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Corrosion in the Food Industry and Its Control

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1. Introduction

From ancient times human beings have survived on a diet consisting on a relatively few species of plants and animals, domesticated and then cultivated and grown. Three cereals, wheat, rice and corn, supply the need of human energy, protein and vitamins requirements for the network of metabolic processes to maintain normal body function and temperature. In a prehistoric era, indigenous peoples all over the world were moving in inhospitable grounds obtaining their daily sustenance by hunting and gathering fruits, seeds and roots.

Actually, the three largest markets worldwide, according to their production extent, the number of consumers and their economic and social significance are the food, energy and water markets. Furthermore, their increasing scarcity and soaring prices lead to a global critical situation. The demand for increased food supply is related both, to population increase and personal and family income. Consequently, the food market is the largest one, including all the inhabitants of this planet, about seven billion, since everyone eats!

The organized food production and supply starts with the agricultural revolution, developed and implemented in the fertile valleys of the rivers Tigris-Euphrates in Mesopotamia and the Nile in ancient Egypt. Afterwards the food industry expanded, avoided widespread famine and ensured that sufficient food is supplied for all people to stay healthy. Current food research had been largely stimulated by rapidly growing world demand but technological advances in food processing, equipment and production plants have also contributed. A most significant aspect in the search of new nutritional food is the requirement for adequate protein in regions where meat and fish are not available. Additionally, advances in the food industry (FI) such as preservation, packaging and storage facilitate food delivery and minimized health hazards. Space flight conditions have stimulated the creation of space food which meets highly demanding standards for conservation and to be ready for easy digestion e.g. solid dehydrated food easily converted into liquid or paste food.

Techniques for preserving food from natural deterioration following harvest or slaughter dated to prehistoric times applying drying, salting, fermentation of milk and fruits and pickling of vegetables. Modern techniques include canning, freezing, dehydration, cooking under vacuum and addition of chemicals. The principal causes of food spoilage are growth

of microorganism, enzyme action, oxidation and dehydration. The economic and social relevance of the FI is evident by the diverse international and national professional associations, R & D institutions, regulation and standards agencies and potent multinational industrial enterprises involved in all aspects of food science, engineering and technology (S.O. Jekayinfa et al, 2005). It includes authorities from government, industry and academia that address progress crucial for national and global prosperity. Lately, the threats of bioterrorism by poisoning food have pushed the FI to the front of efforts by safety and security organizations to prevent these hazards events.

Among others, aluminium, tin, cooper, titanium and mainly stainless steel (SS) are widely used in FI for the manufacture of processing, production, storage and transportation equipment and machinery. Modern science and technology have developed an extended range of materials with increased corrosion resistance, improved mechanical strength, easier forming and fabrication, weldability and health friendly features. The workhorses of food processing industry are UNS S30400 and S31600, but other austenitic and duplex SS are in useful service in food plants.

Food consists mainly of proteins, carbohydrates and fats. Processed foods contain diverse aqueous solutions, syrups and additives, used to improve food appearance, quality and preservation. They have a wide pH range and salt, water and vinegar content, that impact on food corrosivity.

Many cleaning and sanitation agents are employed to remove bacteria, scale, fouling and corrosive biological and mineral deposits. They include alkaline, acidic, strong or weak oxidizing and reducing chemicals to ensure a high hygiene level. This great variety of corrosive environments and aggressive chemical agents require the use of Corrosion Resistant Alloys (CRAs). SS are the obvious choice of the FI to prevent equipment damage and food contamination.

2. General corrosion considerations

FI is a complex network conformed by primary producers and the industries linked to them. The plants involved in the processes of products and packaging must preserve the capital invested and minimize operation costs. The physicochemical characteristics of processed foods permit them to achieve different corrosivity grades depending on the type of content (Valdez et. al., 2004, Jellesen, et. al., 2006).

Three types of foods are recognized according to their corrosivity:

- Non corrosive: milk, meat, fish, oil, fat, cereals
- Mild corrosivity, foods with pH 6 – 7 and less than 1% of salt: dairy products, fruit syrups, wine, carbonated sweet drinks, beer, soups, canned meat.
- High corrosivity, foods with pH 3 – 5, such as citric fruit juices, jams and acidic canned fruits or hot gravies, sauces and dressings, vegetables and fish pickled in brines with 1 – 3 % salt.
- Many cleaning, disinfection and sanitation agents are employed to remove bacteria, scale, fouling and corrosive biological and mineral deposits. They include alkaline, acidic, strong or weak oxidizing and reducing chemicals to ensure a high hygiene level.

Acetic acid, used as an acidifying agent for the production of pickles and canned vegetables is mildly corrosive to SS. Three types of cleaning and sanitation agents are applied in the FI:

1. Alkaline: such as caustic soda (NaOH), alkali phosphates (Na_3PO_4), sodium carbonate and bicarbonate (Na_2CO_3, $NaHCO_3$).
2. Acidic: phosphoric, citric and sulphamic acids.
3. Oxidizers: chlorine, nitric acid, ozone, hypochlorite, hydrogen peroxide (H_2O_2)

This great variety of corrosive environments and aggressive chemical agents require the use of Corrosion Resistant Alloys (CRAs). SS are the obvious choice of the food industry to prevent equipment damage and food contamination.

Food main constituents.- Foods are constituted by two essential groups of substances: those with nutritional values: proteins, carbohydrates and fats and the components imparting particular tastes: salt (NaCl) for saltiness, acids for sourness or acidity and sugars for sweetness. Few peculiars foods have a bitter taste e.g. almonds. A central component of food is water as in fruits, vegetables, meat, eggs, milk, etc.

Water.- The vegetables and ripe fruits contain a considerable amount of water between 70% and 90%. Since water is used as a medium for food preparation e.g. cooking , confectionery, hot and cold beverages, even cooked foods contain water. The water behaviour and its interaction with food depends on its physicochemical properties, its molecular and ionized structure and its chemical bonding. Water is considered as the universal solvent since all chemical substances have a finite solubility in water ranging from acids, bases, salts, sugars, alcohols, etc. Water is dissociate into ions: $H_2O \rightarrow H^+ + OH^-$ forming the hydronium ion H_3O^+ a bonding between an hydrogen ion H^+ and a water molecule, these are the ions involved in corrosion of metallic materials used for the construction of food processing equipment.

Acidic metallic salts undergo hydrolysis in water:

$$2FeCl_3 + 3H_2O \rightarrow 6HCl + Fe_2O_3, \quad (1)$$

forming an acidic and corrosive environment.

Water is the medium for countless chemical and biological reactions. With the exception of petrochemical and combustion reaction, most chemical processes occur in aqueous systems, including vegetal and animal respiratory and metabolic functions. Food preparation involving dehydration, softening, takes places in water. The operation requires some energy to break hydrogen bond and form new bonds between the solute: food components and water: the solvent.

Salt.- Table salt (NaCl) is encountered in many natural environments: seawater, natural brines, enclosed seas, e.g The Dead Sea, Israel and the Salt Lake, Utah, USA, with a salt concentration of about 300 g/L; in aboveground and underground mines found as rock salt. An aqueous salt solution is decomposed by electrolysis into several useful products: metallic sodium, hydrogen, sodium hydroxide and chlorine, all important raw materials for the chemical processing industry (CPI). The meat packing, sausage making, fish curing and food conservation employ salt as a preservative or seasoning or for both purposes. Up to the 19th Century, during the invention of industrial food freezing and cannery; commercial and navy ships conserved meat in wood barrels full of solid, granular salt for their long voyages since putrefaction bacteria cannot live in salt. Salt is a hygroscopic substance, absorbing atmospheric moisture, forming a concentrated salt solution or slurry, corroding steels and deteriorating ceramic materials such a masonry bricks. Salt is part of mankind history and tradition. Modern and ancient words, in many languages, are derived from salt: salary,

salad, salutary, salud (Spanish for health) . The Bible describes hospitable reception of visitors and travellers offering water, salt and bread (M. Schorr et al., 2011).

Acids.- Acids in water solution impart a sharp sour taste to food but also a corrosive action on steel. Therefore steel for food containers should be protected with corrosion-resistant material or fabricate from stainless steels or plastic materials. The word acid derives from ancient European language meaning sour. Acids and bases play a large part in industrial chemistry and particularly in chemical cleaning in food processing equipment. Water, the "universal" solvent, dissolves acids and bases. The acidity of foodstuffs is determined by measuring their pH. The majority of the vegetables and fruits consumed by human beings are acidic, with a pH between 5 and 2; in particular citrus fruits displaying pH values between 2 and 4. Two acids: acetic acid (vinegar CH_3-COOH) and phosphoric acid (H_3PO_4) are widely applied in the FI, the first for the conservation of vegetables and the second for acidifying beverages, drinks and juices.

Sugar.- Sugar is a sweet substance obtained from the juices of various plants, chiefly the sugarcane and the sugar beet but also from date palm and the maple tree. It is an article for human nutrition and a sweetener for other foods, especially beverages, confectionaries and canned fruits. It is a carbohydrate, called sucrose and the prime source of energy in the human diet, needed to maintain body temperature and activity. Most of the sugar is consumed in the form of white, granulated sugar, produced in refineries processing sugar cane or beets. Liquid concentrated sugar syrup is used for sweet food manufacture purposes, such as confectionary and candies. Sugar dissolves easily in water forming a molecular solution without electrical conductivity and therefore slightly corrosive since there is some amount of dissolved oxygen.

Environments in FI.- The pH values associated with foods ranges from 3 to 8 that corresponds to a mildly acidic water and has an acceptable corrosive behaviour for aluminium, stainless steel and tin. Table 1 shows the pH ranges for different foodstuffs branch in the FI. Nevertheless, the aggressive ions hypochlorite and chloride could be concentrated by evaporation of the cleaning solutions on specific localized areas of the metal surface, inducing pitting corrosion. The combination of both anions chloride and hypochlorite can lead to a more positive redox potential (E^0 = +0.9 V vs Satured Hydrogen Electrode (SHE)) and to synergize the pitting corrosion process of stainless steel.

Foodstuff	pH range
Vegetables	3.0 to 6.0
Fruits	2.0 to 5.0
Bakery	5.0 to 6.5
Meat	6.0 to 7.0
Fish	5.5 to 6.0
Dairy	5.0 to 6.5
Beverages	2.0 to 5.5

Table 1. Ranges of pH values for different foodstuffs

The cost of corrosion.- The food processing industry is one of the largest manufacturing industry in the United States of America, accounting for approximately 14 percent of the

total U.S. manufacturing output. The total food sales including the supermarket and traditional food store, restaurant food and drinks, non-traditional food store and convenience stores sales were 1,638 billion US dollars in 2010 (Plunkett Research, 2010). Assuming that SS consumption and cost in the FI is entirely attributed to corrosion, total annual direct cost corrosion was $ 2.1 billion, according to National Association of Corrosion Engineers report for corrosion costs in 1999. This cost includes SS usage for beverage production, food machinery, cutlery and utensils, commercial and restaurant equipment and appliances.

3. Public health and hygiene

Food can be an important source of disease-causing organisms, the investigations on risk management in food handling, diet and health (Buchanan et. al., 2001, and Oddy et. al., 1985), revealed an association between human diseases and food contaminated by flies. Food can contain beneficial bacteria, but contamination with harmful microorganisms from external reservoirs must be prevented not only by removal of food residues and disinfection but also by the modification of surfaces specially designed to avoid sites for the development of bacterial colonies, such as accumulated corrosion products or degraded protective coatings. These surfaces must not introduce toxic substances or influence flavour. Materials that fulfil these requirements are glass, earthenware, some plastics, and metals like SS and aluminium alloys. Glass is sensitive to shock and fragments are sharp, while inexpensive plastics are not heat resistant and, in thin gage, they are permeable to gases. Metals do not have these disadvantages, but they must be corrosion resistance in food environments.

The modern FI combines the application of the latest production processes, the use of cleanable corrosion resistant SS equipment and computerized information with an efficient, environmentally sound approach to meet the needs of food products consumers everywhere. Cleanability is important in relation to taste, colour, odour and contamination of edible products such as milk, processed and canned foods and alcoholic beverages. This is of particular hygienic importance in food handling. Food processing involves operations by which raw foodstuff are suitable for human consumption, it includes the basic preparation of food, preservation and packaging techniques. Many innovations have resulted in new products such as concentrated fruit juice, freeze-dried coffee and instant food.

Sterilization is one of the most important aspects of hygiene and sodium hypochlorite is a disinfectant widely used to kill microorganisms through an oxidizing reaction that yields sodium chloride as final product.

$$NaClO \rightarrow NaCl + O^* \quad (2)$$

Where O^* represents oxygen species capable to kill biological material by oxidation. Both sodium chloride and sodium hypochlorite can be easily removed from surfaces used in the FI by rinsing with water, but it is not permissible to leave any residue because residual chlorides and hypochlorites can be concentrated by evaporation and induce localized pitting corrosion

4. Microbiological induced corrosion in the food industry

Microorganisms are primitive unicellular organisms capable to live in colonies at aqueous media. They are diverse and for the interest of this chapter it is appropriate to mention;

bacteria, fungi and algae. These microorganisms are not corrosives by themselves, but due to the impossibility to produce their nutrients by photosynthesis, they must metabolize organic content present in the media, producing other substances that are returned to the solution.
The nutrients needed include a source of energy such as glucose that supplies carbon and minerals containing phosphorous, sulfur and nitrogen for the cell structure of bacteria. The growth, development activity and death of bacteria are also influenced by the pH and concentration of some ions, which establish the best conditions. Bacteria are diverse and can live in extreme conditions such as high concentration of chlorides (halophilic), higher temperatures (thermophilic) or to realize different chemical transformations; reduce sulfates, reduce sulfides, use hydrogen or reduce nitrates, etc. Bacteria can participate in corrosion processes in different ways: changing the environment by replacing a substance by another, covering partially the metallic surface with their biofilms creating local corrosion cells or inducing the corrosion process by depolarization of hydrogen at the metal surface.

5. Stainless steel in the food industry

The corrosion resistance of SS is due to the presence on its surface of a protective, passive oxide film which is stable, tightly adherent and very thin: about 50 Å. When broken, the film regenerates itself by exposure to air or moisture. A broad summary of the utilization of various categories of SS in the FI is given in Table 2.

SS UNS * number	Chemical composition % w/w				Characteristics/Uses
	Cr	Ni	Mo	C_{max}	
Martensitic and Ferritic chromium steels					
S41000	11.5-13.5	---	---	0.15	Hardenable by heat treatment. Turbine blades, valve trim, freezer blades.
S41600	12-14	---	---	0.15	Easy machinable. Valve stems, plugs and gates.
S42000	12-14	---	---	0.35-0.45	Hardenable by heat treatment. Cutlery, cladding over steel.
S44000	16-18	---	---	0.6	Very hard. Pumps, plungers, gears, bearings.
S43000	16-18	---	---	0.2	Good corrosion resistance. Structural purposes
S43100	15-17	1.5-2.5		0.16-0.17	
Austenitic chromium-nickel steels					
S30200	17-19	8	---	---	Good corrosion resistance. General purpose.
S30400	18-20	8-12	---	0.08	Good corrosion resistance. General dairy equipment.
S31000	24-26	19-22	---	0.25	Heat resistance. High temperature equipment.
S31600	16-18	10-14	2-3	0.10	Superior corrosion resistance. The workhorse of the dairy industry
***UNS: Unified Numbering System**					

Table 2. Stainless steel for use in the food industry

Selection of SS is an activity that requires the participation of specialized expertise in materials technology, coupled with a sound knowledge of the chemical and physical characteristics of the food products (S.H. Zhang and B. Monitz, 2006, R.M. Davidson et al., 1987). Ferritic low carbon SS UNS S44400 has the advantage to be immune to Stress Corrosion Cracking (SCC) while its resistance to localized pitting and crevice corrosion is comparable to UNS S31600 austenitic SS. The austenitic SS group is the most popular group used for the construction of infrastructure in the FI, mainly the UNS S30400 and S31600 due to their good corrosion resistance properties. The 400 series, e.g., UNS S41000, is specified for applications such as pump impellers, plungers, cutting blades, scrapes and bearings. Corrosion resistant properties of the different SS depend on the alloying elements such as chromium, nickel and molybdenum. The duplex SS is a group that contains similar amounts of ferrite and austenite in their microstructure are increasing their use in the FI in the last years. These steels have high strength and good corrosion resistance compared with the austenitic SS, but one concern is that duplex SS tend to form brittle intermetallic phases and the service temperature must be limited to a maximum of 315 C.

In the FI, the equipment is manufactured from SS with a finely polished surface that tends to have a better corrosion resistance regarding to non-polished ones, and is easy to clean and to keep clean. A smooth surface is less susceptible to an accumulation of deposits, fouling or biofouling, which often become focal points for localized corrosion. Seamless and welded austenitic SS sanitary tubing and pipelines intended for use in the FI should have special surface finishes, as the ASTM A270 standard specifies. The finishing process results in SS with varying smoothness, brightness and light reflectivity.

The standard designations for SS finishes are classified by mill forms. For instance, standard mechanical sheet finishes comprise unpolished or rolled finishes: No. 1; No.2D and No 2B (dull and bright respectively) and polished finishes, since called mirror finishes from No. 3 to No. 8, with a most reflective surface. No. 4 finish is a general-purpose polished finish commonly used for food equipment. In addition to the mechanically rolled and polished finishes, other types of finishes are achieved by chemical, electrochemical or thermal treatment and sometimes these techniques are applied for rehabilitation of damaged SS surfaces.

6. Cleaning and sanitation of stainless steel

SS are used extensively by the FI to ensure purity and quality of the products and cleanness and durability of the equipment. Hygiene and sanitation are basic requirements of this industry, and the metallic surfaces are cleaned, maintained or restored by manual or automated mechanical or chemical cleaning, the later referred to as ´cleaning in place´ (CIP), without disassembling the equipment.

The different foodstuffs have a considerable quantity of nutrients representing an ideal media for bacterial growth, which can induce corrosion processes on the metallic SS surfaces by microbiologically induced corrosion (MIC) or corrosion under acidic, salty, fatty fouling deposits or calcareous scaling from cooling water on heat transfer surfaces. The concentration of bacterial population present on a surface is the parameter to measure in order to establish the ability of such surfaces to be disinfected. Several studies have been published showing that the SS have very similar characteristics for disinfection regarding to

aluminum, rubber, polyester, etc., (J.T. Hola and R.H. Thorpe, 1990). Cleaning is a mechano-chemical operation for sanitation and disinfection of the machinery used for the food processing, to prevent contamination of products and damage to the SS surfaces. The CIP system evolved from recirculation cleaning solutions in tubing, pipelines and equipment to an update automatic system with actuated valves, controls and timers. The easiness in which SS can be cleaned allows fast turnarounds of tankers, coolers, pumps, heat exchangers and pipes, particularly during high production cycles. The SS alloys resist corrosive attack from chemical specialties formulated for cleaning and sanitation, such as chlorine, alkalis, mixed acids, organic ammonium quaternaries, halogenated hydrocarbons and detergents. To obtain better luster finishes, soft clothes or sponges are used in order to avoid scratching highly reflective surfaces. After cleaning, the surfaces are rinsed with hot water, dried and exposed to air to rebuild the protective, passive oxide layer of SS. Mechanical conveyors constructed of SS for moving and transportation of food raw materials and processed products containers are easy to maintain clean and sanitized. Water or food steam cleaning and visual inspection can verify that all products residue has been removed and that surfaces do not become stained, corroded or abraded. Currently environmental concerns are resulting in some modifications of CIP systems to allow water reuse and to minimize waste discharges.

Materials scientists at the University of Birmingham, UK, made stainless steel surfaces resistant to bacteria in a project funded by the Engineering and Physical Sciences Research Council. By introducing silver or copper into the steel surface (rather than coating it on to the surface), researchers developed a technique that not only kills bacteria but the surface is very hard and resistant to wear and tear during cleaning. This type of modified steels could be used in the FI and kitchens (ASM News, 2011).

7. Food industry and corrosion

The corrosion processes occurs due to different factors or conditions that define the corrosive characteristics of the media in which the SS elements of the FI are exposed. To illustrate the corrosion characteristics of the FI, dairy, beverage and canned food products have been selected and are described as follows:

7.1 The dairy industry

Dairying has been an agricultural practice before the dawn of history. Milk and its derivatives are a vital part of the diet for human beings. The dairy industry (DI) collect, treat and distribute milk that is used as feedstock for the manufacturing of other products particularly cheese, butter, yogurt and creams. The corrosion control in DI plants depends on the nature of these products and the processes involved during their production. DI has a large capital investment in infrastructure, which is exposed to a mild corrosive environment. Nevertheless, a considerable effort is expended to reduce corrosion losses by selecting corrosion resistant alloys (CRA´S), in particular SS and by the implementation of preventive, corrective and preferably, predictive maintenance. At first, milk looks as a simple white liquid, but in fact, is a complex emulsion/suspension mixture of lactose, whey proteins, fat globules, minerals and vitamins among others, in aqueous solution. The fats are present as an emulsion of tiny globular particles, while casein, the most abundant protein combines

with calcium ions and remains dispersed in the liquid phase as a colloidal suspension. Fermentation processes of milk are possible due to its content of sugar in the form of lactose, which used as a nutrient by bacterial cultures naturally presents in the milk. The bacteria *Lactococcus lactis* and *Lactococcus cremoris*, convert lactose into lactic acid during souring. The minerals presents are calcium and phosphorous and the vitamins are fat soluble (A and D) and water soluble (B_1, B_2, B_{12}, C and M), these last are unstable when milk is heated modifying the corrosive conditions of the media. The composition of different cow species milk is shown in Table 3.

Milk is fairly neutral in reactions, although lactic acid is present; the lactic acid content is increased by natural souring or by the artificial souring necessary for cheese and butter manufacture. This is perhaps the only constituent of milk which is responsible for metal attack. For a critical FI, such as the DI, the equipment and accessories must be constructed with a smooth, impervious, corrosion – resistant material which can be cleaned easily. Obviously the choice material that fulfills these requirements is the SS. It will be important to take care and to follow the adequate procedures in the use of SS alloys, in order to avoid affecting the odor, flavor and color of milk products.

COW:	FAT %	PROTEIN %	LACTOSE %	ASH %	TOTAL SOLIDS %
Brown Swiss	4.0	3.6	5.0	0.7	13.3
Ayrshire	4.1	3.6	4.7	0.7	13.1
Cebu	4.9	3.9	5.1	0.8	14.7
Jersey	5.5	3.9	4.9	0.7	15.0
Holstein	3.5	3.1	4.9	0.7	12.2
Guernsey	5.0	3.8	4.9	0.7	14.4

Table 3. Composition of milk obtained from different cow breeds.

The metallic alloys to be used in the DI operations where the milk and its products will be in contact with them, must have low toxicity and physiological tolerance, corrosion resistance to milk, products and other chemical food additives and cleaners, and availability of the desirable profiles in the market at acceptable costs. The main SS equipment installed in a modern dairy plant is listed in Table 4.

Milking machines	Homogenizers
Vacuum pumps	Pasteurizers
Centrifugal pumps	Tubular and plate heat exchangers
Agitators and Mixers	Vacuum evaporators
Milk coolers	Milk dryers
Bulk milk storage tanks	Spray milk dryers
Clarifiers	Conveyors
Cream separators	Vessels for cleaning solutions
Centrifuges	Piping and tubing equipment fittings
Bulk milk tankers	CIP spray devices

Table 4. Typical stainless steel dairy equipment

Electric energy is used for heating in small equipment, and for instrumentation and control of process machinery. Steam and hot water required for heating, pasteurization, sanitation and production of evaporated and dried milk is supplied by boilers. A wide variety of equipment for cooling, pasteurization, homogenization, transportation, etc, is fabricated from austenitic SS mainly USN S30400 and S31600. SS tubing and piping of different nominal diameter and wall thickness fitted with standard SS fittings are widely used for moving milk and its products throughout the plant.

The standards and specifications for design, construction, operation and sanitation of equipment for producing, handling and processing milk products have been formulated jointly by the International Association of Milk, Food and Environmental Sanitarians, the United States Public Health Service and the Dairy Industry Committee. These three associations Sanitary Standards are recognized and accepted as the official guides for the sanitary design of equipment for the DI. For the surfaces not in contact with the product the SS are preferred over other less expensive materials, nevertheless, if for economical reasons, other metals are used in the proximity to SS, precautions must be taken to avoid galvanic corrosion problems. Most of the SS are passivated and are less reactive than the majority of the engineering metals and can stimulate attack (D.E. Talbot and J.D. Talbot., 2007)

7.2 The beverage industry

A great variety of beverages includes beer and wine made by fermentation; distilled spirits requiring alcoholic fermentation and distillation, and soft drinks, carbonated and non carbonated, consisting of water flavored with sweeten natural or artificial sweetened syrup. The fabrication of beer requires barley, hops, yeast, and water as main raw materials. A series of by-products result from the processed yeast for health foods, animal feed from spent barley and the used hope is used as a fertilizer.

Beer is produced by fermentation of germinated barley and wine of the fermented juice of grape. Soft drinks are non-alcoholic beverage; they include mineral water or treated water containing sweetening agents, edible acid, flavors and sometimes fruit juices. Carbon dioxide gas gives the beverage its sparkle and tangy taste and prevents spoilage. The production of these beverages involves the use of great quantities of water in the cleaning, storage and bottling procedures. Many beverages are acidic and aggressive to carbon steel requiring corrosion –resistant SS equipment. In addition, the wet, damp and high humidity conditions contribute to plant corrosion and premature equipment failure. Application of SS will prevent the occurrence of these noxious corrosion events.

At the beginning, breweries were small places with a low production volume and their operations were carried out in wooden vessels and the first metallic components used were made form carbon steel and copper. Nowadays, many of the plants for beer, wine or sweetened beverages are large and most of the equipment is manufactured from UNS S30400 and include tanks, piping, plate coolers, pasteurizers and conveyors for bottle and can filling. Sometimes scaling occurs with chloride content in the hard, salt deposits. Remedial action involve acid treating of the water to remove dissolved carbonates and cleaning with mild acids such as phosphoric or citric to remove dissolved carbonate scaling. SS is the main material for fabrication equipment of the beverage industry infrastructure to avoid the formation corrosion products that could contaminate the beverage and affect its taste. The producing equipment include tanks, vessels, steamers pasteurizers, coolers,

blenders, filters, working tables, packaging and vending machines (J. Beddoes, 1999, H.S. Kathak, 2002).

From a point of view of general corrosion resistance aspects, beer and their raw materials are in the pH range from 4 to 5. The S30400 SS low carbon content and stabilized variants are resistant to this pH range under cold and fully aerated conditions and are used for fermenting vessels, grist hoppers, holding tanks and the piping accessories, fabricated with welded sheet or plate. Under conditions of hot or boiling liquids the environment turns more aggressive because of the higher temperature and the depletion of the oxygen content. This inconvenient is solved by the choice of a more strongly passivating SS; S31600 is used for the mash tuns, whirlpool separators and heat exchanger plates in the wort cooler. SS30400 is also satisfactory for casings used to hold the mineral lagging used as isolating element to conserve the heat in hot zones of these vessels.

The SCC is a common cause of corrosion failure in vessels handling hot liquids and it can occur due to external or internal sources. The external source situation appears when chloride ion is leached from the lagging by condensing water vapor and the SS surface has not an appropriate anti-chloride coating or interposed vapor sealing barriers of aluminum foil between successive layers of lagging. In the case of internal source, the chloride ions are contained in the water used for brewing or residues of disinfectants and from acids used in descaling. The chlorides become concentrated locally after thermal cycling or evaporation, which is a well known mechanism for SCC. The internal source of SCC can be controlled by deionizing the water and prohibiting the use of hypochlorite solutions as disinfectants.

In the wine industry, bisulfites are widely used to prevent non desirable biochemical process. The most corrosive agent found in wines is the sulfur dioxide that forms sulfurous acid. Sulfur dioxide is usually present in wine either bound to carbonyl or unsaturated compounds and/or phenol derivatives or free, as HSO_3^- and SO_2 (Araújo C., et. al., 2005, Ruiz-Capillas C., et. al., 2009). It is added to wine during its production as small amounts of sulphur dioxide (Preservative 220) or potassium metabisulphite (Preservative 224). Sulfur dioxide provides three important properties in winemaking:

1. SO_2 has antiseptic qualities.
2. It helps to protect wine from the deleterious effects of oxygen.
3. Destroy the enzyme that causes enzymatic browning in juice (similar to what happens to apples when they are sliced and exposed to the air). Without SO_2, wine would likely be brown or amber in color, smell oxidized (or have a sherry-like aroma), and probably be ruined by bacterial spoilage.

When sulfur dioxide is added to wine it is rapidly converted into bisulphite ion (HSO_3^-). Approximately half quickly combines with other wine constituents and is bound within complexes formed with aldehydes, ketones, phenolics, etc. The remaining sulfur dioxide/bisulfite is thus free in solution and it is this free portion that is readily available as an antioxidant. If oxygen is dissolved into a wine the sulfur dioxide levels will be reduced as they oxidize to sulfates (SO_4^{2-} and HSO_4^-). If SO_2 is greatly in excess, it can also produce a pungent aroma in white wines, considered by most to be a fault. The aroma is best described as that of a match that has just been struck. Many people have trouble smelling the sulfurous aroma of SO_2, but instead perceive it as an irritation of the membranes of the nose. High SO_2 can also render the palate of the wine harsh, metallic and frequently bitter.

In addition citric, tartaric, tannic, acetic and malic acids are also found in wines. SS is corrosion resistant to all of them in the concentration ranges in which they usually are found in wine fabrication steps (B.J. Connolly, 1971 in ASM).

7.3 Canned food products

The practice of preservation of vegetables and fruits by drying or salting can be traced to prehistory. Today, major processes for food preservations are cooling, freezing, dehydration, candying and canning. The main concern is for food quality, conservation and the prevention of spoilage. For cans fabrication is used tin one of the oldest available metals with a non toxic nature. The cans have been made from tin since 80 years ago when refrigeration of food was not easily available. According to their convenience the use of cans has been focused on food and beverages dispensers creating an intense competition between manufacturers not only for tinplate cans but also other materials, notably chromized steel, aluminum alloys and polymers.

Modern tinplate for cans is getting by continuous electrodeposition on steel strips, chemical conversion coating and finish polymeric coating. The manufacturing is made following three different types classified according to the methods of fabrication: a) The three piece can, b) The two piece draw/redraw (DRD), and c) The draw/wall ironed (DRW). In all of them the tinplate process is customized to economize and fulfill the requirements for corrosion resistance, filling and mechanical properties.

Aluminum cans are also widely used as containers for pressured beverages which are designed to have a minimum of material at the strength required for operation. The walls acquire rigidity by effect of the internal gas pressure from the content, but the bottom base support and the top are made from thicker metal and formed into an internal dome.

The processed fruits and vegetables are hermetically sealed and sterilized by heat and stored in glass jars and aluminum or coated steel cans. Sterilized canned food, include all types of vegetables under acidic or salty conditions and fruits in acidic, sweet syrup. The canning process consists of several stages: vegetable and fruit cleaning, filling the containers, closing and sealing, sterilizing the canned product, labeling and warehousing the finished goods. All these operation, carried out under excessive, humid conditions; require corrosion resistant equipment and machinery, currently fabricated from SS such as S30400 and S31600.

8. Corrosion control

Corrosion prevention and control require the application of appropriate methods and techniques from the early stages of design through the construction, erection and operation of the food processing plant.

Today, the main and fastest source of information on corrosion control of industrial equipment, plant and facilities is the Internet. Computer-based expert systems dealing with various aspects of corrosion prevention and control for many industries are listed in Roberge's Handbook. It is very important at the time to select an anti-corrosion material, ensure that we have investigated that the choice material is the most appropriate for the expected type of corrosive environment occurring in the plant (R. Nash, 2007).

Data on corrosion resistance of SS is displayed on NACE International's website (www.nace.org). Questions on corrosion prevention and control are answered in the NACE

Corrosion Network. SS for food processing industry is reported by the International Association of Food Industry Suppliers (www.iafis.org).
The Nickel Development Institute (www.nidi.org) presents info on the use of SS and conducts workshops on related subjects. The SS Appeal (SSA), which groups SS equipment suppliers, launched a website (www.stainlessappeal.com) to promote the application of SS. The International Association of Milk, Food and Environmental Sanitarians (www.iamfes.org) provides food safety professionals worldwide with a forum for exchange of information on sanitation practices. Many producers of SS and fabricators of SS processing equipment are listed in the Stainless Steel World Buyer's Guide published in the SS World Journal, the Netherlands.
The National Sanitation Foundation (NSF) in the USA is best known for its role in the development of standards for equipment, primarily in the food service area. The NSF's materials and finishes guide refers to three zones: the food zone, the splash zone and the non-food zone. The NSF stipulates that the food zone "surface materials shall be smooth, corrosion resistant, non toxic, stable and non absorbent under use conditions. They shall not impart odor, color or taste, nor contribute to the adulteration of the food. Exposed surfaces shall be easily cleaned".
Corrosion control in the FI involves three different methods to reduce corrosion: design considerations, materials selection and protective coatings.

8.1 Design considerations

The variety of structures: tanks, heat exchangers, cooling systems, hygiene control systems, conveyors, cans, fillers, etc., used in the FI, should be designed to provide functional qualities along to all the process steps.
It is necessary to avoid risks by underdesign or excessive costs due to overdesign considerations. Knowledge, technical information, and creative engineering principles must be used in an intelligent way to avoid corrosion. There are three important aspects in general to remember when designing a system for demanding service (P. Roberge, 2008, Avery et al., 1992):

1. Design for complete and free drainage
2. Eliminate or seal weld service
3. Make it easy to inspect.

Cathodic protection and corrosion inhibitors are also employed to protect some installations for water supply, cooling system and underground tanks and pipelines. Normally they are applied as a dual anti-corrosion system together with coatings, linings or paints.

8.2 Materials selection

Corrosion resistance is the main property to be considered in the choice of materials for such plant, but the final selection must be a compromise between technological and economic factors. It is sometimes more economical to use high-priced SS that will provide long and trouble-free service than to use a lower priced material that may require frequent maintenance or replacement.
Although the materials selection by trial and error frequently works, it does not always lead to an optimal or innovative decision. The evolution of computer and software has

revolutionized the availability of data bases on materials characteristics and performance. These data bases are integrated in smart system as tools for the design operation improving the materials selection required for a specific environment. The methodology created by Michael Ashby integrates in this way the materials selection to the design process (M. Ashby, 2005). In this model the material has attributes such as density, strength, electrical properties, costs, etc., that must be compared with those of real materials to find the best match.

8.3 Protective coatings

The coating of surfaces is so ancient as well as rock paintings in caves dated to be thirty thousand years old. They were done on the surface of granitic rock; an igneous, hard rock with a coarse – or medium – grained texture, rich in quartz and feldspar. The ancient painters took advantage of the natural, exfoliated, rough surface, with diminutive cracks, voids and hollows for the mechanical anchorage of its mineral-based paint applied as a paste or as slurry (B. Valdez et al, 2008). Varnishes were used by the Egyptians, polychrome sculptures were realized by the Greek hundreds of years BC and Romans used coatings for protective and decorative purposes.

The organic coatings form an excellent physical barrier between possible corrosive environments and metallic surfaces protecting the material from degradation and corrosion. The organic coatings include paints, resins, lacquers and varnishes, while the inorganic comprise enamels, glass linings and chemical conversion coatings. They are used in the FI protect the interior of cans, water tank containers, and the exterior of installations made with carbon and galvanized steel, concrete or wood.

For best results in corrosion protection coatings are commonly applied as a system composed by several layers that are classified as follow:

- Primer. Is the first coating applied to the substrate and has adhesive affinity for it and to provide if it is necessary a better adhesion for the subsequent coat layer.
- Intermediate coating. Is added when multiple thin layers are required. It is also called secondary coating when applied as top or final coat. Sometimes the intermediate is used to provide thickness to the coating film.
- Topcoats. It is the final layer applied to extend the life of the previous coatings. This film is more dense and hydrophobic in order to avoid the penetration of moisture to the underlying coats. Commonly provides an aesthetic appearance to the surface.

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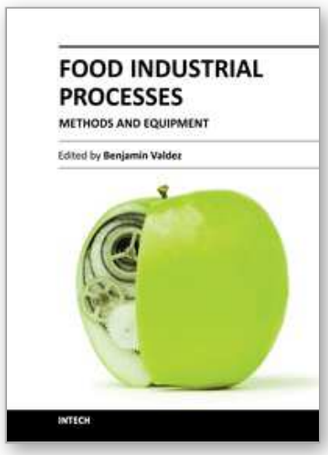
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The global food industry has the largest number of demanding and knowledgeable consumers: the world population of seven billion inhabitants, since every person eats! This population requires food products that fulfill the high quality standards established by the food industry organizations. Food shortages threaten human health and are aggravated by the disastrous, extreme climatic events such as floods, droughts, fires, storms connected to climate change, global warming and greenhouse gas emissions that modify the environment and, consequently, the production of foods in the agriculture and husbandry sectors. This collection of articles is a timely contribution to issues relating to the food industry. They were selected for use as a primer, an investigation guide and documentation based on modern, scientific and technical references. This volume is therefore appropriate for use by university researchers and practicing food developers and producers. The control of food processing and production is not only discussed in scientific terms; engineering, economic and financial aspects are also considered for the advantage of food industry managers.

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