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Effect of Corrosion on Mild Steel in Food Processing Industry: A Review

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Abstract— *Corrosion is a watch word when it comes to the deterioration of material exposed tochemical, electrochemical or biochemical substances in the environment, this results to electron loss in metal as they come in contact with oxygen and water. Mild steel is one of the major materials exposed to this corrosion in humid air, acidic and other environment, it finds its application in construction work in the industry because of its low cost, it is chosen as a material of choice even in food processing industry, The aim of the work is to review literature on the effect of corrosion of mild steel in food processing industry, the tomato fruit which is also a vegetable was used as a case study to carried out the review, the review highlighted the detection, prevention, method, inspection and control method to tackle corrosion problem. The review also explained the different forms of corrosion and how they affect metals.*

I. INTRODUCTION

Corrosion have been in existence over the years, it is regarded as a gradual degradation or deterioration of metal, as it interactwith the environment, (Hamzat et al., 2020). This interaction causes loss of electrons in metal as it comes in contact with oxygen and water which causes the breaking down of mechanical properties in the material due to chemical reaction.

According to report United States spends $274billion annually(3.1% of the GDP) on corrosion associated cost which is very devastating, This impact has affected the food processing industry because of the contamination of products.Other challenge encountered as a result of corrosion include plant shutdown, equipment breakdown and loss of production time (Udochukwu Ofoegbu et al., 2011), corrosion attack can appear in different forms such as pitting corrosion, galvanic corrosion, intergranular corrosion, selective leaching.

Mild steel is an alloy composed of 2% carbon and 95% of iron (Fe), other additives include 1.65% manganese (Mn), 0.6% copper (Cu) and 0.6% silicon (Si), there are also a little bit of other metals such as vanadium, cobalt, chromium, and nickel present in the alloy, mild is corrosive as a constructional material because of the amount of carbon content in it.

Mild steel finds its useful application in the industry because of its weldability, malleability and amenability to heat treatment process, to change its mechanical properties (Badmos & Ajimotokan, 2009)mild steel has been extensively used for metallic structures in the industry, because of its low cost(Fuente et al., 2010), regardless of all this wonderful application of mild steel and its properties it is also faced with a big challenge when it comes to corrosion attack, this problem come in various corrosion attack such as fatigue , stress corrosion and lot more.

Battling the effect of corrosion of metallic materials is now a major problem especially in the food processing industry because of the bacteria growth in food, the struggle to ensure food quality and avoiding other related health issues that comes with it(Hamzat et al., 2020). The chemical composition of this metals is also a crucial aspect to be considered in the choice of selecting material in the construction of processing industry this helps to determine

the possible corrosion reaction and the corrosion product formed (Ofoegbu, 2021).

A lot of researchers have investigated the effect of corrosion metal immersed in various food substance such as, tomatoes, cassava, orange and lots more, to know the reaction of metals when they come in contact with these fluids.

corrosion resistance of nickel plated iron carbon steel in tomato fluid was studied by (Oluwole & Olawale, 2010) for 30 days, weight loss and electrode potential were adapted to carry out the experiment. The result showed that the nickel-plated steel had decreased corrosion attack when the weight of nickel coating was increase, this shows also that thinly plated low carbon steel had no significant change on the unplated steel

(Hamzat et al., 2020) studied the corrosion of mild steel immersed in fruit environment, they adopted weight loss technique to determine the rate of corrosion in cashew fluid, pineapple and orange for period of 25days, taken 5days interval, the result showed that cashew fluid had the highest corrosion rate at 0.7mmpy, followed by the pineapple fluid, the lowest corrosion rate was observed in the orange fluid at 5.00mmpy.

(Dey & Agrawal, 2017) used weight loss technique to investigate the behaviour of Tinplate in when exposed to corrosion in fruit juice. The structure of corrosion products and morphology were characterized by scanning electron microscope (SEM). The samples were immersed in different type of fruit juices after the weight was known, natural fruit juice and water. For a period of 20days, taken 6days interval to measured the weight, result obtained showed a significant degradation of template sheet. This was as a result of the sweet fruit juice which is acidic in nature. Packed fruit juice with preservative was most corrosive follow by natural fruit and water.

This work aims at providing a review on the effect of corrosion in the food processing industry by briefly summarizing previous literature on the interaction of mild steel in different fluid media. It explained the different types of corrosion that occur on metals in food processing industry.Then it gives the inspection and control methods. Finally the paper gives the conclusions.

II. DESCRIPTION OF TOMATOES

Tomatoes are one of the major fruits processed in the food industry, it is a fleshy berry (lycopersiconescufentan) which belong to the night shade family, other crops in this family include, potato and egg plant.

Tomatoes is the second most important fruit or vegetable crop next to potato with approximately 1823 million tons produced yearly (FAOSAT, 2019), they are rich in minerals, vitamins, sugar, vitamin B and C, essential amino acids, dietary fibres, iron and phosphorous.

Tomatoes are consumed as everyday diet because of their nutritional values but they also contain citric and malic glutamic acid as one of their prevalent acid, there is also methionine and S-Methionine, which make it acorrosive environment for metals.

Fig 1 mild steel exposed to tomato fluid.

III. TYPES OF CORROSION

According to ASM 2000, corrosion occurrence is classified in three different forms.

i. Nature of the corrodent: This could be “wet” or “dry” environment depending on the medium, an aqueous or moisture corrosion is mostly seen in the former, while dry corrosion occur in high temperature gas environment.
ii. Mechanism of corrosion: This requires the presence a chemical reaction or electrochemical reaction.
iii. Appearance of metal corrosion: This is physical look of the metal, it could be uniform, and the metal corrodes at even rate over the entire surface, or it can be localized.

3.1 Uniform Corrosion:

Uniform corrosion is a type of corrosive attack that is distributed evenly over the entire surface of the metal, it can also be seen as a dissolution of metallic component into metallic ions, the effect of this type of degradation causes the material to become thinner and gradually fails. It is a big effect on waste of metals on the bases of tonnage, although it is not an aggressive type of corrosion but this type of deterioration can have a serious impact on the economy compared to the aggressive ones. (Hauge, 2015)(Sandvik, n.d.)(Jirarungsatian & Prateepasen, 2010)

Fig 2. Uniform Corrosion (Mgonja, 2018)

3.1.1 Preventive or Reduction Method of Uniform Corrosion:

1. Proper material coatings.
2. Cathodic protection
3. Use of Inhibitor

3.2 Galvanic Corrosion:

This involves material contact between two dissimilar metals resulting to one giving up more electrons to the other during the process of transmission, this is also known as electrochemical process (*Corrosion Considerations in Connector Development*, n.d.). Galvanic corrosion has an accelerating effect which increases corrosion in metal exposed to electrolyte. It is particularly seen in outboard motors boats, Galvanic corrosion can be seen in old apartments were modern copper piping are joined to the aging existing carbon steel lines. Although Mg is the highest structural materials which helps in light weighting in automobile, it is very prone to galvanic corrosion when used along with the aluminum (Al) or steel.

Fig 3Galvanic corrosion(Mgonja, 2018)

3.3 Crevice Corrosion:

this a localized type corrosion that happen in confined spaces, the attack is usually caused by stagnant solution which is as a result of lap joint, hole appearance, gasket surfaces, surface deports and crevice under bolts and rivet head, it can also be referred as corrosion that occur when a small volume of stagnant corrosive fluid is trapped in the interface between two material in a shielded region,(Sandvik, n.d.)(Rashidi et al., 2007)(*Corrosion Considerations in Connector Development*, n.d.) Crevice corrosion occur in most engineering structure. Consequently, crevice corrosion has the peculiarity of occurring in only a few microleters of electrolyte(Christian, 2020). Crevice corrosion can be also be caused by biofouling deposits like iron hydroxide (Abdel et al., 2018).

Fig 4: Crevice corrosion

3.4 Pitting corrosion:

It is a form of extremely localized corrosion of a material surface confined at an area, the pit holes are formed quickly on metal surface which eventually makes the material to fail. pit holes can be isolated or close to each other which makes the metal surface look rough ,they can appear in large or small diameter but in most cases in small diameter, pitting is a very dangerous form of metal corrosion, in extreme cases pit corrosion can lead to sudden break down of the material,(Fontana, 1987). Pits can be in the form of covered or uncovered pit with a semi-permeable membrane product of corrosion. Pit appear cupshaped or hemispherical (*NACE International "pitting Corrosion"*, n.d.).

Fig 5 Pitting Corrosion

3.5 Intergranular corrosion:

Intergranular corrosion occurs with relatively little grains of corrosion, it's a localized attack that occurs in the premises of the grain boundaries of a metal, this is caused by chromium depletion, which is as a result of precipitation of chromium carbides in the grain boundaries or chemical segregation effects. the precipitation henceproduces zones with decrease corrosion resistance in the immediate vicinity (*NACE International"intergraualar Corrosion"*, n.d.), intergranular corrosion is strongly associated with the properties and microstructure of a metal (Smithells, 2004). Intergranular corrosion is quite different from pitting corrosion even though it may be initiated from a pit, it grows more rapidly than pitting corrosion along susceptible intergranular pathways. (Birbilis & Hinton, 2011)

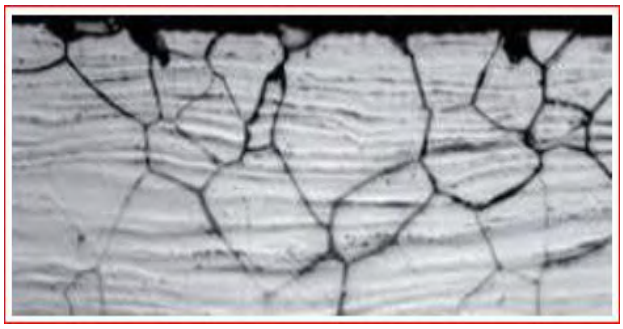

Fig 6: IntergranularCorrrosion

3.6 Erosion corrosion:

Erosion corrosion is an increased degradation of metal surface due to mechanical action or attack on a metal which is caused by rapid movement between the metal surface and the corrosion fluid (Fontana, 1987), it is as a result of turbulence at a particular site due to a disruption in the flow pattern, which causes mechanical near effects or abrasion. On the metal surface(Fontana, 1987)(*Corrosion Atlas Case Studies(General Aspects of Corrosion, Corrosion Control and Corrosion Prevention)*, 2020), erosion corrosion is causes by drops of small particles with inertia, which causes material loss because of strikes on the metal surface [7]. The rate of this type of corrosion is also subject to fluid speed(Sandvik, n.d.).

Fig 7: Erosion Corrosion

3.7 Stress corrosion cracking (SCC): Stress Corrosion Crack are distortion of metals subjected to tensile stress in a specific corrosive environment(Fontana, 1987). This causes corrosion reaction that lead to crack increase at the tip of the metal, The crack increased because of the consumption of reaction of the material at the crack tip, stress corrosion crack occurs suddenly with little or no evidence of corrosion attack on the metal surface(Sandvik, n.d.). Examples of SCC include aluminum alloys steels in chloride solutions, neutral aqueous solutions, cracking of austenites stainless steels in the presence of chlorides.

Fig 8: Stress Corrosion

3.8 Atmospheric corrosion: this is a natural occurrence on metal surface,it is an electrochemical process that is caused by the presence of electrolyte, is a corrosion attack on metal exposed to air and its pollutants. Atmospheric corrosion occurs at atmospheric relative humidity which has exceeded the equilibrium relative humidity over a saturated solution visible on a metal surface, it could occur as dry, damp and wet corrosion. (Ahmad, 2006).

IV. PREVENTION OF CORROSION

Food processing industries have always been faced with the problem of corrosion. In other to reduce these

problems preventive methods are adapted as an effort to reduce the accident that occur as a result of pipe leakage and fracture,most industries now employ the use of cathodic production and coating as a method of protection(Baker, 2008)(Enani, 2016).

4.1 Cathodic Protection:

Cathodic protection Is a proven way of protecting metal against deterioration of underground metallic pipes and offshore structures, in the oil and gas industry, structural foundations and utility lines(Ahmad, 2006), it applies current to pipes to disarray the flow of electrons from anodes to cathode, creating a cathodic field over pipes, cathodic protection is applied by one of two method power imposed current or sacrificial anodes. For cathodic protection to be effectively carried out polarization must take place by applying the positive and negative DC on the structure.

4.2 Coatings

High performance coating has proven to be more effective method of coating by applying the coating to a surface abrasive blast cleaned to a white or near white metal surface finish in conjunction with effective cathodic protection. The surface abrasive blast cleaning promotes good coatings adhersion, the basic function of the cathodic protection system is to protect the bare area on the metal from corrosion (Beavers & Thomposon, 2006)(Baker, 2008).

Inadequate coating has been a major contributing factor to the corrosion susceptibility in the food processing environment, the standard follows that “the purpose of coating is isolate the external surface pipe from the environment,to improve (protection) current distribution and minimize cathodic protection requirement”.

Below are the common interior coating types:

4.2.1 Coal for Enamel:

Coal for enamel (CTE) have coal tar pitch as their basic ingredient, they contain stable molecules which are generated at 1300^{o}c during cooking operation, the coal and fillers add strength and product flexibility. Most of the necessary characteristics necessary to produce pipeline corrosion protection are due to the molecular arrangement provided by CTE. This include water resistant, stable chemical structure, Resistant to cathodic disbanding, most pipelines are protected using impressed current or sacrificial metal anodes, high electrical resistance is another factor that shields cathodic current, adhesion help to form a stiff bond to the material surface which Resistbacteria attack , aquatic organism and root penetrations(Malley, 2018).

4.2.2 Cement Mortar Lining:

TheCement mortar composite has wide range of application in masonry work, patching rendering, it has a long-term reliability and less expense, the main advantage of cement mortar is the user friendly type of application. cement mortar linings protects the steel pipes by providing a stable hydroxide film at the interface of the steel-mortar even at discontinuous pipe joints, the cement mortar linings is known to hold water for an extended period of time, it follows the quality water standard procedure(Malley, 2018). cement mortar lining caninfluence significantly the stiffness of the steel and deflection forces resistance. When calculating stiffness, the mortar lining and steel strength can added together.

Fig 9. Cement Mortar Lining

4.2.3 Liquid Applied Epoxy: This involves the following.

1. chemically cured type of epoxy coating, more than two type of coating of similar part.
2. A single coat of two-part.
3. A chemically cured two-part epoxy primer with more than one coating of dissimilar two-part and a top coat.

However, epoxies are mainly applied on floors, warehouse and automotive facilities, it contains a polyamide or amine agent and needs a near white blast cleaned surface(Nace, 2007). Coal-tar epoxies have coat tar pitch added to the epoxy resin. A coal tar epoxy cured with a low molecular weight amine serve as resistance especially in alkaline environment, example is the occurrence of cathodic protection structure. Some coal-tar epoxies become brittle on exposure to sun ray(Beavers & Thomposon, 2006).

4.2.4 Fusion Bonded Epoxies:

Fusion bonded epoxies is composed of a powdered coating used to provide pipeline protection, they are heat curable and thermoset polymers in nature and are mostly used when no volatile organic compounds (VOCs) are needed.

FBs is usually applied above 450ºf after the heating process to avoid excessive pipe cooling (if cooling is done below 450ºf the FBE curving process may not be fully completed) and it needs not more than one minute or less to dry to the touch and three minutes to be fully cured depending on the material formulation (Malley, 2018), fusion bond epoxy coating were introduced in 1959 but was commercialized in 1961, the coating film is usually applied to largeand smaller diameter pipes(Mgonja, 2018).

4.2.5PolyurethaneCoating:

The aromatic polyurethanes are 100% solids material with VOCs content. Polyurethane materials ensures economic high production rates which makes them cure faster, they have good physical and mechanical properties, and products coated with polyurethane have reliable service life span. They provide strong adhesion to well-prepared steel surface and ferrous steel. Polyurethane coating require the pipes to be thoroughly cleared for in-service pipe before application.

4.2.6 Wax Coating:

Wax is known for centuries, for coating fruits, pipes and cars, they serve as waterproof and protect the material from sunlight UV ray, the microcrystalline wax coatings are mostly used with a protective overwrap. The prevalent application of wax coating is in a combination of machine that cleans, coats, wraps and lowers into the ditch in one operation (Beavers & Thomposon, 2006). Wax coatings are product from different variety of chemicals which may not be suitable for consumption but can be removed by evaporation during drying operations. One can also find the useful application of wax coating in cartons for frozen foods, butter and margarine (Mitsuhiro, 1990).

4.3 Corrosion Inhibitors:

According to (Durowoju et al., 2014)inhibitor are chemical compound added to gas or liquid, to reduce the corrosion rate of the material , they are selected depending on the type of acids, metal expected temperature and choice of protection time when added in small concentration to an environment, the selection of an inhibitor is also controlled by its economic availability, its efficiency inhibit the substrate materials and its environmental side effect (Durowoju et al., 2014), example is the injection of inhibitor substance into the stream of hydrocarbon (oil or gas) close to the wellhead to decrease rate metal degradation in the steel pipe. Inhibitors can be of different types including passivators (anodic inhibitor), Cathode, organic, precipitation inhibitors and vapour-phase inhibitors.

V. CORROSION INSPECTION AND CONTROL METHOD

Different corrosion inspection and control method have been adopted to inspect pipes in food processing industry, they include hydrostatic retesting, direct assessment, and inline Inspection(Beavers & Thomposon, 2006).

5.1 Direct Assessment(DA): DA is essentially a structural process that does not cause any clogging in the pipeline operation(Mgonja, 2018). It is the most widely accepted method of inspection used globally and it has proven to follow protocols guiding pipeline integrity operation, it determines the presence of corrosion in a system by assessing the overall condition of the pipeline and coating.(Pillai, 2011), DA is a structured process that combined data integration, use of existing survey tools modeling for identifying areas where corrosion is more likely to occur and physical examination of the pipe (Kowalski & Beavers, 2011).

5.2 Hydrostatic testing:this involves testing component such as piping system, gas cylinder and pressure vessel for strength and leaks, it is done by applying pressure to verify the integrity of the pipeline, it is used mostly for testing pipe and pressure vessel, the operation is carried out by filling up the component with water and initiating pressure to examine the strength of pipe without bursting it(Sankara, 2014). It is one of the quality-control measure which ensures that installed pipes reliable for service. (Mgonja, 2018).

5.3 In-line Inspection (ILT) device: These are“smart or intelligent” Pigs devices used as preventive maintenance method to examine pipelines for cracks, corrosion identification, and other defects, that might lead to major breakdown of the structure, it is also a non-destructivetype of test.(Corrosionpedia, 2021)

5.4 Magnetic flux leakage tools: Accord to Wikipedia, it is non-destructive type of testing that applies magnetic flux to detect corrosion and pits in steelstructures, they are widely used in the industry for assessing the quality and structural integrity of ferromagnetic components in underground pipelines(Chandra & Bhagi, 2014), it detects cracks in both circumferential and axial direction and are used to measure the change in magnetic flux lines produced by the defect, they are of two types, high resolution magnetic flux leakage tool and standard resolution MFL (Mgonja, 2018) to carryout testing MFL testing, magnetizing unit and sensor are scanned together as a single unit at constant velocity and the sensor response is recorded and interpreted continuously. The magnitude of MFL

signal is strongly related to defect depth(Chandra & Bhagi, 2014).

5.5 Ultrasonic tools (UT):this is a non-destructive examination technique thatuses high frequency ultrasonic waves to detect flaws in a steel pipe,(Wikipedia, 2017) it evaluates stress state using the influence of the strains respectively, they are used to measure the thickness of materials and the size of defects (Onyekpe, 2002), ultrasonic (UT) uses high frequency sound waves (ranging from 0.5 to 15MHz) to examine and take measurement. It can be used to measure the thickness of material and the size of defects, ultrasonic techniques finds useful application in nondestructive testing, radia consist, acousto-optics, microscopy etc.

VI. CONCLUSIONS

The effect of corrosion of mild steel in food processing industry have been presented, corrosion has been a watch word used throughout the paper presentation. This is because of the challenges industries and society in general faced as a result of material deterioration. It has been explain that the mild steel which is one of cheapest metal used in food processing industries is attacked majorly by corrosion which occur in different forms. The effect of corrosion has led to contamination of food which can cause serious health challenge. The study has shown that corrosion related problem constitute 33% of all failure in the food processing industry, reports shows that the annual cost of corrosion is alerting as industries and countries like the US have spent tones of dollars to take the problems of corrosion. Preventive measure have been put in place to curve the effect of corrosion which has been effective to some extent. The keys to effective corrosion control in the food industries and proper material selection, quality design and installation of equipment use of high technological corrosion monitoring technique and assigning maintenance and monitoring to trained professionals.

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