevention Techniques in The Niger Delta Region, Nigeria: A Review

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Abstract:
Corrosion monitoring and prevention has remained a subject of engineering concerns and investigation for over hundreds of years. Causing an annual lost estimate of 10% of global materials, consuming over 42 billion dollars within the developed nations and depleting the economics of developing countries. This has made corrosion management and prevention a major concern within the oil and gas industry as well as in the pipeline management and its operational setting. The deployment of corrosion monitoring techniques changes across pipelines wall by reason of operational conditions and the environment. In this review, corrosion mechanisms and several types of corrosion monitoring and preventions techniques were considered with a recommended approaches adopted by major oil and gas firms in the Niger Delta region of Nigeria in corrosion monitoring and its prevention.

Keyword: Corrosion, corrosion mechanism, corrosion monitoring, corrosion prevention.

INTRODUCTION

Corrosion in the oil and gas sector has created an enormous economic and environmental impact within the industry and will continue to rain havoc on installations such as pipelines, storage tanks and platform's jackets. Corrosion of metals within the oil and gas and chemical refineries is a major source of the industry problems as well as a dangerous mode of the system failure. The world total length of pipelines conveying oil and gas from storage stations, refineries, and reservoirs across the globe down to their final consumers point is put above three million kilometres [1].

Cost of Corrosion

The world economic impact indicator of corrosion effect in the oil and gas industry according to [2] has it that, 10% of worlds metal output is lost to the destructive activities of corrosion yearly. As put forth by [3], the rate of corrosion in the industrialized countries is estimated to be about 3-4% of their GDP and this has multiple effects when compared to the developing nations. Deductively, survey studies have it that the United State in 2003 spent as high as $41.9 billion in combating corrosion [4], with this figure, one can thought of what is becoming that of a growing economic.

To get rid of corrosion within the system, is principally by getting the understanding of the operational system and the oilfields environment with an upended factor contributing to corrosion problem. To make a meaningful impact in corrosion prevention, checking and control as well as its mitigation, good knowledge mechanism of corrosion occurrence in the oil and gas sector is crucial to benefit the exploration activities in the system [5]. Aside the loss of lives occasioned by pipeline leakages and flaring, corrosion has created a huge overhead cost to pipeline industries operational activities due to recurrent equipment replacement. These impacts range from economic costs occasion by downtime to replacement and repairs of corroded parts [6]. There has been rising cases of fire related incidents owed to oil and gas pipelines leakages coupling with fire flare-up in the pass decades [7]. Apart from the economic loss, the impacts of corrosion can equally be seen on loss of lives and properties and environmental effects such as pollution of water bodies and useful farmland [8]. The structural design and construction of pipelines have been viewed by some experts as one medium of guiding the challenges of corrosion against the operational lives of these critical assets [9]. Meeting the materials design specification is one thing to uphold but creating a good and proper oil and gas monitoring and maintenance culture will drop hazards and give a degree of dependability (reliability) in the system operation [10]. From the study of Operational Pigging [11], accidental discharge of hydrocarbon into the operational environment, causes corrosion problems thereby unnerving the efforts of the industry operators in combating the tasks. The influences of corrosion in the oil and gas sector have caused considerable damage and unproductive time of 20-30% in lost from exploration to production [12].

CORROSION PROCESS MECHANISMS

Corrosion of metals is an environmental factor; it can be defined as the unprompted destruction and a degenerative condition of operating pipelines of either chemical, electrochemical, or biochemical contacts within the internal or external environment. Corrosion is a destructive attack on metallic material through chemical or electrochemical reactions within a period of environmental interaction [13]. Some forms of corrosion are shown in Fig. 1.

Fig.1: Different forms of Corrosion [14]

Corrosion has resulted in degenerative condition of oil and gas pipelines whose effects can be ascribed to pipe material interaction with the external location as well as the internal working liquid. The premise or foundation of pipeline corrosion existence points to two main mechanisms of electrochemical or electrolytic corrosion and galvanic corrosion. In electrochemical or electrolytic corrosion, [15] the effects of corrosion formation are built up between anodic and cathodic zones. This involves the flow of electrons between the anodic and the cathodic environments. At anodic area, oxidation action releases electrons, destroying anodic metals by either dissolving or assuming combining state as oxide. This causes corrosion to occur in anodic zones. At cathodic zones, there is a reduction process or gain of electrons via an electrolyte, these events take place instantaneously and give a neutral balance Figs. 2 and 3.

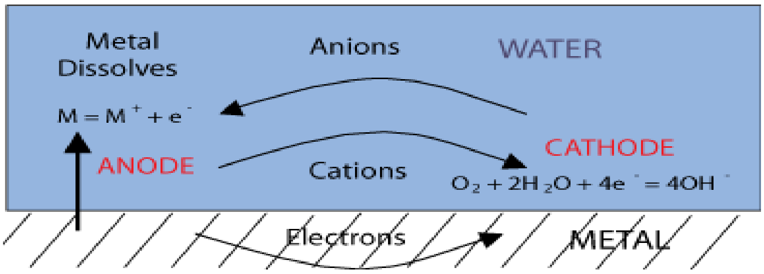

Fig. 2: The electromechanical process of corrosion [16]

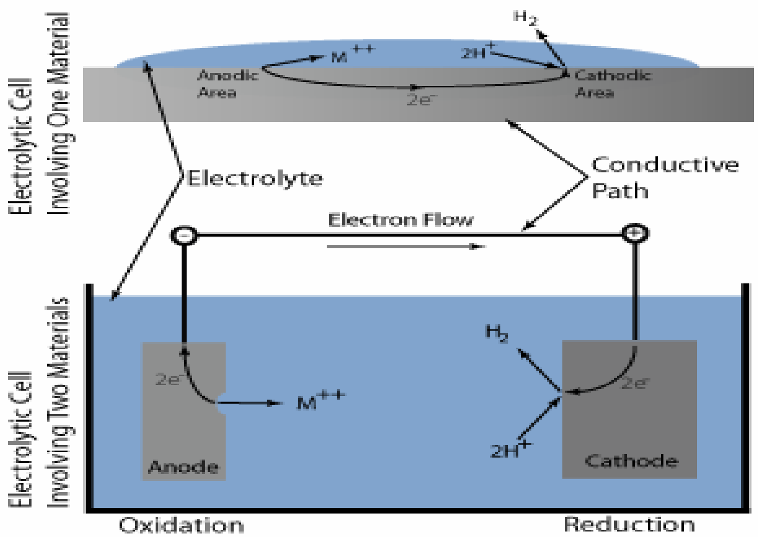

Fig. 3: Electron flow paths involving two materials [16]

The galvanic corrosion can be said to be self-created when two different types of metals come in contact, the married zones create electrolyte by an aqueous fluid, ensuring an ionic conduction between the two materials. Based on this mechanism, this type of corrosion can be prevented through the application of metal combination technique in the pipe construction, especially with class of material closer in the galvanic series in-order to reduce such reaction. Lining layer is also ideal to be place between the regions, as well as the help of cathodic surface, equation (1) in corrosion of Zinc.

$$Zn = Zn^{2+} + 2e^{-} \quad (1)$$

Due to the diversity in water flow within the upstream oil and gas sector, pipelines are open to different formations of water that contain hydrocarbons as well as the condensate water that build up due to temperature drop [17]. This significantly aids the electrochemical reaction within the acidic environment when hydrogen sulphide and carbon dioxide are dissolves in them. Carbon dioxide and hydrogen sulphide corrosion mechanism reaction as summarised in equation (2) to (4) and carbon dioxide (CO_2) are noted as the root causes of local and general forms of corrosion [18].

$$\begin{aligned} &CO_2 + H_2O \rightarrow H_2CO_3 \\ &2H_2CO_3 \rightarrow 2H^+ + 2H_2CO_3^{2-} \\ &HCO_3^- \rightarrow H^+ + CO_3^{2-} \end{aligned} \quad (2)$$

For pipeline polarization because of H_2CO_3:

$$Fe + H_2CO_3 \rightarrow FeCO_3 + H_2 \uparrow \quad (3)$$

Hydrogen embrittlement because of hydrogen sulphide ionization in water:

$$\begin{aligned} &Fe + H_2S \rightarrow FeS + 2H^+ + 2_{e-} \\ &H^+ + H^+ \rightarrow H_2 \end{aligned} \quad (4)$$

The above gases develop high pressure and cause cracking or blistering of the pipes while H_2SO_4 in hydrogen sulphide H_2S reaction results in the production of electrochemical as well as chemical corrosion.

Types of Pipeline Corrosion

Pitting Corrosion:

Pitting corrosion, otherwise known as pitting, is a form of dangerous localized corrosion which results in a random creation of trivial cavities or holes on the material. Pitting corrosion is more dangerous when compared to uniform corrosion in damage as it is harder to perceive, forecast and guide against. According to [19-20], pitting is a severe state of deterioration on a pipe's surface that is located on a partial zone with a fast cavity or holes formation. The mechanisms behind the form of corrosion can be said to be destructive chemical type causing infiltration, mechanical damage to the protective inert film and flaws on the material surface.

Crevice Corrosion:

Crevice or crack corrosion is another damaging form of localized corrosion. Crevice corrosion transpires in the zone underneath deposits where free access to the neighbouring environment is constrained. It takes place on the connection of metals with metals or metals with non-metals similar couplings, joints, and gaskets. This reaction starts due to absorption variance of corroded metal of one exterior part on another. [21]. [22] explains that the electro-potential alterations result in the biased pitting or crack damaging occurrence. Oxygen softened in oil production mud backers' gap and crack attack of material in the protected areas of drill string and is the joint cause of the disasters and damage under duct protections.

Galvanic Corrosion:

Galvanic corrosion, also known as dissimilar metal corrosion, denotes corrosion mutilation induced when two varied materials are joined together in a corrosive electrolyte. For galvanic corrosion to occur, there must be two diverse types of metals in contact, the presence of an electrolyte and electrical continuity between the materials. This type of corrosion can be formed in the area amid the below deposit area and the area deprived of deposit. From the work of [23], this corrosion can be prevented through the application of industry metal joint technique, particularly with type nearer in the galvanic sequence to decrease its reaction.

Uniform Corrosion:

Uniform corrosion is considered the most common type of material corrosion. It is a corrosion outbreak upon the entire material surface that is bare to the corrosive atmosphere ensuing in an even loss of such metal; this forces the material to become thinner and eventually collapse. Uniform corrosion is the most noticed form of corrosion with its primary root cause on steels and other metals being oxygen and the easier preventive procedures of this corrosion are cathodic protection and surface coating [12].

Stress Corrosion Cracking:

Stress Corrosion Cracking (SCC) occurs because of the concurrent action of stress, alone the static and tensile of the materials, and the environmental reaction. It is the mutual and synergistic effects, as well as interaction of mechanical stress with oxidation reaction [24]. Stress corrosion cracking can be disallowed or lessened by eradicating the stress residual through stress relieving heat treatment, choice of suitable material or avoiding machining stress alone the surface.

Selective Leaching:

Selective Leaching, otherwise known as 'De-alloying,' occurs in the material zone where the metal surface existence differed metallurgically from another. A good example is brass, as an alloy of zinc and copper in a solid solution, can disintegrates with the zinc existence selectively detached from the alloy, parting the copper [25]. It brands the alloy porous and concessions its mechanical properties. For brass, this may be noticed when the yellowish natural colour turns reddish in its appearance. So, it is obliging to add a little quantity of tin to the alloy to stop the de-alloying.

CORROSION MONITORING

Corrosion monitoring in the oil and gas industry involves the process of evaluating and supervising oil and gas components, structures, and processing elements for signs of corrosion. Corrosion monitoring aims at finding and measuring the corrosivity of process stream conditions of extending the service life and serviceability of oil and gas assets, increasing operational safety, and reducing maintenance cost. Monitoring involves the deployment of low-cost techniques in obtaining a large volume of reasonable quality measurements. The central aim of monitoring of corrosion is to buy a near real-time signal of the estimated rate of corrosion outbreak on the pipeline as well as finding transient operating conditions that may lead ultimately to collective grave impairment. The choice of corrosion monitoring procedures has no central regulation but is based on the expert logical conclusion and its efficacy [26]. Among other benefits, corrosion monitoring helps in supplying managerial information relating to the facility maintenance requirement and operational condition of the plants. Several corrosion monitoring techniques exist, and virtually all need expert knowledge in their applications.

Corrosion Coupons (weight loss measurement)

The corrosion coupon, widely known as 'weight loss measurement' remains one simplest technique in the field of corrosion monitoring. The weight loss measurement includes revealing a sample of material known as coupon to a process environment (corrosive medium) within a given time, and later recovered for further analysis and investigation. The central idea for the analysis and measurement are to decide the material weight loss and this is expressed as the corrosion rate. The ease of measurement associated with this method is what makes the coupon practice function as a model way of measurement in many corrosions monitoring plans [27]. The corrosion coupon is extremely multi-purpose and useful because the weight loss coupon can be invented or fabricated from any available alloy material. The technique is all environment enabling, aid visual inspection, assessing inhibitor performance and effective in localized corrosion identification and measurement. Typically, in conducting this technique, the coupon is exposed to a corrosive medium for a period of ninety (90) days before being taken for further analysis in the laboratory.

Electrical Resistance (ER):

The electrical resistance probe like the coupon monitoring technique offers an elementary measurement of metal loss, the value of the metal loss can be taken at any period or interval as often as obligatory while the probe stays enduringly exposed to the corrosive medium. This monitoring technique enables one to take the change in ohmic resistance of an erosion metal part that is bare in the corrosive medium. The corrosive action upon the surface of the part crops a decrease in the cross-sectional area through a consistent increase in its electrical resistance. This upsurge in resistance can be linked to metal loss and it is a function of time which is the corrosion rate. ER probe can remain installed in-line through the operational life of an asset while supplying a direct corrosion rate [28].

Linear Polarization Resistance (LPR):

Linear Polarization Resistance technique is founded on a complex electro-chemical model. The advantage of this method is that corrosion rate measurement is complete at once. LPR technique is an immensely powerful tool of corrosion measurement when compared to ER or coupon, where the fundamental reading is metal loss and requires a certain period of exposure of material within the medium to determine the corrosion rate [29]. As a setback, LPR cannot be performed in gases, or in oil suspensions as the method requires relatively clean aqueous electrolytic medium for a successful operation.

Galvanic (ZRA):

Galvanic monitoring or Zero Resistance Ammeter (ZRA) is another electrochemical corrosion monitoring method whose probes with two electrodes of different materials are bare to the process fluid. While in the exposed medium, potential difference is created naturally between the electrodes, the current produced because of the potential difference relates to the corrosion rate that is occurring on the electrode couple that is more active [30]. ZRA found its application mostly in the monitoring of weld decay, bimetallic corrosion, crevice, and pitting attack, as well as corrosion caused by highly oxidizing natures.

Microbial:

Microbial or biological corrosion monitoring and investigation usually look to address the presence of Sulphate Reducing Bacterial – SRB. Biological monitoring involves anaerobic bacteria that devours slulphate from the procedure stream and produce sulphuric acid. Sulphate lessens bacteria that would cause plain corrosion attack in oil and gas pipeline due to their aptitude to create enzymes capable of reducing sulphate compound to hydrogen sulphate [31]. There are certain bacteria organism that promote microbial corrosion in the oil and gas pipelines, which include carbon dioxide reducing bacteria, sulphate reducing bacteria as well as manganese-oxidizing reducing bacteria, the most overriding of all is the sulphate reducing bacteria because of its aptitude of living in the anaerobic medium.

CORROSION PREVENTION

Corrosion prevention practices or control in oil and gas pipelines are vindictive tactics aim at cutting corrosion occurrence, it is conducted to thwart pipeline failure and related significances like environmental pollution as well as minimizing product loss and potential industrial mishap. According to the National Association of Corrosion Engineering, NACE recommendations, [32] and [33] agreed that in managing corrosion outbreak on oil and gas pipelines, the following prevention guards must be put in place. These methods are:

The Choice Material

Material choice or selection is very crucial and pivotal in design consideration for corrosion prevention. This is so because pipeline corrosion has a direct effect on the pipeline material, as many of the material in use have the enhanced ability to either improve the asset lifespan or increase the vulnerability of the pipes to corrosion. PVC, stainless steel, and high-quality alloy steel materials can enhance the asset lifespan while other pipelines like steel concrete, steel pipes and cast iron are more prone to corrosion. Nevertheless, carbon steel that has corrosion resistance alloy coating or use of complete corrosion resistance alloy material is real and endorsed where high rate of corrosiveness is foreseen [34].

Pipes Coatings and Linings

Pipes coating and lining supply a protective surface for pipelines, it is the simplest and prime to oil and gas industry technique in controlling corrosion. Coating and lining offer resistance against bacteria and environmental mushrooms that may attack and mutilate oil pipelines. This technique is premised on properties such as confrontation to cathodic disbandment, bond to pipeline surface, resistance to seawater and confrontation to soil stress [35, 36].

Corrosion İnhibitors

This is the application or use of chemical substances in the oil and gas industry to alter process environment in-order to limit and prevent the formation of corrosion within the seawater. The oxygen scavenger and biocide chemical are injected into the process water system to eradicate micro-organisms and bacteria that enhance micro-biologically prejudiced corrosion. This oxygen scavengers' chemicals are vaccinated to de-oxygenate the water system which too encourage corrosion course. Moreover, corrosion inhibitors are used as jabbed in the pipelines either as slug treatment, continuous booster or as batching with pig trains. The added corrosion inhibitors are adsorbed on the internal wall of the pipeline to build an inert layer that serves as a shield and prevent direct contact with pipe liquid [37] and [38].

Cathodic Protection

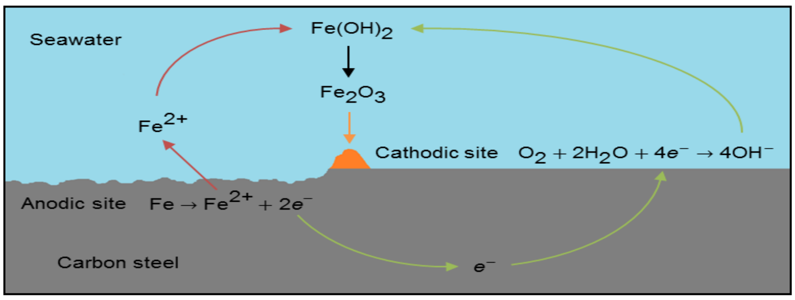

Fig.4. Cathodic reactive path [39]

Cathodic protection technique involves the application of direct electrical current that will counteract peripheral or outside corrosion in relation to metal pipelines. This practice is based on the code of electrochemical procedure where potential of one metal is dropped to opposite the flow of current and stops corrosion. This method is typically applicable once a pipeline system is buried underground or in the water; Fig. 4 demonstrated the cathodic reaction. Cathodic protection, if executed on a new project pipeline, will help to foresee corrosion from the onset, on an existing or old pipeline, cathodic protection method hinders the existing corrosion of the pipes [40]. Cathodic protection (CP) is considered as the most real and effective method of preventing oxidation of underground metal structures. This is obtained by imposing between the structures and the ground a small electrical voltage that opposes the flow of electrons and is stronger than the voltage present in the oxidation process [41]. Cathodic protection is divided into two main methods: the sacrificial anode (galvanic) and the impressed current.

The Practice in Niger Delta

In recent time, many oil and gas companies have adopted the approach of management in describing the corrosion monitoring and prevention dealings, in the oil rich Niger Delta region of Nigeria, giving to her environmental factor and the acidic composition of her water bodies, major oil and gas firms operating in this region have adopted the used of telemetry system in addition to other industry best known practices in carrying out the corrosion monitoring and prevention surveillance in the pipelines, Fig.5. This technique involves the deployment of Cathodic protective installations whose source of power is driven by solar panel. This monitoring and prevention installations are set-up along the pipeline route with different test post for online monitoring of corrosion activities on the pipelines.

This adoption and the engagement of a risk-based method has promoted the involvement of corrosion sensors, the application of contemporary arrangement capable of detecting on-site remote pipelines corrosion, propagation of localized and uniform corrosion attack as well as prompt connection of real-time corrosion and data inspection. These enhance periodic inspection, updating periodic results and presents opportunity in evaluation of corrosion severity as well as duration of corrosion attack, in addition, it allows for real-time control of corrosion conditions within the pipelines. To this end, there is still greater room for future development of advanced on-line electrochemical monitoring equipment that will offer prospect for real-time and automated supervision, considering it allied benefits, improved safety, as well as reduction in operation and maintenance cost.

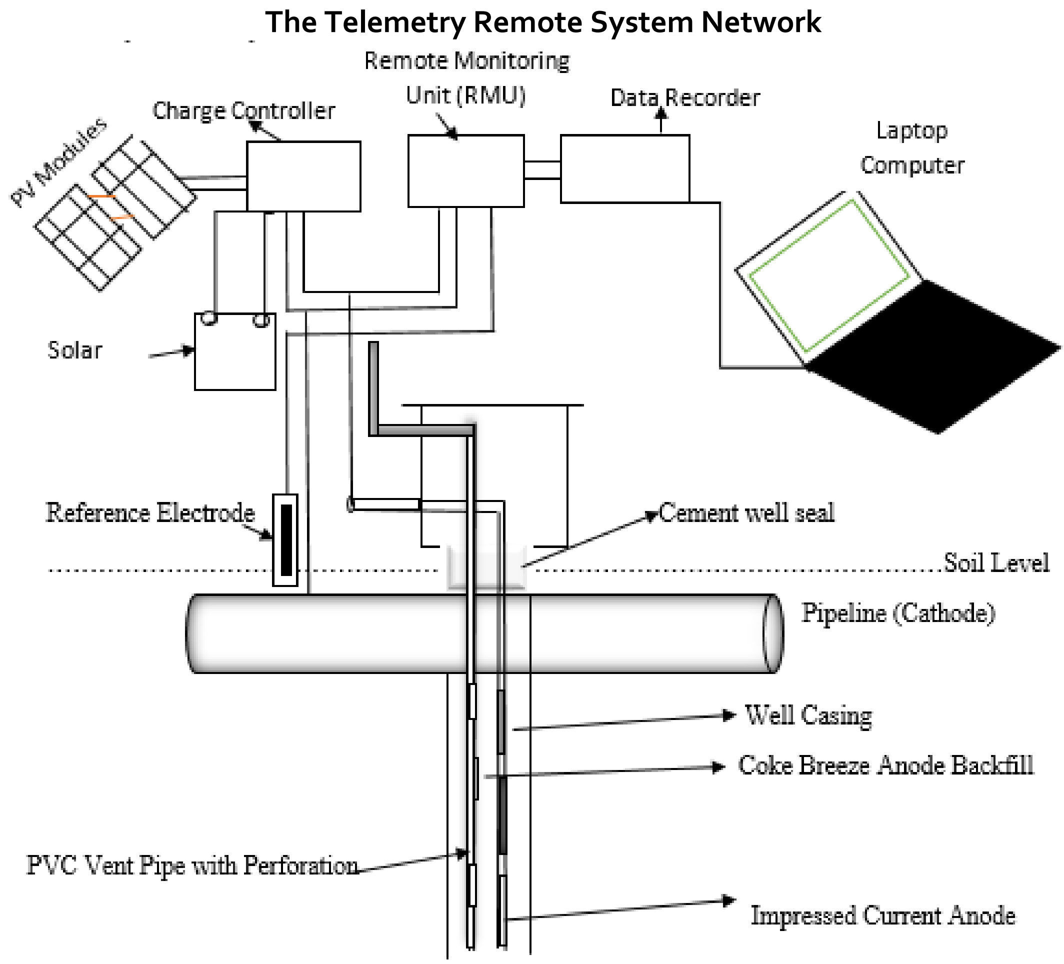

Fig.5. Cathodic Protection and Corrosion Remote Monitoring Component

CONCLUSIONS

The incidence of corrosion in the oil and gas industry has been a subject of great concern that has resulted in huge investment both in human as well as in technology, in-order to battle the effects of this menace whose impact has led to product leakages, environmental pollution, and loss of lives. Nevertheless, with topical improvement in monitoring and prevention practices, aided with corrosion experts' decision, corrosion outbreak in oil and gas pipelines can be managed in a bid to reduce cost and enhance assets performance. In supporting the pipelines integrity, a good monitoring flow parameter is necessary for enhance performance and assets evaluation, as well as real-time inspection that will offer information on the corrosion profile of the pipelines. In other instances, standard corrosion resistance materials must be used for pipes lining while reinforced composite and PVC materials need to be exploited as an alternate material in pipeline construction. For industrial best practices, and to achieve a more economical means of extending the service life of oil and gas pipelines against corrosion attack, we recommended that a good material coating technique be used in combination with any of the above preventive methods.

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