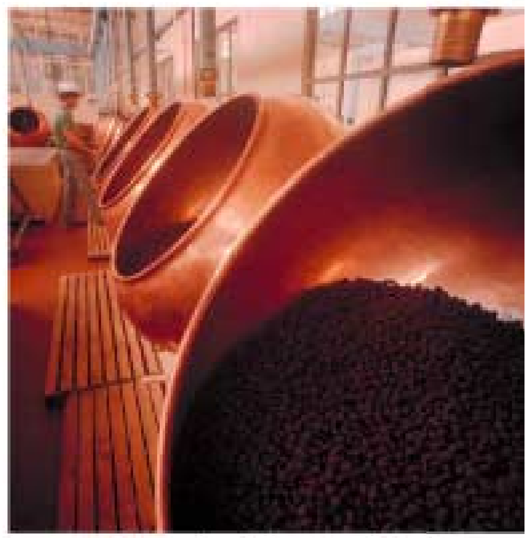
APPENDIX Y

FOOD PROCESSING

Stainless steel tanks for beer storage

Stress-induced cracking

Cracked weld in stainless steel



Copper vessels for chocolate manufacturing

Reactor vessel

FOOD PROCESSING

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SUMMARY

Product quality, health, and sanitation issues are major concerns in the food-processing industry. The industry cannot tolerate corrosion deposits in the manufactured product. The industry, therefore, needs to account for corrosion control before production starts. Stainless steel consumption and cost in food processing is attributed to corrosion control and prevention. The total estimated stainless steel cost for the food-processing industry is $1.8 billion per year. This cost includes stainless steel utilized in beverage production, food machinery, cutlery and utensils, commercial and restaurant equipment, and appliances. The annual cost of aluminum cans is $250 million and the annual cost for corrosion inhibitors in the food-processing industry is approximately $50 million. Therefore, the total estimated cost of corrosion in this sector is $2.1 billion per year.

Maintenance management systems are implemented in food-processing plants to monitor machine production histories, downtime, and reliability to prioritize equipment and maintenance problems. Reliability-based maintenance (RBM) teams are used in conjunction with maintenance management systems to predict maintenance needs and conduct root-cause analyses of food-processing equipment failures. Strategic maintenance programs are part of the plant's overall vision of the future, which aims at boosting production efficiency.

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SECTOR DESCRIPTION

The food-processing industries are among the largest manufacturing sectors in the U.S. economy, accounting for approximately 14 percent of the total U.S. manufacturing output. From 1972 to 1987, the number of food-processing facilities has declined from 28,193 to 20,583 (a 27 percent decrease). Since 1992, the number of facilities has increased again to 20,792 (a 1 percent increase).[(1)] According to composite statistics, sales for public food-processing companies were $265.5 billion in 1999. Sales are projected to increase to $315 billion in 2001.

In the 2000 manufacturing survey conducted by *Food Engineering*, food-manufacturing professionals in top management, production management, engineering, quality control, packaging, and purchasing across every segment of the industry were interviewed on the improvements needed in food-processing facilities. The results show that improvements on equipment (17.9 percent of the total respondents) and maintenance systems (65.4 percent of the total respondents) need more attention.[(2)] According to 24 percent of the total respondents, the results show that 25 percent or more of the budget is allotted for purchasing production, packaging, or process control equipment. Improvements on equipment include selection of corrosion-resistant materials with surface finishes and replacement of parts or components. Improvements on maintenance systems require implementing a schedule program where food-processing systems are routinely checked for failing parts due to corrosion or mechanical problems.

The number of U.S. food plant construction projects in 1999 was 753, compared with 327 construction projects in 1994. Table 1 shows a summary of the total number of projects, renovations and expansions, and new plants from 1994 to 1999. In 1999, 68 percent of the total construction projects consisted of plant expansions or renovations.[(2)] Renovations and expansions can include an increase in installation of improved equipment for optimal process operation and new processes.

Table 1. U.S. food plant construction projects from 1994 to 1999.[(2)]

YEAR	TOTAL NUMBER OF PROJECTS	RENOVATIONS/ EXPANSIONS	NEW PLANTS
1994	329	188	141
1995	406	250	156
1996	485	286	199
1997	756	484	272
1998	867	557	310
1999	753	512	241

DESCRIPTION OF FOOD-PROCESSING COMMODITIES

In the food-processing industry, product quality is the key issue. Corrosion products are not acceptable in the food product due to health reasons; therefore, almost all production equipment is fabricated from corrosion-resistant material. The New Mexico Environmental Improvement Board defines a corrosion-resistant material as “a material that maintains its original surface characteristics under the prolonged influence of the food, cleaning compounds, and sanitizing solutions that may contact it.”[(3)] Food-processing equipment includes stoves, ranges, hoods, meat blocks, tables, counters, refrigerators, sinks, dishwashing machines, and steam tables.

The processed-foods sector is much larger than the farm sector in both total value of production and international trade. Distinctions are made between agricultural products and processed foods at both the producer and the consumer levels. Agricultural production is based on abundant fertile land and favorable farm structure; however, the food-processing industry emphasizes technology and convenience for consumers.

U.S. processed-foods commodities include processed seafood, fresh meat products, frozen specialties, bottled/canned soft drinks and carbonated waters, frozen bakery products, prepared flour mixes and dough, distilled and blended liquors, macaroni and noodles, and ice cream and frozen desserts. The largest food-processing industry groups are meat products and grain mill products.

AREAS OF MAJOR CORROSION IMPACT

The corrosion environment in the food and beverage industry involves moderately to highly concentrated chlorides, often mixed with significant concentrations of organic acids. The water side of the processing equipment can range from steam heating to brine cooling. Purity and sanitation standards require excellent corrosion resistance to pitting and crevice corrosion. Sulfiting agents producing sulfur dioxide when used to treat foods include sodium sulfite, sodium bisulfite, potassium bisulfite, sodium metabisulfite, and potassium metabisulfite. All are generally corrosive to food-processing equipment.

Underdeposit Corrosion

Underdeposit corrosion is likely to occur in cooling systems where scales or foulants exist. The presence of general fouling and scales can cause the formation of a differential cell, which begins the process of corrosion. Due to the difference in oxygen concentration at the metal surface beneath the deposit and the oxygen concentration in the water, a differential cell forms, resulting in the corrosion reaction.

The food-processing industry uses water for washing, transporting, blanching, cooking, cooling, and cleaning. In particular, heating and cooling processes require large amounts of water. Underdeposit corrosion is caused by using water in boilers, rotary cookers, and hydrostatic sterilizers.

Aluminum alloys are susceptible to underdeposit corrosion. Stainless steels are also susceptible to underdeposit corrosion, as well as deep pitting. Anodic, cathodic, and filming inhibitors are used to mitigate corrosion.[4]

Biocides such as chlorine dioxide and bromine compounds (oxidizers) are used for sterilization; however, these chemicals can interfere with the performance of the inhibition system. In order to prevent corrosion, the concentration of biocides into the water stream must be controlled.

Galvanic Corrosion

Galvanic corrosion is an accelerated attack between two dissimilar metals that are coupled in electrical contact and exposed to an electrolyte. For example, in hydrostatic sterilizers, the flight bars are made from aluminum or stainless steel, the transport chain is made from carbon steel, and both are exposed to hot water and steam.[4] The less noble metal of the couple is susceptible to galvanic corrosion. In the case of aluminum and carbon steel, the aluminum is less noble and, therefore, will corrode. Replacement of chains and flight bars can cost up to $250,000 in a typical commercial sterilizer.

Stress Corrosion Cracking

Stress corrosion cracking (SCC) in types AISI 304 and AISI 316 stainless steel piping and tanks is a problem in water lines in brewery applications.[5] A common form of stress corrosion cracking occurs at temperatures higher than ambient in the presence of chlorides. Duplex stainless steels and alloys containing molybdenum alloys are used as alternatives that are more resistant to stress corrosion cracking. Cracking may occur from the process or from the outside, for example under insulation. Reducing the amount of oxygen ingress and lowering the process temperature minimizes the possibility of stress corrosion cracking.

CORROSION CONTROL METHODS

Corrosion-Resistant Materials in the Fabrication of Food-Processing Equipment

A variety of materials are being used for food processing, depending on the type of food and the processing conditions, such as temperature and pH values Stainless steels and aluminum alloys are the primary materials used in food processing. Plastics and other metals may be used; however, lead- and cadmium-plated materials may impart toxic substances into foods.(6) Food contact surfaces must be smooth, non-adsorbent, non-leaching, and insoluble in the food.

Stainless Steels

Stainless steel is very resistant to corrosion in food-processing environments. Although stainless steel is generally resistant to corrosion, it is not immune in a chloride-containing environment. Corrosion is a problem in stainless steels when exposed to chlorine, commonly used to sanitize equipment, and hydrochloric acid, used in some cleaning agents and processing liquids. Corrosion products should be removed immediately because they impede proper cleaning of surfaces.

Table 2 shows the total stainless steel consumption used to manufacture food equipment and machinery and the estimated cost for stainless steel. The stainless steel consumption in the food-processing industry is approximately 15.3 percent (370,000 tons) of the overall stainless steel market of 2.4 million tons per year.(7)

The price per pound of each stainless steel increases with more complex geometry. The price per pound for 2,600 lb of type 316 stainless steel was used to determine the estimated cost for stainless steel in the food-processing industry. The price per ton for each type was the following: (1) sheet and strip = $2,620 per ton ($1.31 per lb), (2) plate = $2,500 per ton ($1.25 per lb), (3) bar = $10,820 per ton ($5.41 per lb), and (4) pipe and tube = $22,300 per ton ($11.15 per lb).(8-10) The estimated total cost of stainless steel for the food-processing industry was determined to be approximately $1.8 billion, which is only a portion of the total cost for the food-processing industry.

Table 2. Annual tonnage and cost of stainless steel specified by final form in the United States, as reported by the Specialty Steel Industry of North America in 1998. (See references 7 through 10.)

FOOD EQUIPMENT	**SHEET & STRIP**		**PLATE**		**BAR**		**PIPE & TUBE**		**TOTAL COST**
	$2,620 / ton		**$2,500 / ton**		**$10,820 / ton**		**$22,300 / ton**		
	tons	**$ x million**	**tons**	**$ x million**	**tons**	**$ x million**	**tons**	**$ x million**	**$ x million**
General	8,854	23.2	2,528	6.3	3,198	34.6	4,490	100.1	164.2
Beverage	6,566	17.2	64	0.2	10	0.1	-	-	17.5
Food Machinery	139,618	365.8	25,157	62.9	21,974	237.8	18,490	412.3	1,078.8
Food Service Machinery	43,614	114.3	5,940	14.9	3,215	34.8	4,093	91.3	255.2
Cutlery/Utensil	38,102	99.8	-	-	6,887	74.5	-	-	174.3
Commercial/Restaurant Equipment	15,269	40.0	60	0.2	-	-	-	-	40.2
Appliances	21,974	57.6	37	0.1	-	-	-	-	57.7
TOTAL TONNAGE	**273,997**		**33,786**		**35,284**		**27,073**		**370,140**
TOTAL COST		**$717.9**		**$84.5**		**$381.8**		**$603.7**	**$1,787.8**

1 ton = 1,000 kg

Aluminum

Aluminum is also often used in processing equipment and is much less expensive than stainless steel; however, it is not as strong or as durable. Aluminum alloys are commonly used in the processing, handling, and packaging of foods and beverages. Approximately a quarter of all aluminum goes into packaging. In addition to high corrosion resistance, many of these applications depend on the nontoxic nature of aluminum and its salts, as well as freedom from catalytic effects that cause product discoloration.(11)

Aluminum cans contain internal and external coatings, primarily for decoration and protection of product taste. Oxygen is also removed before the can is filled with the product. This prevents the can from oxidizing and from the potential risk of toxicity.

Its shiny appearance, the relatively low weight per volume, and favorable mechanical properties, such as material strength and ease of forming and handling, are some of the many reasons for using aluminum for food packaging. In addition, aluminum has superior corrosion resistance over coated carbon steel because it forms a naturally protective oxide on its surface, which effectively prevents further atmospheric corrosion from occurring. Also, aluminum is lighter than, for example, stainless steel; therefore, aluminum is the preferred material used in beverage cans. In 1996, 99 billion aluminum cans were produced and 63.5 percent of these cans were recycled.(12) In comparison, the U.S. steel industry remelted nearly 19 billion steel cans in 1996, which is 58 percent of the total 33 billion steel cans produced. If 0.45 kg (1 lb) of aluminum cans yields 29.51 cans, approximately 1.54 billion kg (3.4 billion lb) of aluminum were consumed.(13) Assuming that the price of 1 kg of aluminum is $1.62 ($0.73 per lb),(14) the total cost of aluminum consumption for 99 billion cans is $2.5 billion. If it is assumed that 10 percent of the aluminum consumption is due to corrosion, then the direct corrosion cost can be estimated at $250 million per year.

Corrosion Inhibitors

Inhibitor technology has been introduced for harsh environments encountered in equipment such as rotary cookers and hydrostatic sterilizers. They are exposed to hot water, steam, and cooling water. A single approach to treating these systems will not provide adequate protection. Combinations of anodic, cathodic, and filming inhibitors are selected for corrosion prevention, depending on the water composition and equipment material.

The cost of inhibitor consumption depends on the water quality and quantity, the size of the equipment, and the operation time. A food-processing industry expert provided a cost estimate for a food plant operating nine rotary cookers and five hydrostatic sterilizers. The plant treats the potable water and hot water system for corrosion protection. Based on the annual cost divided by the annual water usage, the scale/corrosion protection cost would average about $2.50 to $3.00 per 3,785 L (1,000 gal) of water used in the plant for these systems.(4) Therefore, the annual corrosion cost associated with inhibitor use of this plant is between $2,500 and $3,000. Extrapolation of this cost to the approximately 20,000 food plants currently in operation results in a total inhibitor cost ranging from $50 million to $60 million per year.

Coatings

Coatings used in food-processing plants must withstand high-pressure cleaning and microbial attack. Microbial attack is a major maintenance problem in breweries and beverage bottling plants. Antimicrobial additives are used in order to control bacterial activity and growth. Urethane coatings instead of epoxy coatings are preferred in the food-processing industry because they are resistant to cleaning compounds.(15)

Calculating the Cost of Corrosion

In summary, the total estimated stainless steel cost for the food-processing industry is $1.8 billion per year. The annual cost for aluminum cans is $250 million per year, and the annual cost for corrosion inhibitors in the food-processing industry is approximately $50 million per year. Therefore, the total estimated cost of corrosion is $2.1 billion per year.

CORROSION MANAGEMENT

Maintenance management systems are implemented in food-processing plants to monitor machine production histories, downtime, and reliability to prioritize equipment and maintenance problems. Reliability-based maintenance (RBM) teams are used to predict maintenance needs and to analyze the root cause of food-processing equipment failures. Strategic maintenance programs are part of the plant's overall vision of the future, which aims at boosting production efficiency.

CHANGES FROM 1975 TO 2000

To meet consumer needs, food-processing companies are expanding and renovating their facilities in order to improve operating efficiency. Food manufacturing has undergone technological changes, including aseptic processing and microwaveable processing. Thus, there is a great demand for technology and machinery to meet consumer demand.

Food manufacturers' continuous efforts to boost income and market share through acquisitions, overseas growth, cost controls, and new-product development have resulted in prosperous economic times. Many companies are restructuring to consolidate operations after acquisitions. According to the Food Institute, food manufacturing mergers and acquisitions reached a record 288 in 1999, continuing an upward trend throughout the decade.

The brewery industry has realized that it is more cost-effective to select corrosion-resistant materials than to use coatings and cathodic protection on the processing equipment. In the 1980's, cathodic protection was used on pasteurizers made from mild steel;[(5)] however, modern pasteurizers are protected from corrosion by selecting AISI 304 stainless steel instead of using cathodic protection. Inhibitors are used to eliminate underdeposit. Coatings are avoided due to concern about product contamination.

The food-processing business focuses on product quality and mass production. Food-processing equipment is designed for low failure rates and long life expectancy; therefore, equipment replacement rates and costs are kept to a minimum.

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