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Appearance, management and prevention of corrosion in the brewing industry

In the food industry, the brewing sector is one of the most severely affected by corrosion. The process uses large quantities of water for beer production, bottling, storage and cleaning. The beer itself is acidic and aggressive to low carbon steel. Furthermore, it contains live microorganisms, which can cause biocorrosion. The cleaning agents used in the plant are also known to cause corrosion problems. Corrosion causes significant expenses, in terms of equipment damage. Moreover, corrosion products dissolved in the beer can cause impairment of its quality.

This paper deals with the appearance of corrosion in different stages of the brewing process, as well as with the methods of management and prevention of corrosion. Different types of materials used in breweries are analyzed, regarding their corrosion resistance. Also, the conditions of the process which may cause corrosion are considered. The corrosion control and prevention are reviewed through controlling the process parameters and selection of improved materials.

***Key words**: brewing industry, corrosion, causes and solutions*

1. INTRODUCTION

Production of beer is a process that involves different operations while processing raw materials, such as malt, water, hops and yeast, as well as adjuncts. The equipment cleaning is done by the use of various cleaning agents: sulphuric and phosphoric acid, caustic soda and chlorine and iodine for sterilization. For utility services, coal, fuel oil and ammonia are used. The brewing process consists of batch processing of different materials and it is conducted in strictly defined and controlled conditions [1].

Regarding the equipment, brew making is heterogeneous as well; the following materials are used: copper, stainless steel, coated mild steel and, in some cases, aluminum. Considering the fact that the process of brewing is complex, that the auxiliary operations are inevitable and the materials used for equipment production, there is general conclusion that in various points of the process there could be appearance of corrosion.

2. PRODUCTION OF BEER

Brewing is the production of beer through steeping a starch source (commonly cereal grains) in water and then fermenting with yeast. The process consists of few steps:

Malting is the process of preparing barley for brewing. It is comprised of three steps: steeping, germination and kilning.

Milling is cracking of the malted grains.

Mashing, which serves to convert the starch from the malting process, into sugar.

Lautering is separation of the wort from the grains.

Brewing is a complex process, in which wort is boiled when hops are added. During this step, a number of changes occur in the wort, such as coagulation of proteins, evaporation of the wort and flavor and color changes.

Cooling is the process of filtration and rapid cooling of the wort to a temperature suitable for adding the yeast.

Fermentation is the step in which the yeast metabolizes the substances that can be dissolved in the wort. Formation of ethanol, carbon dioxide and heat is characteristic.

Conditioning is the stage when the immature bear has to be held for a period of time to refine the flavor of the beer. During this process, hydrogen sulphide is released from the beer.

The last two steps are *filtration* and *packaging* of the mature beer.

3. APPEARANCE OF CORROSION IN THE BREWERY

Before determination of corrosion prevention and management methods, it is essential to identify the areas affected by corrosion. On Figure 1, schematic presentation of the processes in the brewery is given, and the critical points are marked. According to this, corrosion could appear in different places, such as the lauter tun, storage tanks, CO_2 recovery units, fermentation tank, etc., as well as in the equipment for auxiliary operations, i.e. CIP (clean-in-place) stations [2, 3].

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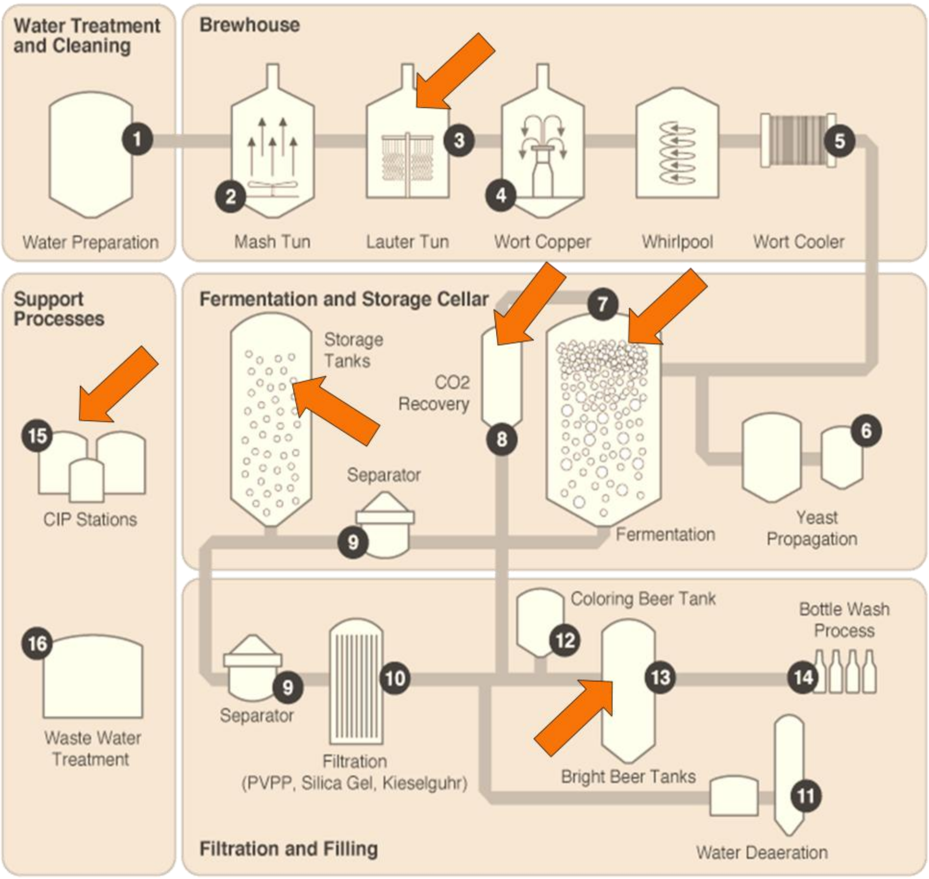


Figure 1 - Diagram of the brewing process with critical corrosion locations

The use of different materials in the lauter tun (e.g. steel for the vessel and brass for the false bottom), combined with the damaging of the internal floor coating, can cause forming of galvanic corrosion cells [2].

The fermentation tanks have more severe environments than the storage tanks. Today, most of these vessels are made from stainless steel, which provides satisfatory results, but materials such as low carbon steels are known to be used, also. The heating copper coils located in the tank, combined with a bare steel surface (on location with damaged coating), can result in aggresive corrosion of the steel in the acidic CO_2-saturated product [1].

Two examples of stainless steel tank corrosion are given on figure 2; appearance of a) pitting, b) cracks [4].

The corrosion in the CO_2 recovery plant often affects the gas side of the stainless steel piping, compressors and valves. Usually, it is caused by processed water, treated with ClO_2 in the brewery. The chlorine dioxide acts as an oxidizing agent and undergoes the following reaction:

$$ClO_2^- + 2H_2O + 4e^- \rightarrow Cl^- + 4OH^- \ (E^0 = 0.76 \text{ V})$$

This spontaneous reaction causes corrosion in the CO_2 recovery plant.

The agents used for cleaning of the equipment and piping are also associated with corrosion. Corrosion only occurs under harmful circumstances, such as rapid thermal changes (which are an underlying cause for tank implosion) and contact of CIP acid with dirty surfaces (which causes pitting corrosion) [5]. Under the described conditions, the disinfectant will oxidize the metal surface, as described by the following reduction half-reaction:

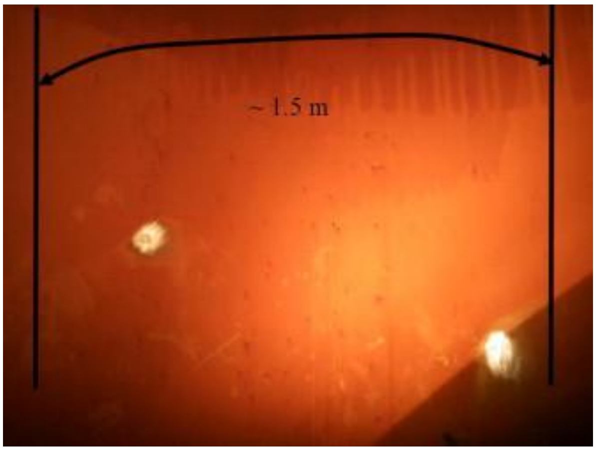
$$OCl^- + H_2O + 2e^- \rightarrow Cl^- + 2OH^- \ (E^0 = 0.89 \text{ V})$$

In this reaction, hypochlorite is shown as the oxidizing agent, but in fact, there are other cleaning agents that could be used instead (e.g. peractetic acid, hydrogen peroxide and chlorine dioxide). The hypochlorite is also an inhibitor of bacterial corrosion that kills the bacteria before they are involved in the corrosive damage. For this reason, this process is not affected by microorganisms.

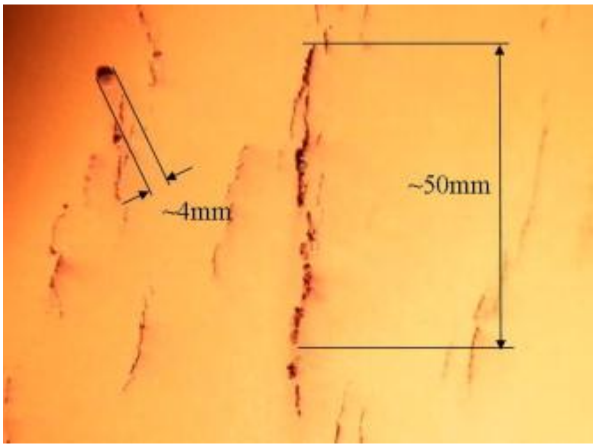
The oxidation half-reaction of brewery-related metal (e.g. steel) would be:

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^- \ (E^0 = 0.44 \text{ V})$$

The overall reaction potential is 1.33 V, which means that this reaction occurs spontaneously.



a)



b)

Figure 2 - Examples of corrosion in stainless steel tank

3.1 Common materials in the brewery and their corrosion

Every brewery has various types of equipment, ranging from standard power plant equipment (boilers, condensers, etc.) to specific sophisticated laboratories for handling yeasts, malts and hops essences. This wide range of equipment implies use of different metals and special alloys.

Any metal in direct contact with the beer should not react to produce off-flavors. This is the main reason that stainless steel is commonly used. These steels are acid resistant and do not taint the product. Other metals and alloys used in the brewery are: brass, copper, aluminum and mild steel [6, 7].

3.1.1 Steel

Because iron affects the shelf-life of beer, steel is not a major material for construction of equipment which is in direct contact with the product. Steel can be used as a material for less important auxiliary equipment or combined with linings or coatings for brewery equipment (e.g., epoxy-lined fermentation and storage tank) [6, 8].

3.1.2 Stainless steel

Most of the brewery equipment currently used is fabricated from the 300 series alloys (AISI 304 or 316) [9] and includes kettles, tanks, tubs, plate coolers, and even some pasteurizers [2]. These alloys are much more corrosion resistant and, when passivated, are essentially inert to the beer. However, the one weakness of the stainless steel is chlorine, which is a common ingredient in cleaning solutions [1, 5-7].

Active chlorine present in bleach solutions can cause the protective oxide layer on stainless steel to deteriorate; if there is a scratch on the wall, or a crevice created by a rubber gasket against the steel, then these areas can become electrically different from the surrounding area, creating a galvanic cell, which leads to crevice corrosion [7]. The corrosion develops following the mechanism described in the previous section. This type of corrosion can occur when the bleach water is still in the vessel i.e., not circulating, or, at the water surface, if the keg is only half-full. In the latter case, the crevice is represented by the waterline. Usually, this type of corrosion manifests as pitting or pinholes.

Bio-fouling and beerstone scale (CaC_2O_4) can cause the same corrosion phenomena. The metal surface underneath the deposit becomes depleted of oxygen via biological or chemical means, and corrosion occurs [7, 8]. This is the main reason why the removal of beerstone is important.

3.1.3 Copper

Because of its properties, copper has been the traditional metal in breweries for centuries. However, with the advent and the use of new alkaline cleaners, some corrosion issues have arisen. Copper is relatively inert to both wort and beer; with regular use, a stable oxide layer will form on the vessel wall, which will protect it from further interaction with the product [2, 6].

However, copper can develop a toxic oxide called verdigris. Verdigris includes several chemical compounds – cupric acetate, copper sulfate, cupric chloride, etc., which are soluble in weakly acetic solutions, like beer, and can lead to copper poisoning [8]. Because of this, proper cleaning of the copper vessels is required.

In general, copper is more acid than alkaline resistant. Oxidizers such as bleach and hydrogen peroxide will cause blackening of copper and brass due to formation of black oxides [7]. When these oxides are removed, a new metal surface is exposed to corrosion. For this reason, alkaline cleaners, such as ammonia and oxidizers, which are very useful for dissolving organic deposits, should be used with caution. Copper is not resistant to oxidizing acids and non-oxidizing acids containing dissolved oxygen. Usually, it is resistant to non-oxidizing acids, such as acetic, hydrochloric and phosphoric acids [2, 7].

3.1.4 Brass

Brass is an alloy of copper and zinc, which also contains a small percent of lead, for improved machinability. The present lead can be dissolved by the wort and although this small amount of lead does not present a health issue, the best solution is to avoid the use of leaded brass altogether [6, 8].

The reason that brass fittings are not commonly used in commercial breweries is that the CIP systems and the chemicals used with stainless steel are too corrosive to brass.

3.1.5 Aluminum

Aluminum has many favorable properties – good formability, machinability and thermal conductivity. The most commonly used alloys are 3003 and 3004, which have very good corrosion resistance [6, 8]. Under normal brewing conditions, aluminum by itself will not corrode and does not affect the product in any way.

However, aluminum will corrode if placed adjacent to another metal (e.g., copper) submerged in wort or beer; aluminum and brass or copper couples should not be used for long term storage of beer [8]. The use of casting cleaners and bleach should be avoided, because they will cause pitting.

4. CORROSION CONTROL IN THE BREWING PROCESS

Beer is corrosive; not only it is acidic, but it also contains live organisms that cause biofouling and biocorrosion [1, 7]. Beer can be corrosive to the tanks and fluid lines used in the brewing process, as well as to the brewing building.

The only way to control corrosion during the brewing process is to control the pH value. This parameter depends on multiple factors, such as yeast strain, water hardness, bacterial infection and the process itself [7].

The pH value of the beer is about 4 when fresh, but when exposed to oxygen, for example, after dispense, this value can drop to 3.5 – 3.3 and even bellow 3 [10-13]. These acidity levels usually do not affect stainless steel, which is not the case with aluminum alloys. These materials' oxide layers are attacked by any pH less than about 4 or over about 9. The pH values of common fluids in brewing industry are given in table 1 [13].

Table 1 - Most common fluids in the brewery

pH	Fluid
1.0	Hydrochloric acid
2.2	Lactic acid
3.3 – 3.7	Wheat beer
4.4 – 4.7	Lager beer
5.5	Unfermented beer
7 – 8	Tap water
8.5	Sodium carbonate
13	Caustic soda

Because of this, the aluminum containers are lined with protective coatings. However, if the coating is damaged, the broken down coating flakes can get into the extractor valves, and more important, the keg itself can be corrosively attacked. This is most expressed on the welded joints and can compromise the vessel's integrity [7].

Acidity is usually expressed in terms of lactic acid, although there is great number of other organic and inorganic acids present. The acidity levels should be maintained at constant values, but slight fluctuations can be expected. This parameter can be affected by the various strains of yeast, as well as improper wort aeration, but it also depends on the character of the product.

Although the highlight of this paper is on preservation and protection of the equipment, the most important concern is the final quality of the product. For this reason, the best solution would be to establish a balance between these two aspects. From the beginning, through the entire process of beer production, the pH value fluctuates, depending on the different phases. Various factors can contribute towards higher or lower pH values [5].

The increase of pH can be caused by cold fermentation coupled with a reduced assimilation of buffering substance by yeast, use of water high in carbonates, as well as by a number of other factors. Lower pH can be expected in all-malt beers, yeast that tends to flocculate early, a slight upward adjustment of pitching temperatures and of the maximum temperature during fermentation, etc [10-13].

The pH value should be maintained in optimal range in every stage of the process; this can be achieved by balancing these factors with opposite effects. The process should be properly executed, to avoid large pH variations, which would also contribute to higher quality of the final product.

5. CORROSION PREVENTION IN THE BREWING INDUSTRY

The corrosion prevention methods are the best way to eliminate corrosion in the breweries. This can be accomplished in several ways:

- Use of special alloys – several alternative corrosion resistant alloys are available. The corrosion and stress corrosion cracking of the stainless steels from the 300 series can be prevented by use of type 444 or 446 ferritic stainless steel [2]. These alloys are also more resistant to biofouling conditions than 304 [7].
- Use of coatings and linings – these materials provide effective protection of the metal surface and serve as a barrier between corrosive environment and metal. The coatings and linings are safe and do not affect the quality of the final product.
- Use of inhibitors in wastewater – this method is a good way for corrosion prevention in the waste treatment facilities, which are especially subjected to aggressive conditions.
- Use of cathodic protection – this technique can be very effective in such equipment as the bottle-line pasteurizer. Cathodic protection works very well in preventing galvanic and biological corrosion. However, one problem when applying this technology is the possible formation of oxygen as a by-product on the cathode [2, 7].

The most common types of corrosion found in the brewing industry are: pitting, crevice and intergranular corrosion, as well as biofouling and biocorrosion, to a lesser extent [1, 5, 7, 9].

Pitting and crevice corrosion can be prevented by control of the alloy's environment. This can be achieved with good welding preparation, choosing appropriate steel grade for corrosive environments, as well as appropriate post-welding treatment [5, 9].

Prevention of intergranular corrosion can be accomplished in several ways: treatment at high temperatures (> 1050^{o}C) and rapid cooling, which enables precipitation of carbides, reduction of carbon content and addition of titanium and niobium, which reduces or stops the diffusion of carbon across grain boundaries [5].

6. CONCLUSION

Beer production process is complex one from aspect of corrosion – many different materials are used and various types of fluids and environments are included.

Corrosion in the brewing industry is important from several major points of view: expenses, health and safety and risk management.

When corrosion occurs in the brewing equipment, financial expenses can include repair and replacement of the equipment, resulting in loss of product or efficiency and contamination of the product.

Beer is a food product, which means that the quality of the product must be in accordance with the international food quality standards. Corrosion in the brewery equipment produces metal ions that dissolve in the liquid product. Furthermore, if there is severe corrosion, there is potential for mechanical failure of the metal, resulting in a safety risk for the employees.

Corrosion presents a major risk to an industry and therefore, companies need to follow industrial risk assessment techniques in order to prevent it from having negative economic, environmental and safety repercussions. This is why it is important to understand corrosion, and the chemistry behind it – in order to prevent its occurrence.

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IZVOD

POJAVA, UPRAVLJANJE I PREVENCIJA KOROZIJE U INDUSTRIJI PIVA

U prehrambenoj industriji, sektor proizvodnje piva je jedan od najteže pogođenih korozijom. U samom procesu se koriste velike količine vode za proizvodnju piva, flaširanje, skladiranje i čišćenje. Samo po sebi, pivo je kiselo i agresivno u odnosu na niskolegirani ugljenični čelik. Osim toga, pivo sadrži žive mikroorganizme koji mogu da izazovu biokoroziju. Sredstva koja se koriste za čišćenje postrojenja isto tako mogu da prouzrokuju probleme sa korozijom. Korozija izaziva velike troškove, u smislu oštećenja opreme. Povrh toga, korozioni produkti rastvoreni u pivu mogu da umanje kvalitet finalnog proizvoda.

Ovaj rad se bavi pojavom korozije u različitim fazama procesa proizvodnje piva, kao i proučavanjem metoda upravljanja i prevencije korozije. Analizirani su različiti tipovi materijala koji se koriste u pivarama, sa aspekta njihove korozione otpornosti. Takođe, razgledani su uslovi procesa koji mogu da izazovu koroziju. Takođe su razgledani upravljanje i prevencija korozije putem kontrolisanja procesnih parametara i selekcije poboljšanih materijala.

Ključne reči: *industrija proizvodnje piva, korozija, uzroci i rešenja*

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