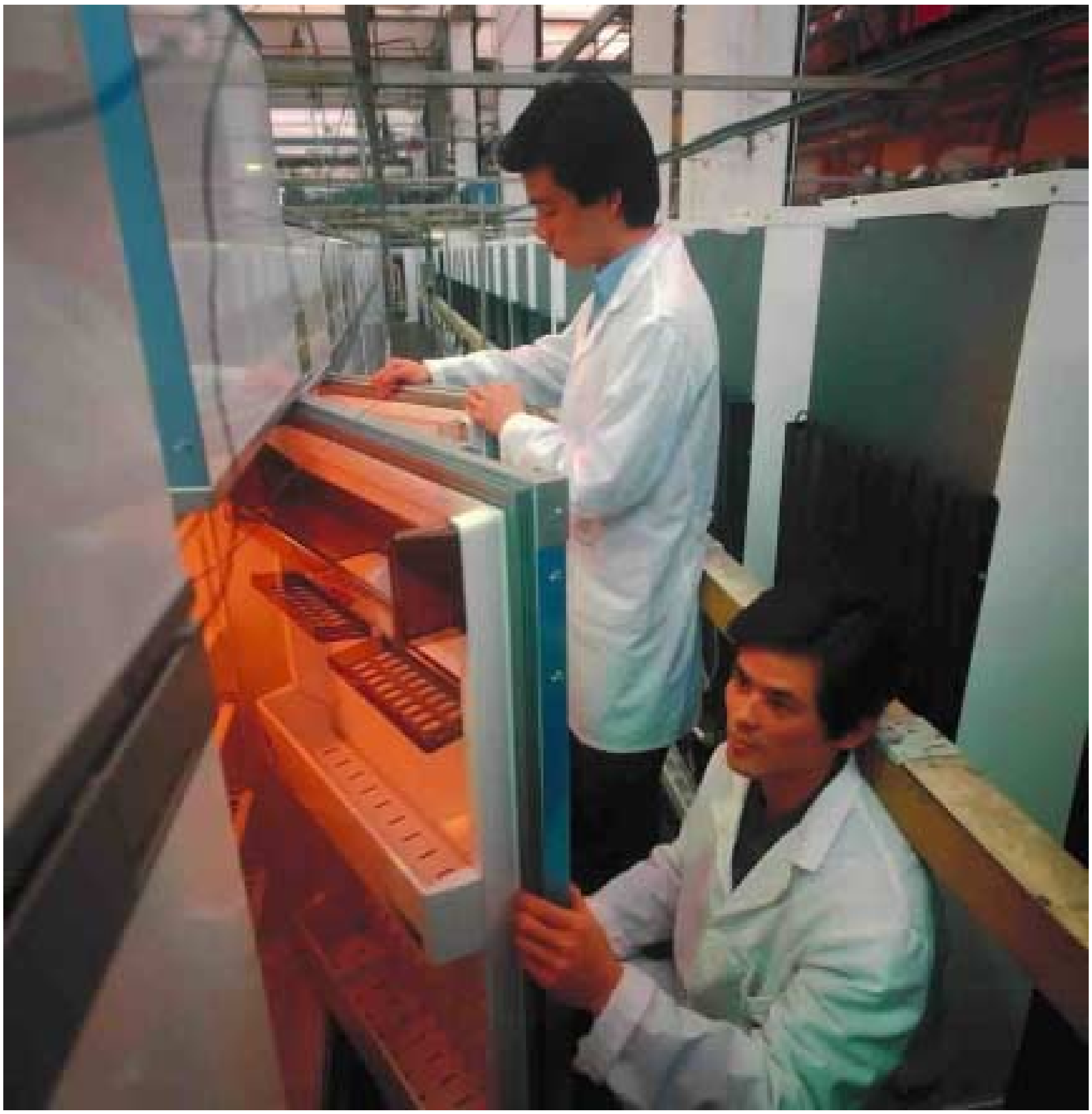
APPENDIX AA

HOME APPLIANCES



Refrigerator and water cooler

Stove

Comparison of a new anode and a spent anode

HOME APPLIANCES

MICHIEL P.H. BRONGERS[1] AND IVELISSE TUBENS[1]

SUMMARY

The appliance industry is one of the largest consumer product industries. For practical purposes, two categories of appliances are distinguished: "Major Home Appliances" and "Comfort Conditioning Appliances." In 1999, 70.7 million major home appliances and 49.5 million comfort conditioning appliances were sold in the United States, for a total of 120.2 million appliances.

The average consumer buying an appliance is only marginally interested in corrosion issues; therefore, during the useful life of the appliance, no corrosion management is done by consumers. For example, very few people realize that there is an anode in every water heater, and that this sacrificial bar of metal should be checked and, if necessary, replaced with a new one to prevent water heater failure due to internal corrosion. The life expectancy of appliances is determined from past experience and sales data. Improved corrosion design for appliances can increase their life expectancy; however, if improved corrosion protection would mean the use of more expensive components for the appliances, then consumers may not be interested.

A corrosion cost calculation was made for the sacrificial anodes in the 104 million water heaters in the United States. The benefits of anode maintenance are longer tank life, less rust build-up, and savings on costly changeovers. The increased life expectancy from anode maintenance can save consumers money. However, a cost-benefit analysis may show that the cost of replacing anodes could exceed the benefits of increased life expectancy and postponing water heater replacement. The annual cost of replacing water heaters was estimated at $460 million per year, the cost of anode replacement was estimated at $780 million per year, and the cost benefit of a hypothetical design improvement that would increase the life expectancy of water heaters by 1 year was estimated at $778 million per year.

A corrosion cost calculation was also made for the annual coating costs of the 120.2 million newly purchased major appliances in the United States. Based on an estimated installed cost for coatings of $2 per appliance, the total cost is approximately $240 million per year. The cost of $2 is a marginal value in the average cost of appliances. Therefore, this cost is probably worth spending because of the more appealing appearance of non-corroding appliances. On the other hand, the internal components of appliances, those that are not directly visible to consumers, should be protected from corrosion as well. For example, the above calculation does not consider the application of internal coatings, such as galvanizing steel, for longer life.

The assumptions made in the anode calculations and the coating calculations are only approximations, and no adjustment is provided for the use of corrosion-resistant materials in most appliances. It is recognized that the estimates are probably not very accurate, because of the large variety in appliances. Considering the significant costs of appliances to consumers, and the fact that the potential savings from longer life expectancies can be considerable, it is recommended that a broad study, including a full analysis of statistical data, be performed to research the potential cost-savings related to the increased life expectancies of appliances.

[1] CC Technologies Laboratories, Inc., Dublin, Ohio.

In summary, the cost of corrosion in home appliances is very significant. The first cost is the purchase of replacement appliances because of premature failures due to corrosion. It is evident that water heater replacement is often attributed to corrosion. For water heaters alone, this cost was estimated at $460 million per year, using a low estimate of 5 percent of the replacement being corrosion-related. The cost of internal corrosion protection for all appliances includes the use of sacrificial anodes ($780 million per year), corrosion-resistant materials (no cost estimate), and internal coatings (no cost estimate). The cost of external corrosion protection using coatings was estimated at $260 million per year. Therefore, the estimated annual total cost of corrosion in home appliances is at least $460 million + $780 million + $260 million = $1.5 billion per year.

TABLE OF CONTENTS

LIST OF TABLES

SECTOR DESCRIPTION

This sector describes the U.S. home appliances industry and the estimated cost of corrosion for this industry. In this sector, the focus will be on those appliances that people have in their homes, and will not be on commercial appliances, such as those used in warehouses, office buildings, or restaurants. More information on commercial equipment used in manufacturing environments is given in the sectors titled "Chemical, Petrochemical, and Pharmaceutical Industries" (Appendix V); "Agricultural Production" (Appendix X); and "Food Processing" (Appendix Y) of this report.

Home appliances are an integral part of the American lifestyle, providing convenience and high-quality performance for cooking, washing, cleaning, heating, or cooling purposes. Appliances save time, sanitize, and contribute to safety and conservation in the course of any daily chores. The appliance industry is one of the largest consumer product industries.

Every year, *Appliance Magazine*(1) publishes an annual report on the number of appliance unit shipments in the United States. In this review, a distinction is made between "Major Home Appliances" and "Comfort Conditioning Appliances."

MAJOR HOME APPLIANCES	**COMFORT CONDITIONING APPLIANCES**
Microwaves	Fans
Ranges	Air conditioners
Refrigerators	Humidifiers
Water heaters	Furnaces
Washers	Portable heaters
Dryers	Heat pumps
Dishwashers	Dehumidifiers
Food waste disposers	Room heaters
Freezers	Boilers
Water softeners	
Trash compactors	
LP ranges and cooktops for RVs	

In the current sector description, both categories will be described, because both are equally important in maintaining a home and everyday comfort of living. In addition, the costs for both types of appliances are fully paid by their individual owners. Table 1 and table 2 show the trends of (new) appliance shipments over the last 25 years. In 1999, 70.7 million major home appliances and 49.5 million comfort conditioning appliances were sold in the United States, for a total of 120.2 million appliances.

Table 1 shows a summary of the number of new major home appliances shipped annually for the period 1975 to 1999. The table shows that microwaves, ranges, and refrigerators are the leading appliances in sales, followed by water heaters, washers, dryers, dishwashers, and food waste disposers. Smaller quantities are sold of freezers, water softeners, and trash compactors. The table also shows that the sales of microwaves have increased from 0.79 million in 1975 to 11.6 million in 1999. The growth in sales for the other appliances has been less dramatic, but the sales of almost every appliance have seen an increase of approximately 100 percent in the last 25 years. The sales of freezers and trash compactors have decreased.

Table 1. Statistical review of unit shipments of new major home appliances (excluding commercial appliances) in the United States for years in the period 1975 to 1999, as reported in annual reports of *Appliance Magazine*.[1-3]

APPLIANCE	1975	1980	1985	1990	1995	1999	CHANGE 1975-1999
	Quantity	Quantity	Quantity	Quantity	Quantity	Quantity	%
Microwaves	790,000	3,320,000	10,883,000	9,276,330	8,975,000	11,581,085	+1,366
Ranges	5,077,400	6,468,500	7,952,000	8,322,800	9,641,500	11,118,600	+119
Refrigerators	4,895,000	5,667,000	6,863,500	8,033,800	9,825,500	10,737,383	+119
Water heaters	4,828,510	5,269,284	6,981,214	7,132,585	8,370,330	9,214,858	+91
Washers	4,478,000	4,816,000	5,581,500	6,536,100	7,101,100	7,508,200	+68
Dryers	3,060,000	3,383,000	3,913,500	4,595,100	5,384,600	6,477,700	+112
Dishwashers	2,702,000	2,738,000	3,575,400	3,636,900	4,553,500	5,711,200	+111
Food waste disposers	2,080,000	2,962,000	4,105,000	4,137,200	4,518,900	5,369,400	+158
Freezers	2,736,000	2,062,000	1,235,800	1,296,000	1,690,500	1,987,200	-27
Water softeners	-	-	-	574,133	717,542	951,498	-
Trash compactors	233,000	235,000	177,200	185,000	98,400	114,700	-51
LP ranges and cooktops for RVs	-	123,896	-	-	-	-	-
TOTAL	**30,879,910**	**37,044,680**	**51,268,114**	**53,725,948**	**60,876,872**	**70,771,824**	**+129%**

Table 2 shows a summary of the number of new comfort conditioning appliances shipped annually, for the period 1975 to 1999. This table shows that air fans, air conditioners, and humidifiers are the leading appliances in sales, followed by furnaces, heaters, and heat pumps. Smaller quantities are sold of dehumidifiers, room heaters, and boilers. The table further shows that sales of humidifiers have increased from 1.0 million in 1975 to 9.8 million in 1999, and sales of room heaters have increased from 0.13 million in 1975 to 0.50 million in 1999. The growth in sales for the other appliances has been less dramatic, but sales of almost every appliance have seen an increase of approximately 100 percent in the last 25 years. The sales of portable heaters have decreased.

Table 2. Statistical review of unit shipments of new comfort conditioning appliances (excluding commercial appliances) in the United States for years in the period 1975 to 1999, as reported in annual reports of *Appliance Magazine*.[1-3]

Appliance	**1975**	**1980**	**1985**	**1990**	**1995**	**1999**	**Change 1975-1999**
	Quantity	**Quantity**	**Quantity**	**Quantity**	**Quantity**	**Quantity**	**%**
Fans	7,839,000	14,640,000	18,919,054	31,918,667	14,340,000	19,100,000	+144
Air conditioners	4,441,484	5,150,885	5,716,787	7,353,275	8,363,476	11,467,276	+158
Humidifiers	1,031,000	821,000	1,231,000	1,058,330	3,140,000	9,800,000	+851
Furnaces	1,994,166	1,948,430	2,564,090	2,537,856	2,917,694	3,419,024	+71
Portable heaters	2,990,000	4,569,000	6,684,000	6,155,900	3,138,000	2,700,000	-10
Heat pumps	-	442,829	820,623	808,655	1,024,885	1,293,395	-
Dehumidifiers	392,000	673,000	588,400	742,500	1,002,800	871,000	+122
Room heaters	125,130	282,300	282,969	317,775	575,940	503,131	+302
Boilers	187,021	344,972	295,982	316,073	338,003	349,943	+87
TOTAL	**18,999,801**	**28,872,416**	**37,102,905**	**51,209,031**	**34,840,798**	**49,503,769**	**+161%**

Replacement Rates and Life Expectancies

The life expectancy of appliances is determined from past experience and sales data. Table 3 shows a list published in the year 2000 by *Appliance Magazine*, showing life expectancies for each type of appliance, with a low, a high, and an average number of years before a first owner purchases a replacement for an appliance. This does not necessarily mean that the appliance is worn out. When a replacement is purchased, the old unit is either traded in, relegated to use elsewhere, given away, or discarded, thereby ending the first-owner life cycle. The estimates contained in the table represent the expert judgement of *Appliance Magazine* staff based on input obtained from many sources.

In addition to the life-cycle expectancy for each appliance category, the estimated number of units that will be eligible for replacement in 2001 are given in the table. These appliances may be replaced with the same type of product, an appliance of a different type, or not at all. To obtain these figures, the average life expectancy (in years) was taken and used to find the number of unit shipments made that many years prior to 2001. It is noted that these replacement numbers do not take into account the changes in life expectancy over the years.

Table 3. Life expectancy / replacement time of appliances, as reported in the 23rd annual portrait of the U.S. appliance industry.[4]

MAJOR HOME APPLIANCES (EXCLUDES COMMERCIAL APPLIANCES)					
	Life Expectancy, years			**Units to be replaced in 2001**	**Units that were shipped in 1999**
	Low	**High**	**Average**		
Microwaves	5	10	8	8,132,300	11,581,085
Ranges, electric	13	20	16	3,227,700	7,016,939
Ranges, gas	15	23	19	1,367,400	3,136,200
Ranges, hoods	9	19	14	2,595,000	3,000,000
Refrigerators, compact	4	12	8	1,030,000	141,283
Refrigerators, standard	10	18	14	6,972,100	9,098,600
Water heaters, electric	6	21	14	3,396,395	4,281,199
Water heaters, gas	5	13	9	4,241,354	4,933,659
Washers	8	16	12	6,607,500	7,508,200
Dryers, electric	11	18	14	3,381,200	4,864,700
Dryers, gas	11	16	13	1,046,800	1,443,000
Dishwashers	9	16	12	3,668,400	5,711,200
Food waste disposers	10	15	13	4,232,600	5,369,400
Freezers	12	20	16	1,472,800	1,987,200
Water softeners*	-	-	-	-	951,498
Compactors	7	12	11	185,000	114,700
TOTAL				**51,556,549**	**71,138,863**

COMFORT CONDITIONING APPLIANCES					
	Life Expectancy, years			**Units to be replaced in 2001**	**Units that were shipped in 1999**
	Low	**High**	**Average**		
Fans, ceiling	7	18	13	6,400,000	19,100,000
Air conditioners, room	7	16	12	5,091,100	6,113,600
Air conditioners, unitary	8	19	13	3,214,606	5,353,676
Humidifiers	6	13	10	612,000	9,800,000
Furnaces, electric	9	20	14	375,055	-
Furnaces, gas	11	23	17	2,049,335	3,293,646
Furnaces, oil	13	23	18	127,305	125,378
Portable heaters	8	13	11	5,542,900	2,700,000
Heat pumps	6	21	14	918,432	1,293,395
Dehumidifiers	9	13	11	742,500	871,000
Room heaters, vented gas	7	18	13	91,426	35,927
Room heaters, unvented gas	13	23	18	217,566	467,204
Boilers, gas*	-	-	-	-	200,893
Boilers, oil*	-	-	-	-	149,050
TOTAL				**25,382,225**	**49,503,769**

*No data available for the life expectancy of water softeners and boilers.

AREAS OF MAJOR CORROSION IMPACT

Corrosion Impact by Type of Corrosion

There are some common areas of significant corrosion impact for major home appliances and comfort conditioning appliances. The corrosion types include: internal corrosion from process water and external corrosion from wet locations.

Internal Corrosion

The most important reason for corrosion in appliances is the water that is being handled by the equipment. This type of corrosion affects the internal components of appliances and limits life expectancy. In the category of major home appliances, the following appliances are most susceptible to internal corrosion: refrigerators, water heaters, washers, dish washers, and water softeners. In the category of comfort conditioning appliances, the following appliances are most susceptible to internal corrosion: air conditioners, humidifiers, furnaces (especially those high-efficiency furnaces, because of condensate formation in the heat exchangers), dehumidifiers, and boilers.

Internal corrosion in appliances is a problem because it limits the useful life. This is a direct cost of corrosion. For example, a unitary air conditioner has an average life of 13 years, as mentioned in table 3. One of the reasons for this limited life expectancy is that condensate in the air conditioner corrodes the internal metal components. If the useful life would be longer, people would not be buying a new unit after 13 years, which would save a significant amount of money for consumers.

A quick estimate of the annual cost that could be saved if unitary air conditioners would have one more year of useful life can be made as follows: Table 3 shows that 3.2 million units are up for replacement in 2001. If improved corrosion resistance could make the average life of a unit 14 years instead of 13 years, then 1/14th of the replacement cost would not have been incurred. The estimated average unit cost is approximately $300. It is recognized that this number may be reasonable for window air conditioners while being too low for whole house air conditioners. If this estimate is used, then the hypothetical cost-savings due to improved corrosion design would be: 3.2 million x 1/14 x $300 = $68.5 million per year.

The above estimate is only an example, and it is only showing a calculation of one type of appliance. Also, it is not shown how much the annual cost would be to achieve the improved corrosion design. For a complete analysis, both costs and benefits should be considered, and for a national estimate, the results for all appliances should be combined.

External Corrosion

The second type of corrosion that affects the appliances is external corrosion. External corrosion can deteriorate the appearance of the surface of an appliance, but that generally does not limit the capability of an appliance to function properly. However, the value of appliances surely decreases when external corrosion occurs, because consumers do not find rusty appliances in their home appealing. In addition to corrosion of non-coated surfaces, corrosion can occur when coated or painted surfaces become chipped or nicked. Examples of wet environments around appliances are a furnace or a boiler in the humidity of a damp basement, an air conditioning unit standing in a yard or hanging from a window, being exposed to the rain and moisture (especially in coastal areas where salt is in the air), and kitchen equipment of which the exteriors are often cleaned with water or wet towels.

External corrosion of appliances is a problem because it deteriorates their appearance, and therefore affects their resale value. This cost is a direct cost of corrosion. The tables at the beginning of this sector description show the number of new appliances shipped in the United States. But, in many cases, people decide to upgrade appliances before the entire useful life has been consumed. Therefore, the resale value of second hand appliances is important, because the money received from a trade-in or resold appliance can pay for part of the cost of a new appliance.

Corrosion Impact by Type of Appliance

Corrosion issues vary with the type of appliance. Corrosion can build up and destroy parts of or the entire appliance. In the following text, the areas of major corrosion impact regarding the internal components of appliances are described for several appliances that can be significantly affected by corrosion. These appliances include: water heaters, boilers, high-efficiency furnaces, and air conditioners.

Water Heaters

The heating coils in water heaters are exposed to the water in the heater tank. Common water contaminants such as chlorides, fluorides, and sulfates can cause corrosion of the heating coils, the water heater connections, the tank wall, and the tank frame. The elevated temperature of the water in the heater is further likely to increase the rate at which internal corrosion occurs.

One method to control internal corrosion is the use of corrosion-resistant materials, such as stainless steels and other corrosion-resistant alloys (CRA) for the heat exchanger coils. Another method that is always applied in water heaters to control the internal corrosion is the application of sacrificial anodes. The condition of the water heater's sacrificial anode is critical for its corrosion protection. In sacrificial cathodic protection of water heaters, a magnesium rod is permanently inserted into the water and the rod serves as a sacrificial anode to protect the carbon steel parts.

Boilers

Boilers are heat exchangers constructed of carbon steel to produce hot water or steam by being heated with an oil or gas burner. The hot water or steam is transferred to radiators to provide heat. After releasing heat, the cool water or steam condensate is returned to the boiler for reheating.

A common problem in boilers is the occurrence of calcium oxide scale build-up on the heating elements. This is not a corrosion problem in itself, because it is caused by a chemical reaction in the water at higher temperatures. However, a scale deposit present on a metal surface may cause corrosion under the deposit. This type of under-deposit corrosion can be aggravated when corrosive elements such as sulfides and/or chlorides are present in the water. While scale deposits reduce the thermal conductivity of the steel, and thereby increase energy costs, corrosion of the heating element can lead to a catastrophic tubing failure, which requires costly repairs.

High-Efficiency Furnaces

Corrosion can occur in furnaces when condensation occurs, which can corrode the internal metal surfaces. Condensation is a problem in high-efficiency furnaces, because operating at greater efficiencies means that the appliance must operate in a condensing mode. Currently, these types of furnaces are designed with a maximum annual flue utilization efficiency (AFUE) of 90 percent, compared to the standard minimum efficiency of 78 percent. To operate a high-efficiency furnace, the flue gas must be cooled to a temperature below the dew point, by which the combustion-generated moisture is condensed in the heat exchanger, and the latent heat of vaporization is recovered for utilization.

Research in the mid-1980s on corrosion of materials used in condensing heat exchangers in furnaces indicated that the greatest probability of corrosion occurs when the appliance goes through the transition from wet to dry conditions. This is because the acidity of the condensate increases as the water evaporates. The flue gas generated is a mildly acidic liquid that is corrosive to alloys such as Type 304 and Type 316 stainless steel commonly used in heat exchanger furnaces. The corrosivity of the condensate can increase due to common airborne contaminants, particularly chlorine-containing compounds, present in indoor environments and carried into the burner by the combustion process. Research on corrosion-resistant materials for condensing heat exchangers, such as by

Battelle[5-6] and the American Gas Association (AGA) Laboratories for the Gas Research Institute (GRI),[7-8] resulted in recommendations for condensing heat exchanger design. These recommendations included design recommendations on how to minimize condensation in non-condensing regions of heat exchangers, how to reduce the corrosiveness of flue-gas condensate, and a list of materials that are corrosion-resistant to flue-gas condensate.

The application of non-metallic materials for full condensing types of appliances is an alternate option to steel. For example, polyvinyl chloride (PVC) is preferable in the vicinity where the exit flue gas would be in the temperature envelope in which stress corrosion cracking of stainless steels is a problem. However, the application of some plastics is difficult at temperatures higher than ambient, because they become increasingly soft.

Air Conditioners

Aluminum and copper are materials used for the internal components of air conditioners. Coils and cooling fins are made from aluminum and piping is usually made of copper. Aluminum is susceptible to galvanic corrosion when it is in contact with copper components. Galvanic corrosion can occur when two dissimilar metals are in electrical contact in an electrolyte (in this case, water).

Piping or plumbing systems made from copper alloys are susceptible to erosion-corrosion in unfavorable fluid flow conditions. Erosion-corrosion can occur when erosive action of the flowing stream removes the protective copper oxide film from the metal surface, thereby exposing non-passivated bare metal to the corrosive environment.[9]

CORROSION CONTROL METHODS

There are three basic corrosion control methods that are used to protect or mitigate corrosion in home appliances: corrosion control by sacrificial anodes, the use of corrosion-resistant materials, and corrosion control by coatings and paint. The following text describes each of these basic methods, using some practical examples and showing some basic cost calculations.

Corrosion Control by Sacrificial Anodes

Most people do not realize that by checking and changing a deteriorating anode, the life of a hot water heater can be extended considerably. It has been stated that the direct cost of not having to replace broken water heaters can result in savings for individuals and businesses of as much as 70 percent – both in time and money.[10] In addition, checking and, if necessary, replacing the (one or two) anode(s) of a water heater provides protection from sudden floods, which can result in indirect costs for clean-up and damages. The indirect cost can potentially be much larger than the costs related to installing a new tank, or of retrofitting an old one. The life expectancy of sacrificial anodes depends on the local water conditions, and can range from 2 to 3 years to more than 10 years.

The key benefits of proper anode maintenance are:

- Tank lasts longer.
- Less rust build-up.
- Save on costly changeovers.

Calculating the Cost of Corrosion Protection by Sacrificial Anodes

Every water heater has one or more sacrificial anodes to protect the internal components from corrosion. There are two types of possible corrosion costs related to anodes: the cost of replacing the entire water heater because it failed due to corrosion, and the cost of replacing the anode(s) only, which includes the cost of materials and labor. Alternatively, one could consider an improved design with a longer anode life that could possibly increase the life expectancy of water boilers. In the following paragraphs, these three methods of estimating corrosion costs are applied. It is noted that the assumptions made in these calculations are only partial approximations (for one type of appliance), and that should be performed to get national estimates for all appliances.

Cost of Replacing Water Heaters

As shown in table 3,[(4)] the total number of new water heaters shipped in 1999 was 9,214,858 heaters, distributed over 4,281,199 electric water heaters and 4,933,659 gas water heaters. The average life expectancy is 14 years for electric water heaters and 9 years for gas water heaters. According to *Consumer Reports Online*,[(11)] the range of installed costs for new water heaters is $800 to $1,200 (average $1,000). If this average $1,000 value is multiplied by the total number (9,214,858) of new water heaters in 1999, it is estimated that a total of $9.2 billion was spent in the United States on replacement of water heaters.

The *Appliance Magazine* report[(4)] does not specify the reasons for appliance replacement, but it may be assumed that some portion is due to modernization, while another portion is due to substitution because of wear and tear. Corrosion failure would be ranked in the wear-and-tear category. If it is assumed (no other data available for this calculation) that 5 percent of the annual replacement of water boilers is due to corrosion failure, then the cost of corrosion in 1999 would be $9.2 billion x 5 percent = $460 million per year.

Cost of Anode Replacement

Using the numbers in table 3,[(4)] an approximation of the total number of current water heaters can be made by multiplying the number of unit shipments by the average life expectancy of the appliance. This calculation results in estimates of approximately 4,281,199 heaters per year year x 14 years = 59,936,786 electric water heaters, and 4,933,659 heaters per year x 9 years = 44,402,931 gas water heaters. Adding these two numbers results in a total of 59,936,786 + 44,402,931 = 104.3 million water heaters in use.

Statistical data were not found on the number of water heaters that are serviced with a replacement anode each year. Therefore, to complete this calculation, an assumption was made that, on average, 5 percent of all water heaters would have their anodes replaced each year. In other words, it was assumed that 1 out of 20 water heaters gets its anode replaced each year. The other estimate required for the calculation is made as a total cost of $150 per anode replacement for materials ($80 per anode) and labor ($70 for one hour). The total annual cost of anode replacement then becomes: 104 million anodes in water heaters x 5 percent replaced per year x $150 per replacement = $780 million per year.

Cost-Savings of Increased Life Expectancy

In an earlier calculation, the assumption was made that the corrosion life could be extended by 1 year by improved corrosion design. If this were true, the average life expectancy of electric water heaters would increase from 14 years to 15 years, and the average life expectancy of gas water heaters would increase from 9 to 10 years. Under these assumptions, the hypothetical cost-savings because of improved corrosion design for electric water heaters would be 4.28 million x 1/15 x $1,000 = $285 million per year, and for gas water heaters it would be 4.93 million x 1/10 x $1,000 = $493 million per year. The total cost-savings would be $285 million + $493 million = $778 million per year.

Summary of Costs Related to Sacrificial Anodic Protection

In the above paragraphs, the cost of replacing water heaters was estimated at $460 million per year, the cost of anode replacement was estimated at $780 million per year, and the cost of increased life expectancy of water heaters was estimated at $778 million per year. The magnitude of the dollar values is similar.

The benefits of anode maintenance are longer tank life, less rust build-up, and savings on costly changeovers. However, a cost-benefit analysis may show that the cost of replacing anodes could exceed the cost of the increased life expectancy or the cost of water heater replacement. In addition, it was not shown that increased life expectancy without increased cost would be technically feasible. Also, it is not known how much life is actually gained by the replacement of water heater anodes, because the appliance may fail because of another reason, such as a heating element failure. As noted earlier, the assumptions made in these calculations are only approximations, and therefore it is recommended that a full analysis of statistical data be performed to get an insight into the nationally incurred costs of the corrosion issues related to sacrificial anodes in water heaters.

Corrosion Control by Corrosion-Resistant Materials

If possible, one would like to manufacture all appliances of unpainted carbon steel, because of its high strength and relatively low cost. However, in reality, corrosion-resistant materials must be used to prevent corrosion from occurring. Common materials used for this purpose are plastics, galvanized steel, stainless steel, aluminum, and copper-nickel alloys.

Plastics are used because they are corrosion-resistant and they prolong the product life and the durability in the hostile environments where major appliances must operate. It has been reported(12) that the use of plastics can increase durability and equipment life by 30 to 40 percent.

Galvanized steel is carbon steel with a zinc coating, that protects the cold-rolled steel from corrosion in aqueous and high-temperature environments. Galvanized steel is used in laundry appliances because it provides detergent resistance. The cost for processing steel into galvanized parts is dependant upon the facility, but generally ranges from $50 to $100 per metric ton of zinc.

Stainless steels are commonly used to design high-efficiency furnace components (heat exchangers). According to the Specialty Steel Industry of North America, the total stainless steel usage for heating and air conditioning equipment is 81.0 million kg (89 thousand tons). The annual (1998) consumption of stainless steel for the appliance industry was estimated at $315 million per year.(13) Assuming that the reason for using stainless steel is to control corrosion, the estimate can be attributed entirely to corrosion.

Aluminum is often used for control panels of appliances. The thin aluminum oxide film that forms instantaneously on aluminum when exposed to air serves as protection against corrosion. Surface treatments such as anodizing and cladding help to further improve corrosion resistance.

Copper-nickel alloys are typically used in tubing and coils of heater and air conditioning systems because of their high thermal conductivity in heating and cooling applications. Copper-nickel alloys (e.g., 70/30 Cu/Ni and 90/10 Cu/Ni) have acceptable erosion-corrosion resistance in water compared to pure copper.

Corrosion Control by Coatings and Paint

Liquid coatings (paints), powder coatings, and porcelain enamel coatings are used in the appliance industry. Pretreatments that influence the appliance performance level are used for surface cleaning and adhesion purposes of coatings. Pretreatment systems include iron phosphate and zinc phosphate. The cost of iron and zinc phosphate pretreatments depends on the following factors: (1) continuous or intermittent manufacturing, (2) the geometry of the part, and (3) control of chemical processing.

Liquid coatings are used for refrigerators since they are corrosion-resistant and have a relatively low cost. For refrigerator coils, the thickness of the coating is on the order of 0.05 mm to 0.10 mm (0.002 to 0.004 in). In clothes washers and dryers, a primer coating is applied to galvanized steel. The average cost of liquid coating[14] is estimated as $1.32 to $1.50 per kg ($0.60 to $0.68 per lb). If the cost of primer and topcoat are both considered, the total cost is estimated as $2.64 to $2.99 per kg ($1.20 to $1.36 per lb).

Powder coatings are organic coatings that are used primarily on boiler and furnace steel sheets. They are applied by depositing a mist of powder on the product in an electrostatic field, followed by a baking process. Powder coatings are becoming more widely recognized because of their benefits with regard to environmental issues and quality of coating, coating requirement, and cost. Powder coatings are applied as single coatings, and have an estimated price of $2.20 to $3.30 per kg ($1.00 to $1.50 per lb). When the recovered material is captured and reused, this price is reduced by 60 percent; therefore, the cost is reduced to $1.32 to $1.98 per kg ($0.60 to $0.90 per lb).

Porcelain enamel is mainly used in high-level performance appliances. They are more scratch-resistant and heat-resistant than the thinner liquid and powder coatings; however, porcelain enamel is porous. Holidays are sometimes found in the porcelain (glass). Magnesium, zinc, and aluminum anode rods are used in combination with porcelain enamel coatings in water heating systems to act as a sacrificial anode. Enamel coatings are applied as thick films, ranging between 0.10 to 0.15 mm (0.004 to 0.006 in). The estimated cost is $2.20 to $3.30 per kg ($1.00 to 1.50 per lb). In the application, the material costs are estimated to cost 50 percent less than those used for organic coatings; however, the process of applying porcelain enamel to metal substrate is costly.

Calculating the Cost of Coatings on Appliances

The above analysis showed some estimated costs for three types of coatings. These costs only include the ingredient materials, not the application cost. In summary, the estimated material costs were:

Liquid coatings:	$2.64 to $2.99 per kg
Powder coatings:	$1.32 to $1.98 per kg
Enamel coatings:	$2.20 to $3.30 per kg

To calculate a national estimate of coating costs, an average coating cost per appliance must be assumed, and for the following calculation, this average is estimated at $2 per appliance. Table 1 and table 2[1-3] summarized that in 1999, the total number of major home appliance and comfort conditioning appliance unit shipments was 70,771,824 + 49,503,769 = 120,275,593. Applying a coating to all these new appliances is therefore estimated to cost a total of 120,275,593 x $2 = $240 million per year.

CORROSION MANAGEMENT

The average consumer buying an appliance is only marginally interested in corrosion issues. If an appliance looks acceptable in appearance in a store, it is automatically assumed that it will maintain that appearance over the life of the appliance. Therefore, during the useful life of the appliance, no corrosion management is done by consumers. For example, very few people realize that there is an anode in every water heater, and that this sacrificial bar of metal should be checked and, if necessary, replaced with a new one to prevent water heater failure due to internal corrosion. The life expectancy of appliances is determined from past experience and sales data. Improved corrosion design for appliances can increase their life expectancy; however, if improved corrosion protection would mean the use of more expensive components for the appliances, then consumers may not be interested.

CHANGES FROM 1975 TO 2000

Statistics of the last 25 years (1975 - 1999) show that the number of new appliances has consistently exceeded the number of replacement appliances purchased. The average life expectancy of appliances has probably increased in the same period because of improved use of anodes, corrosion-resistant materials, and paints and coatings. A portion of this increase has been due to the increased standard of living, while another portion can be attributed to the growth of the population from 1975 to 2000.

Replacement and limited useful life is preferred by manufacturers of appliances. The calculations in this sector description show that the non-optimal performance of appliances comes at a significant cost to consumers. Although the consequences of an appliance undergoing corrosion or failing are not catastrophic, the costs to replace appliances are considerable. Statistics show that, on average, every American buys one appliance every 2 years and 3 months (270 million citizens / 120.2 million appliances per year).

REFERENCES

1. "A Ten-Year Review 1990-1999 of the U.S. Appliance Industry, Appliance Statistical Review," 47th Annual Report, *Appliance Magazine*, May 2000.

2. "A Ten-Year Review 1975-1984 of the U.S. Appliance Industry, Appliance Statistical Review," 32nd Annual Report, *Appliance Magazine*, April 1985.

3. "A Ten-Year Review 1985-1994 of the U.S. Appliance Industry, Appliance Statistical Review," 42nd Annual Report, *Appliance Magazine*, April 1995.

4. "23rd Annual Portrait of the U.S. Appliance Industry," *Appliance Magazine*, September 2000.

5. G.H. Stickford, S.G. Talbert, B. Hindin, and D.W. Locklin, "Research on Corrosion-Resistant Materials for Condensing Heat Exchangers," Presented at the 39th Annual International Appliance Technical Conference, University of Wisconsin-Madison, May 1988.

6. G.H. Stickford, S.G. Talbert, and D.W. Locklin, "Condensate Corrosivity In Residential Condensing Appliances," Battelle, Columbus Division, USA, *Proceedings of the 1987 International Symposium on Condensing Heat Exchangers*, April 1987.

7. C.A. Farnsworth, "Materials and Design Options for Avoiding Corrosion in Condensing Appliance Heat Exchangers and Vent Systems," *Proceedings of the 1987 International Symposium on Condensing Heat Exchangers*, April 1987.

8. C.A. Farnsworth, "Corrosion and Venting Concerns of High-Efficiency Appliances," *Proceedings of American Gas Association (AGA) 1985 Operating Section*, American Gas Association Distribution/Transmission Conference, Boston, MA, May 1985.

9. B.J. Moniz, "Copper," *Metallurgy*, American Technical Publishers, 1994.

10. "About Anodes," *Plumbing World*, www.plumbingworld.com.au/about.htm, May 2001.

11. *Consumer Reports Online*, consumerreports.org, August 2000.

12. R.S. Hagan and W.R. Keelan, *Plastics: Key Materials for Innovation and Productivity in Major Appliances*, pp. 1-18, American Plastics Council, February 1994.

13. B. Leslie, Specialty Steel Industry of North America, Personal Communication, December 2000.

14. R. Talbert, Technical Director, Chemical Coaters Association, Personal Communication, September 2000.