A BEST PRACTICES INVESTIGATION INTO THE PRESENCE AND CONTROL OF MICROBIOLOGICALLY INFLUENCED CORROSION IN WATER-BASED FIRE PROTECTION SYSTEMS IN THE FABRICATION AREAS OF A MAJOR SEMICONDUCTOR MANUFACTURING ORGANIZATION IN THE UNITED STATES

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ABSTRACT

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A Best Practices Investigation into the Presence and Control of Microbiologically
Influenced Corrosion in Water-Based Fire Protection Systems in the Fabrication Areas of
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Microbiologically influenced corrosion (MIC) is defined as a distinct type of corrosion where microscopic organisms or microbes influence the corrosion process (Bshart, 1998). In recent times this influenced corrosion process has been identified within fire protection systems (FPS). In severe cases MIC has been found, under the right conditions, to cause complete failure of piping systems in less then two weeks after startup (Scott and Davies, 1989). MIC can therefore, be considered a serious risk to any organization that has a fire protection system.

This research study examines the current best practices, associated risks, and minimization techniques used to control outbreaks of MIC, with a specific focus on a major semiconductor organization in the United States. Certain characteristic factors contribute to increased incidence and therefore increase potential risk to an organization. Because semiconductor fabrication facilities are a high-risk operation, due to chemicals and gases used in the manufacturing production process, an increased risk caused by failure of the FPS is unwanted and may potentially increase an incident exponentially in an undesirable direction.

This research study's purpose is to determine what current best practices are currently being used by Company XYZ to minimize the effects of microbiologically influenced corrosion on the FPS and investigate the extent of minimization techniques that have been implemented. The study will also provide an outline of factors that may be used to create a guideline to control this problem.

Information from previous studies was used to develop a survey questionnaire. The personnel interviews were conducted with people(s) with in Company XYZ that have an understanding of the problems associated with MIC. A total of six facilities were contacted for information resulting in 100% return of information.

Major findings of this study indicate that specific facilities of Company XYZ have a high degree of risk associated with MIC problems. Certain facilities in geographical regions have seen increased problems when comparing all the facilities. The corporation as a whole has done very little to address and correct the issues and problems that increase the organizations risks.

The identification of exposure risks and provision of adequate controls can effectively reduce the potential problems associated with MIC. To have an effective control program, an organization must address: the understanding of the problem, inspections of the FPS, chemical analysis of the water and piping, a determination of bacteria type, past history of the fire system, pipe cleaning methods, water treatment/adjustment through the use of chemicals, continuous corrosion monitoring, and control of other associated risks. Studies by others conclude that early identification and adequate controls can effectively reduce the presence of MIC in any fire protection system (1996).

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CHAPTER I

Research Problem and Objectives

Introduction

As technology grows at an exponential rate, semiconductor organizations investigate new ways to reduce cost and risk while increasing productivity. Large amounts of time and money are spent minimizing risks associated with the manufacturing process (R. Benson, personal interview, October 4, 1999). Within semiconductor organizations it's likely that millions of dollars are poured into production tools, methods, and process design each year.

According to Van Zant (1997), working in a class one clean room in a semiconductor facility requires extreme cleanliness and attention to possible particle contamination. It is essential to maintain a clean work environment in a manufacturing process due to the microscopic design of microprocessors. The ability to do so helps to minimize the number of malfunctioning die on each wafer. This reduction in contamination may ultimately increase productivity and profitability.

In an interview with Roger Benson, (personal interview, October 4, 1999) semiconductor facilities have used water-based fire protection systems (FPS) as basic risk reducers to control outbreaks of fire for decades. Fire is always a major concern within a semiconductor manufacturing facility. In the burning process, large amounts of particulates are released into the surrounding environment (Goetsch, 1993). Roger Benson (personal interview, October 4, 1999) stated that a small fire in a semiconductor facility has the potential to bring production to a full stop for well over one year, which is the time it takes to decontaminate the clean room(s). In the ceilings above clean rooms lies a water-based FPS. This system is relied upon to protect the investments of the facility and production process in the event of fire. If the FPS is not maintained or is working improperly, the potential for loss to an organization's employees, investments, and assets is greatly increased.

In a paper by Bshart (1998), microbiologically influenced corrosion (MIC) is defined as a distinct type of corrosion where microscopic organisms or microbes influence the corrosion process. MIC attacks have been documented for metals exposed to numerous types of water and petroleum byproducts. Recently, MIC has been known to affect fire protection systems in various industries throughout the country. According to Roger Benson (personal interview, October 4, 1999), when examining the risks of MIC in the semiconductor industry, effects may vary from a small drip on a manufacturing tool, which may cause minimal damage to complete malfunction of the FPS and thus result in total destruction of a facility, major monetary losses, and loss of life. Thus, MIC has the potential to increase an organization's risk to loss.

Purpose of Study

The purpose of this study is to determine the extent of best practices that are currently being used by Company XYZ to minimize the effects of microbiologically influenced corrosion within this semiconductor organization located in the United States.

Goals of Study

The objectives of this paper are to:

1. Develop a protocol to detect and identify MIC characteristics.
2. Investigate MIC controls that Company XYZ have in place to minimize outbreaks of MIC.
3. Compare current proactive MIC controls within Company XYZ to best practices for controlling MIC as determined by recent literature. The comparison will determine if Company XYZ is using best practices to control MIC problems.

Background and Significance

MIC attacks metal piping that is in contact with an aqueous solution. It has been estimated that 10-30% of corrosion in all piping around the country is a result of MIC (Bshart, 1998). This corrosion process involves the colonization of various types of bacteria, algae, and fungi in water-based fire protection systems. MIC can be a reoccurring problem that attacks different types of metal piping at varying rates. In the United States, a significant portion of corrosion related losses, in upwards of $200 billion dollars per year, can be attributed to the action of microorganisms (Choi and Torma, 1993). MIC has been found, under the right conditions, to cause complete failure of piping systems in less then two weeks after startup (Scott and Davies, 1989). Currently, many legal-litigating cases directly and indirectly related to this topic have arisen in numerous semiconductor and high tech-facilities. MIC has been pointed to as a major contributing factor causing numerous FPS problems within organizations.

Limitations

Areas that may limit the study are as follows:

1. Recent litigation regarding this topic resulting in the inability or lack of willingness of semiconductor Company XYZ to participate in the study.
2. Limited information regarding best practices of controlling MIC in water-based fire protection systems.
3. A total of six facilities within Company XYZ were contacted and provided information regarding their practices at controlling MIC

Assumptions

The following items will be assumed during the study:

1. All information reported on the survey is accurate.

2. Literature regarding best practices for controlling MIC has a strong degree of reliability.

Definitions

Anionic – of or related to anions (Webster, 1985).

Biofilm - microbial colonies encased in adhesive, usually polysaccharide material, and attached to a surface (Madigan, Martinko, and Parker, 1996).

Clean Room - an area in which semiconductor device fabrication takes place. The cleanliness of the room is highly controlled in order to limit the number of contaminants to which the semiconductor is exposed (Van Zant, 1997).

Class Number Clean Room - number of contaminant particles in a cubic foot of air (Van Zant, 1997).

Chips - Die or device, one of the individual integrated circuits or discrete devises on a wafer (Van Zant, 1997).

Die - One unit on a wafer separated by scribe lines; after all of the wafers fabrication steps are completed, die are separated by sawing; the separated units are referred to as chips (Van Zant, 1997).

Fire Protection System (FPS) - A permanently piped system of open or automatic water-spray type nozzles that are intended for the protection against out of control flammable liquids, gases, solids, and other combustible materials (Factory Mutual System, 1994).

Microbiologically influenced corrosion (MIC) - an electrochemical process where the participation of the microorganisms is able to initiate, facilitate, or accelerate the corrosion reaction without changing the electrochemical nature (Videla, 1996).

Microprocessor - see semiconductor (Van Zant, 1997).

Polymer – a chemical compound or mixture of compounds formed by polymerization and consisting essentially of repeating structural units (Webster, 1985).

Polysaccharide – a carbohydrate that can be decomposed by hydrolysis into two or more molecules of monosaccharides (Webster, 1985).

Semiconductor - an element such as silicon or germanium, intermediate in electrical conductivity between the conductors and the insulators, in which conduction takes place by means of holes and electrons (Van Zant, 1997).

Tubercle – a small abnormal discrete lump (Webster, 1985).

Wafer - a thin, usually round slice of semiconductor material, from which chips are made (Van Zant, 1997).

Chapter II

Review of Literature

Introduction

The purpose of this chapter is to examine and evaluate literature which is relevant to the risks associated with microbiologically influenced corrosion (MIC) in semiconductor manufacturing facilities. The literature review is divided into the following sub-parts:

1. Formation of MIC
2. Characteristics of MIC
3. Tests Used to Indicate the Presence of MIC
4. MIC Treatment Controls
5. Current Best Practices

Formation of MIC

MIC is a process that involves the colonization of various types of fungi, algae, and aerobic/anaerobic bacteria (Videla, 1996). The colonization involves the building or production of biofilm that allows different types of bacteria to live in a complex matrix (Costerton, Geesey, and Jones, 1988). Walsh, Pope, Danford, and Huff (1993) suggest that formations of biofilms follow a similar growth process on most materials and consist of the following chain of events:

1. Initial microbe attachment to the surface, which is a random event.
2. Continued accelerated proliferation of bacteria as dependent on the metallurgical features of the surface.
3. Formation and development of associated biofilm or slime layer, which facilitates microbial control of chemistry at the surface interface.
4. Continued production of the biofilm and adhering matrix.

5. Differentiation of the biofilm into layers.

Walsh, Pope, Danford, and Huff (1993) state that the above five-step process can take as little as four hours to develop. Once the biofilm has been created, it begins to differentiate between the layers (see Figure 1). The microbial colonization at each layer can differ significantly in that the lower layers contain anaerobic bacteria while the upper layers are made-up of aerobic bacteria. If the environment is suitable for continuous development, the biofilm may begin to develop tubercle growth in as little as five to seven days. These tubercles are a diverse mixture of bacteria that possess corrosion enhancing products and subsequently control the chemistry at the metal surface interface. The growth of biofilm is a complex bio-engineered thermodynamic state where various strains of bacteria work together to flourish. Figure 2 shows the localized chemistry that is involved in the tubercle formation and growth. Figure 3, 4, and 5 show examples of tubercle growth found on a piping from a fire protection system (FPS).

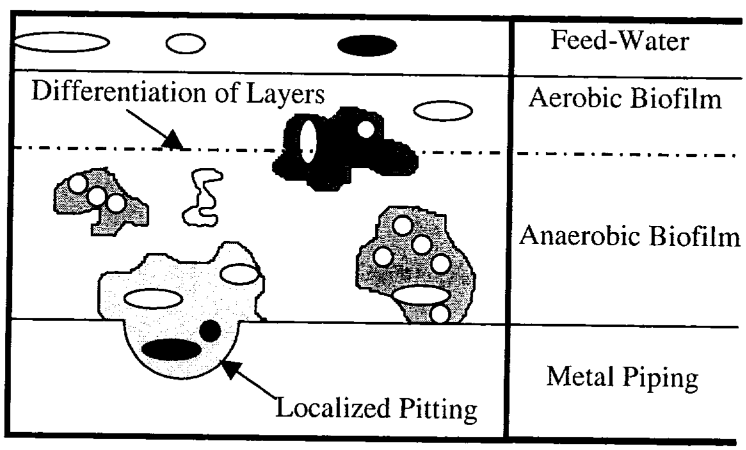

Figure 1 A Schematic diagram of differentiated biofilm.
Based off of Costerton (1992).

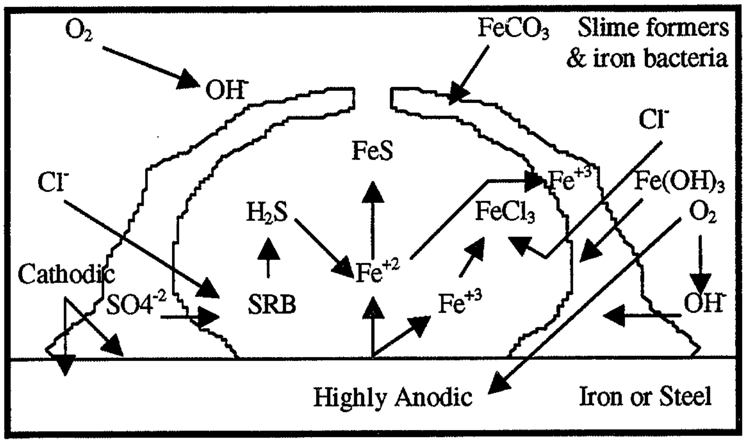

Figure 2 A schematic diagram of the tubercle environment. Based off of Jannasch (1984).

Figure 3 Tubercle growth in a FPS piping (The American Fire Sprinkler Association)

Figure 4 Tubercle growth in a FPS piping (The American Fire Sprinkler Association)

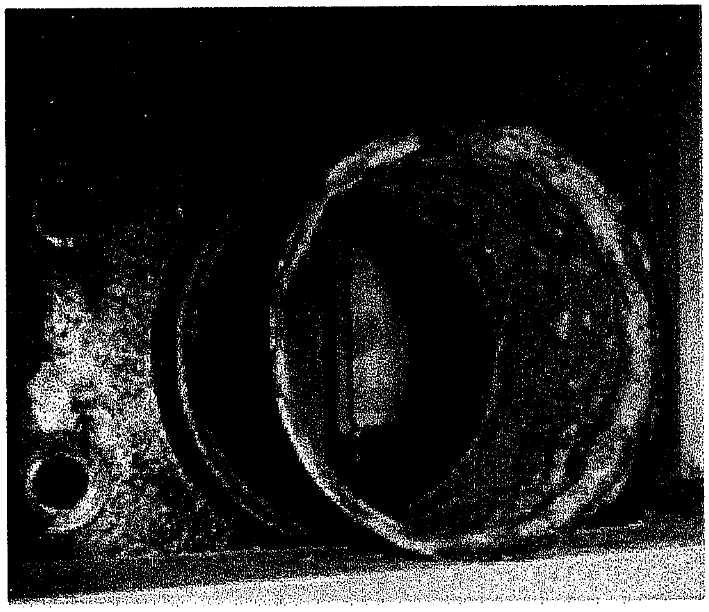

Figure 5 Tubercle growth in a FPS piping (The American Fire Sprinkler Association)

Quite often, the process of draining and refilling the water within a fire protection system reintroduces new oxygen and nutrients to cause a flourish of aerobic bacteria activity (Rittenhouse, 1995). When the FPS changes from an aerobic to an anaerobic state, aerobic bacteria will provide food to the anaerobic bacteria through waste production and the degradation of the aerobic cell structure (Walsh, Pope, Danford, and Huff 1993). Little and Wagner (1997) as well as Costerton, Geesey, and Jones (1998) have reported that the inner areas of the biofilm are often eight to ten cells thick and represent an anaerobic environment with large pH differences existing between differentiating layers. The matrix material adhering the microbes to each other and to the metal surface is made up of a highly hydrated anionic polysaccharide polymer (Costerton, Geesey, and Jones, 1998). The adhering material bridges microbial cells together, thus allowing the localized environment to be formed (Little, Ray, and Wagner, 1998). While surrounding environments and water conditions change constantly, anaerobic bacteria can survive long exposures to oxygenated environments with little adverse effects (Hao, Chen, Huang, Buglass, 1996; Little and Wagner, 1997). Biofilms form complex systems of voids, channels, cavities, pores, and clusters of cells (Little, Ray, and Wagner 1998). This evolving environment contributes to the formation and growth of specific types of MIC within a water-based FPS (Moisidis and Ratiu, 1996).

The extensive amount of literature found on sulfate-reducing bacteria (SRB), indicates that this organism is generally associated with the formation of MIC. SRB are easily cultured and produce hydrogen sulfide, which readily reacts with various types of metal (Little and Wagner, 1997). The use of sulfur in many organisms is necessary in the biosynthesis process (Hao, Chen, Haung, and Buglass, 1996). Other organisms that are associated with MIC are acid producing, aerobic slime forming, iron depositing, and low nutrient type bacteria (Bshart, 1998). While SRB have a tendency to receive a majority of the negative publicity, it should be understood that other microorganisms contribute to the presence of MIC. A recent paper by Pope, D. and Pope, R. (2000) suggests slime forming and iron-depositing microbes, which are a form of aerobic bacteria, as an important species in the MIC process. Microbes have the ability, through nutrient intake and waste output, to produce ammonia, sulfides, hydrogen sulfide, organo-sulfur, sulfuric acid, organic acids, carbonic acid, as well as other compositions in aerobic and anaerobic conditions thus, creating various chemical reactions that contribute to the corrosion of metal (Schultz, 1991).

A majority of fire protection systems are manufactured out of iron or steel, therefore the reaction of most interest is the corrosion process of iron by anaerobic SRB. While there is still some controversy over the way SRB influences the anaerobic corrosion in the scientific world, the cathodic depolarization theory, as presented by Videla (1996), has been accepted by most and consists of the following equations:

$$4Fe + SO_4^{2-} + H_2O \rightarrow FeS + 3Fe(OH)_2 + 2OH^- \quad \text{(Overall Reaction)}$$

$$4Fe \rightarrow 4Fe^{2+} + 8e^- \text{ and } 8H^+ + 8e^- \rightarrow 8H \quad \text{(Metal Reaction)}$$

$$H_2O \rightarrow 8H^+ + OH^- \quad \text{(Solution Reaction)}$$

$$SO_4^{2-} + 8H \rightarrow S^{2-} + 4H_2O \quad \text{(Microorganism Reaction)}$$

$$Fe + S^{2-} \rightarrow FeS \text{ and } 3Fe^{2+} + 6OH^- \rightarrow 3Fe(OH)_2 \quad \text{(Corrosion Products)}$$

In general, the overall biocorrosion reaction involves three separate but important reactions between metals, solutions, and microorganisms in order to complete the whole process. The overall reaction is attributed to the capacity of the SRB to uptake hydrogen through their enzymatic system. This reaction is indirectly accelerated by depolarization of the cathode by removing atomic hydrogen from the cathodic areas on the iron surface. This process results in sulfate being reduced to sulfide with end-products of ferrous sulfide (FeS) and ferrous hydroxide ($3Fe(OH)_2$) (Videla, 1996). Other SRB reactions produce toxic acidic byproducts that not only cause corrosion, but also health and odor problems (Grab and Theis, 1993). The specific SRB microorganism reaction can be seen in the following formula as depicted by Tributsch, Rojas-Chapana, Bartels, Ennaoui, and Hofmann (1998):

$$4H_2 + SO_4^{2-} + 2H^+ \rightarrow 4H_2O + H_2S \quad \text{(SRB Microorganism Reaction)}$$

$$Fe + 2\,H_2S \rightarrow FeS_x + 4H^+ + 4e^- \quad \text{(Corrosion Products)}$$

SRB create a reaction in this equation where sulfate (SO_4^{2-}) is reduced or steals two hydrogen ions ($2H^+$) from the metal to produce four water molecules ($4H_2O$) and one hydrogen sulfide molecule (H_2S). This hydrogen sulfide molecule goes on to make end products of various iron sulfides (FeS, iron disulfide FeS_2, and FeS_x), thus contributing to the corrosion of a metal.

According to Schultz (1991), MIC is a reoccurring problem that has attacked nearly all common engineering metals and alloys including carbon steel, lined steel, stainless steels, aluminum, copper, and high-nickel at varying rates. The only metal material known to resist both aerobic and anaerobic MIC is titanium and its associated alloys. The researcher reviewed the reasons why titanium is so effective in the resistance of MIC and found that the tolerance of titanium is explained best by comparing the environments in which MIC flourishes to the known corrosion properties of titanium. Titanium is highly reactive and will easily oxidize in the presence of oxygen to form a highly stable protective oxide surface film. Oxide films are instantaneously formed when fresh metal surfaces are exposed to oxygen or moisture. Because of the physical nature of titanium, and the low survival temperatures of algae, fungi, and bacteria of approximately 35°C or 98.6°F, organisms typically can not produce conditions that affect titanium. This special metal will allow growth and attachment of biofilm on the metal surface, but does not allow biotoxic environments to affect the physical integrity surrounding it. Corrosion has never been reported under any biofilm that has established growth on titanium (Schultz, 1991).

MIC has the ability to induce corrosion anywhere in a FPS and has a favorable liking for weld areas, especially on stainless steels. Factors and areas that contribute to this liking are weld metal, metallurgical material along the fusion zone, increased surface area, possible thin walls, and the heat-affected zones (Schultz 1991). Jenkins (1996) reported leaks near several welds of stainless steel water piping used to supply coolant to chemical separation equipment. Tests performed on the welds showed positive to the presence of SRB and other acid-producing microorganisms. Walsh, Pope, Danford, and Huff (1993) consider the welded areas to be a variable that significantly affects the MIC process. An interoffice correspondence of Factory Mutual Research Corporation points to MIC as a major contributing factor in the development of rapid corrosion and pinhole leaks of weld seams located on stainless steel flexible hoses in a semiconductor fabrication FPS. Factory Mutual found leakage around the heat-affected zones on welds after two years of service (Examination of Stainless Steel Flexible Hoses, Factory Mutual Research Corporation, October 30, 1997). These reports of MIC existing on the weld areas of the metal suggest that the literature is accurate in stating that this area is favorable for the formation of MIC.

Characteristics of MIC

It is well established that various types of microbial activity can contribute to the occurrence of MIC. Because this problem is very widespread, numerous characteristics can be used to help identify the presence of MIC. Some very basic characteristics are pinhole leaks, tubercle growth, pitting, dark colored slime growth, and retarded or blocked flow of pipes and/or sprinkler heads (McNeal, Jones, and Little, 1991). Figure 6 shows an example of pitting and crevice corrosion found on a pipe from a FPS.

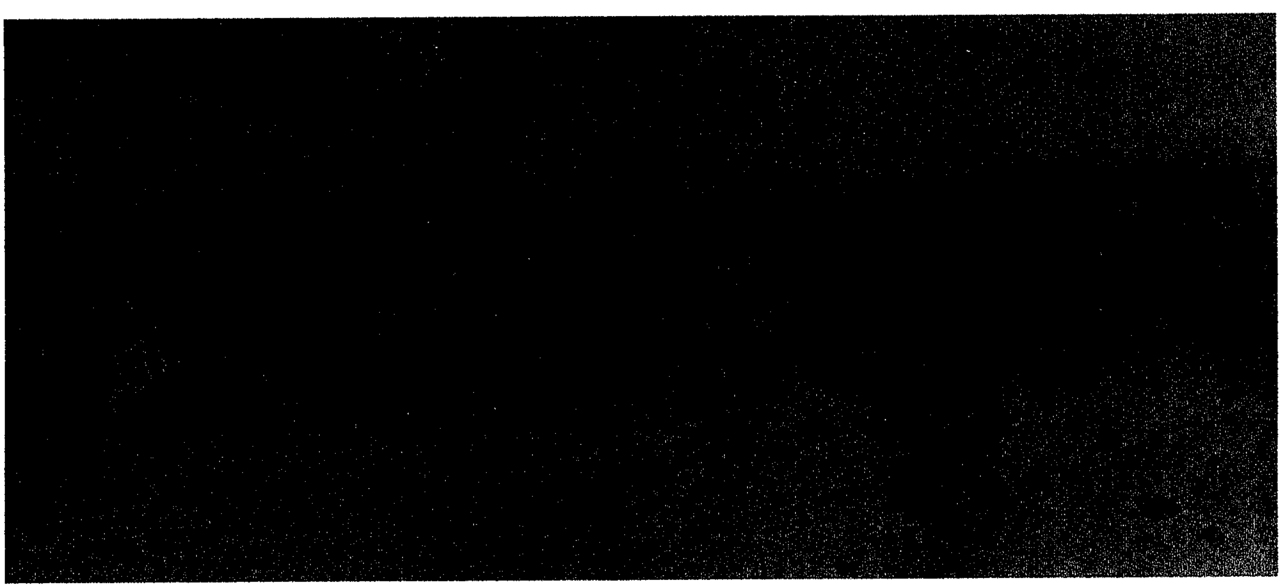

Figure 6 Crevice/pitting corrosion (The American Fire Sprinkler Association)

More specifically, McNeal, Jones, Little (1991); Peng and Park (1994); Hao, Shen, Huang, and Buglass (1996), and Moisidis and Ratiu (1996) suggest that MIC can have the following identification/warning characteristics:

- pipe failure
- crevice corrosion
- pitting corrosion on the metal surface
- presence of microbial slime masses
- presence of hydrogen sulfide in an anaerobic system
- FPS piping with high in metal sulfides in the water
- presence of sulfur odors in the water
- presence of metal or alloy hydroxides in an anaerobic system
- presence of ferrous or ferric hydroxide in aerobic systems
- nodules or shiny flat red deposits located on the inner piping walls
- ringed metal blisters at corrosion sites
- large populations of bacteria, algae, or fungi in the FPS
- thinning of pipe walls
- pH range of 4-9
- specific bacteria types, such as *Desulfovibrio desulfuricans, Gallionella, Beggiatoa, and Shaerotilus, etc.,* under tubercle growth
- formation of minerals (chalcocite and hexagonal chalcocite) that are present in a thick non-adherent layer within the biofilm
- high concentrations of carbon dioxide in the water
- low flow rates throughout the FPS due to tubercle or biofilm growth

- blocked or restricted flow through sprinkler heads and or pipes due to tubercle or biofilm growth
- degrading rubber components such as gaskets and O-rings in the sprinkler heads causing small water leaks

Specific FPS factors that contribute to the occurrence MIC are:

- dry areas of the FPS that has a high moisture content
- temperatures less then 52°C (125°F) with fluctuations less than 18.5°C (65°F)
- FPS that are constantly drained and refilled
- stagnant areas of the FPS that have no water movement

There is no guarantee that MIC is a definite problem if one or more of these indicators exist. While corrosion is a naturally occurring event, it seems that the presence of MIC may increase susceptibility and/or accelerate the time needed to degrade a metal (Videla, 1996). In an interview with Myron Shenkiryk of HERC Products Incorporated (personal interview, February 23, 2000), he pointed out that one can not exclude chemicals and natural mineral compositions in the water as being a root cause of accelerated corrosion in either potable or raw water. Typically, carbon steel FPS contain conditions that MIC need to exist regardless of geographic location (Bshart, 1998). Because of this, organizations across the country are susceptible to MIC.

Tests Used to Indicate the Presence of MIC

Identifying MIC characteristics are easily accomplished, but determining the severity of damage and/or monitoring of a system is more difficult. Besides taking a water sample and sending it to the lab for culture and count off-site, new methods have been developed to help determine the presence and/or severity of MIC in a FPS. New survey field test kits can improve the ability of an organization to measure MIC on-site. Both test kits and direct culture techniques are used to determine specific types of microorganisms and bacteria counts. The present trend of the field test kits is to culture multiple physiological bacteria groups. This will allow an organization to test for multiple bacteria species that may be contributing to a MIC (Little, Ray, and Wagner, 1998).

There are several different types of on-site test kits on the market. Scoot and Davis (1992) evaluated six different in-house field test kits that determine the presence of SRB. Of the six commercial test kits evaluated, they found population counts of SRB in each kit differed greatly within a single water source. A major limitation of the test kits is they only react to the presence of SRB. Other corrosion producing bacteria such as slime forming and iron reducing tend to go undetected. These test kits should be used to measure bacteria trends over time rather than exact counts. The researchers determined that when using these in-house test kits there is no best way and no right answer. Companies that offer these kits are Angus Chemical Co. "Bug Check", Caproco Ltd. "Hydrogenase Test", Bioindustrial Technologies Inc. "MICkit", Petrolite Co. "SRB Broth", Conoco Specialty Products "RapidChek SRB", and Biosan Laboratories Inc. "Sani-Check SRB" (Scoot and Davis, 1992). The article by Scott and Davis was published in 1992, so many of these in-house field kits may have been redesigned to produce a more accurate representation of the bacteria count with multiple types of bacteria.

A new test, reported by Copley (1998), was developed by Edward and Graham Hill of Echa Microbiology, and is designed to determine if SRB are present in bilge areas of steel-hulled ships. This test is performed by taking a sample of bilge water and placing it into the test kit vile. The vile contains a suitable growth medium for SRB and ferrous salts. If the medium turns black-over night, then large numbers of SRB are present in the water sample. Similar to the test-kits reviewed by Scott and Davis, tests like this can easily be used to determine the presence of SRB in a FPS, but do not give actual bacteria count.

Besides culturing bacteria, biochemical assays have been developed for detecting specific microorganisms associated with MIC. This detection process does not require growth of bacteria for detection or quantification, but rather it measures various bacterial processes that are associated with MIC. Results can be determined by extracting liquids, sludge, or solids derived from corrosion products in the FPS (Little and Wagner, 1997).

If in-house test kits are used to monitor bacteria groups, they should be selected on the basis of ease in use as well as consistency of results. The tester should look for changing trends in bacteria populations to determine if significant variation exists. It is also important to remember that just because identifiers of MIC have been found, other techniques like radiography or ultrasonic inspections should be considered to determine positive MIC identification. Felder and Stein (1994), found that in-house test kits have a high variability, therefore organization should not rely upon them as their primary source of MIC investigation.

MIC Treatment Controls

Other than constructing a FPS out of highly expensive titanium, various treatment methods have been designed and subsequently proven to control the outbreak of MIC. Most methods use a type of biocide or inhibitor to control the effects/growth of microbes with some being more effective than others. Various bacteria such as sulfate reducing, acid producing, iron depositing, and aerobic slime forming have been tested in labs, as well as in field studies to determine the effectiveness of biocides and inhibitors. Data shows that biocides are often effective in laboratory tests, but are ineffective in field tests (Pope, Zintel, Aldrich, and Duqette, 1990).

It has been determined that many commonly used biocides are often relatively ineffective against microorganisms contained in biofilms. For a biocide to be effective it must 1) have the ability to penetrate or remove the biofilms and 2) resist various effects that often render a biocide useless (Grab and Theis, 1993). The difficulty of controlling biofilm is to maintain a chemical condition compatible with other treatment strategies, materials in the system, and the surrounding environments. Before circulating biocides through a FPS, it is important to consider the effects it may have on employees, environment, FPS, and surrounding work areas. Reactions of biocides with other gases/chemicals associated with semiconductor manufacturing may create environmental problems due to FPS releases (Pope, Zintel, Aldrich, and Duqette, 1990).

Dr. Dan Pope (personal communication, February 23, 2000) and Myron Shenkiryk (personal communication, February 23, 2000) suggest certain steps that must be performed in order to have a successful MIC control program. The use of these steps was supported by literature from Little, Ray, and Wagner (1998) and consists of 1) penetration and or removal of biofilm and tubercle growth within the pipes and 2) introduction of biocides into a controlled water source. If these steps are followed, they have the potential to minimize the corrosion related activity within the FPS.

Before a MIC treatment control can be implemented, the presence of biofilm buildups/damage must be investigated. Biofilm or tubercle observance must be removed by a pipe cleaning technique. The HERC organization offers pipe cleaning services where chemically customized fluids are introduced into the FPS and circulated for 24 to 48 hours. The completed process establishes a clean metal surface (M. Shenkiryk, personal communication, February 23, 1999). Treatment expenses typically cost between 25% and 50% of the piping replacement costs (Bshart, 1998). If corrosion is caught at an early stage, extreme cleaning techniques, like the HERC process, are not necessary.

While the sources of MIC related contamination might vary, one potential area to control is in an organization's water supply. Feed-water introduced into the FPS may potentially be contributing to a MIC problem. Water from a city municipality is typically processed to drinking water standards, however there is a chance that this water may have a significantly high bacteria concentration. In the past few years health and environmental concerns resulting from the disinfectants have caused many city water suppliers to reduce the concentration in the water to control bacteria, viruses, and fungi. The decrease in concentration potentially allows an increase in microbial survival rate, which in turn is introduced into the FPS (Pope, D. and Pope, R.,2000). Given the likeliness that water introduced into the system may already contain microbes, it appears that the primary means to prevent the continued development of MIC requires the addition of controlling biocides into the FPS.

While there are many proposed methods to control MIC, Costerton, Geesey, and Jones (1988) suggest that mechanically disturbing the biofilm will help retard MIC while also enhancing the penetration and effectiveness of biocides. It is extremely difficult for biocides alone to penetrate through all microbial cellular layers. Some commonly used biocides are chlorine, bromine, hypochlorites, ozone, quarternary ammonium compounds, organotins, and glutaraldehyde (Little, Ray, and Wagner, 1998). Corrosion inhibitors at low concentrations can actually act as a nutrient source that may enhance bacteria populations, therefore proper adjustment of biocides is needed to maintain optimum performance (Freiter, 1992). Potekhina, Pospelov, Gottschalk, Sherisheve, Rakitina, Povetkina, and Waarnecke (1999) suggest that microbial adaptation and reactions with other components in the aqueous environment will decrease biocide effectiveness over time. Increasing the biocide concentration is often used as a counter measure, but has the potential to exterminate bacteria having positive affects on decreasing the corrosion rate. Recently, corrosion research has been initiated to genetically engineer strains of bacteria which will aid in the prevention of biocorrosion (Jayaraman, Lee, Hallock, Manfeld, Carson, and Wood, 1999). New strains of bacteria would secrete poisonous peptide molecules that would destroy specific strains of biocorrosion bacteria, which in turn would help control the affects of bacteria associated with MIC (Schmeider, 1998).

A recent study by Moisidis and Ratiu (1996), surveyed 18 utility organizations investigating the existence of corrosion in fire protection systems that used water from wells, rivers, and domestic sources. The researchers present an in-depth corrosion control program geared toward fire protection systems based on data that was collected in the survey. They suggest the following steps to minimize MIC-related corrosion problems in a FPS.

1. Organizations should consolidate any known plant corrosion information including identification of susceptible systems, mapping locations for samples, testing, and investigating operation parameters of the FPS.
2. Walk-through inspections should be performed at least once a year to confirm, locate, and define any corrosion activity. This should aid in ranking locations for additional inspections, sampling, and testing.
3. After all corrosion information has been consolidated, organizations should perform a system condition assessment to determine the severity of the corrosion. The assessment requires a plan for water, microorganism, metallurgy sampling, pipe thickness tests, and system flow tests.
4. Based on data collected from the previous steps, proper selection of sampling points for high corrosion probability should be addressed. Critical parts of the system like sprinkler heads, hydrants, valves, as well as identified impaired or inoperable areas, should be given priority and special attention. All sampling needs to take into consideration safe shut-down of the FPS, cost associated with system failures, and

areas where 100% protection is needed at all times. Sampling cost needs to be balanced against loss of productivity due to shut-down and desired accuracy. Water samples and corrosion deposits can be used to perform a biological assessment to correlate to the system characteristics. Water sample analysis will provide information towards water corrosiveness. The corrosiveness of a system is usually characterized by its pH, dissolved salts, suspended solids, biological activity and quantity, oxygen concentration, and mineral scale deposits. All information is used to help determine a proper treatment program.

5. In order to assess the extent of MIC damage, corrosion inspections of pipes, elbows, and tee fittings should be performed. This includes a visual inspection of exterior piping to identify surface corrosion, wall cracks, and leaking joints. A more in-depth inspection may involve metallurgical examinations, ultrasonic wall thickness scans, and analysis of corrosion deposits in the damaged areas. These inspections will help identify grooves, pitting, and uniform corrosion of the inner walls.
6. After the initial investigation has identified FPS problems due to the presence of MIC, organizations need to determine proper treatment solutions. Treatment involves the process of establishing frequency, location, methodology of necessary treatments, and possible alternatives. Chemical treatments/reactions need to be investigated for each new proposed modification to ensure chemical compatibility of existing treatments and employee safety. This will minimize side-effects associated with the implementation or modification of existing processes. If removal of biomass or scaling is needed, hydrolazing, flushing, cathodic protection, and chemical treatments should by analyzed to determine best results.

7. Once a sound chemical treatment process has been established, a continuous monitoring program needs to be implemented to ensure a proper functioning system. This includes conducting continuous corrosion testing, determining the ongoing corrosion rate, measuring microorganism populations, and measuring biocide levels. Once administrated, the effectiveness of all treatments should be evaluated to determine if the corrosion activity is decreasing. From a problem source standpoint, this includes determining if the water supply is a contributing factor of corrosion.
8. In order to avoid future corrosion problems, organizations should develop a MIC reoccurrence control program which includes site selection for inspection, analysis of data, corrosion evaluation, inspection procedures, decision for repair or replace, and new recommendations to improve maintenance procedures (Moisidis and Ratiu, 1996).

The control of MIC appears to be a complex combination of chemistry, microbiology, and water resources. Other MIC minimization schemes suggested by Wolfaardt, Cloete (1991), Felder, Stein (1994), and Little, Ray, Wagner (1998), are as follows:

- increasing or decreasing FPS pH levels, temperature, nutrients, chloride concentration, and flow rate to disrupt the biological environment
- eliminating stagnant water sites in the FPS
- replacing current construction materials with corrosive resistant piping
- adjusting amounts and types of biocides in the FPS
- removing sulfates to minimize the reduction process from SRB
- controlling dissolved oxygen concentration in order to avoid bacteria blooms

- implementing new programs to flush and clean pipes to mechanically disturb the presence and formation of MIC
- adding metal sampling coupons to the FPS to evaluate bacteria counts and monitor corrosion rates
- performing surface analysis of corrosion products and biofilms to determine specific types
- performing water quality measurements to determine chemical makeup and corrosiveness
- converting wet pipes to dry pipe systems
- increasing pipe wall thickness
- changing physical layout design of the piping and operating procedures

Microbiologically influenced corrosion is a complicated problem involving different aspects of science. Measures can be taken to minimize the chances of MIC in fire protection systems. If steps are taken to implement a corrosion control program, organizations will reap the benefits of their FPS functioning properly when called upon to minimize a loss-producing incident (Moisidis and Ratiu, 1996).

Current Best Practices

Because microbiologically influenced corrosion has many varying factors, there is no one specific best practice that should be followed. Many variables contribute to the evolution and reproduction of different types of bacteria, virus, and fungi corrosion. Every organization should determine the contributing factors mentioned in previous sections and make decisions based on their findings. In general, organizations need to investigate the potential for MIC problems regardless if the FPS is new or has been in service for a significant amount of time. Dr. Daniel Pope, President of Bioindustrial Technologies Incorporated, has written many papers about MIC and has designed a best practices system for controlling MIC in a FPS. His best practices system agrees with much of the literature from previous sections of this paper and can be broken down into the areas of 1) new FPS MIC control and 2) existing FPS in service. The following information from a brochure supplied by Bioindustrial Technologies Incorporated and a paper by Pope, D. and Pope, R., (2000) focuses on a system that will aid in protecting an organization from risks associated with MIC.

New FPS MIC Control

If the organization has recently installed a new FPS the following steps should be followed to minimize the effects of MIC.

1. Tests should be performed on the make-up/source water of the FPS to indicate bacteria and chemical factors that are important in MIC formation and control. This data is important when choosing a proper treatment strategy.
2. If tests show positive to MIC or potential development of MIC, an organization should develop a treatment plan to remove foreign matter and treat the FPS based on step one. Treatment options may involve flushing with disinfected water or detergents. It is important to remove dirt, oils, and other material, which may harbor bacteria, provide food to microbes, or shield bacteria from biocides. This cleaning allows the biocides to work properly.
3. Once steps one and two are completed, it is important to install a treatment delivery system that will input the proper recommended chemicals into the source water entering the FPS. Entrance of untreated water has the potential to worsen or initiate MIC.
4. Finally, an organization must monitor the treatment process to determine the degree of success. This is accomplished through routine flow tests and reviewing the

implemented program at least once a year or when ever changes are made to the FPS. A well-designed program will monitor at least the microbes, oxygen, pH, total iron, and residual chemicals. If possible, installing monitoring corrosion coupons allow early detection of MIC and ensure that the treatment is continuous and effective in controlling MIC (Bioindustrial Technologies Incorporated Brochure, and Pope, D. and Pope, R., 2000).

Existing FPS in Service

If the organization has an existing FPS in service, the following steps should be followed to minimize the effects of MIC.

1. Tests should be performed on the make-up/source water of the FPS to indicate bacteria and chemical factors that are important in MIC formation and control. It is important to take water samples from the make-up/source water, riser(s), main, inspector's test connection, and from hot-spots (areas of know corrosion) where corrosion or leaks have occurred. If tests show positive for the presence of MIC, there may be a MIC problem.
2. If water tests are positive to MIC activity, a pipe analysis should be performed. Pipes from the riser, cross mains, inspector's test connection, ends of remote branch lines, and hot-spots can help determine the distribution and severity of the problem and provide information to properly choose a treatment method. This information is critical due to the changing environments within a FPS at different locations.
3. If MIC characteristics have been identified or the potential for MIC development is present, an organization should develop a treatment plan to remove foreign matter and treat the FPS based on steps one and two. Treatment refers to taking a

course of action to rehabilitate or mitigate the affected portions of the FPS back to a healthy state. Treatment options may involve flushing with disinfected water/detergents, replacing badly damaged pipes, or cleaning with strong acids/alkalis in extreme cases. It is very important to take the treatment chemicals into close consideration due to potential environmental and health effects. Many biocide chemicals that eliminate microbes in other industries may be toxic and nontransferable to a FPS. This step can vary dramatically depending if organic or inorganic compositions need to be removed. After cleaning, the FPS should be rinsed with a disinfected water to remove any remaining chemical residue.

4. Once all material has been removed, it is important to install a treatment delivery system that will input the proper chemicals into the source water entering the FPS. Entrance of untreated water has the potential to worsen or initiate MIC.
5. Finally, an organization must monitor the treatment process to determine degree of success. This is accomplished through routine flow tests and reviewing the implemented program at least once a year or when ever changes are made to the FPS. A well designed program will monitor at least the microbes, oxygen, pH, total iron, and residual chemicals. If possible, installing monitoring corrosion coupons allow early detection of MIC and ensure that the treatment is continuous and effective in controlling MIC (Bioindustrial Technologies Incorporated Brochure, and Pope, D. and Pope, R., 2000).

Each FPS is unique, therefore every individual FPS needs to be investigated to control potential outbreaks of MIC. There are various companies that can assist in all steps of program implementation and testing. Treatment plans should be developed to return the FPS to full and safe operation with limited expenditures of time and money. It is important to complete a cost benefit analysis to ensure treatment is more economical than pipe replacement. Without a MIC control program, it is virtually impossible to regularly deliver treatment chemicals to all parts of the FPS. All steps and factors should be considered to avoid damage to the FPS as well as minimizing unnecessary costs and jeopardizing human health. Regardless of the FPS age, there are steps that can be taken to control the chances of MIC. With the proper combination of biocides and treatment strategies, organizations can create a best practices program that will reduce the potential for loss though the control of risks associated with MIC.

Summary

Corrosion is a naturally occurring process where material is oxidized or reduced. Recently, corrosion has been found in water-based fire protection systems. Many factors have contributed to this newly found phenomenon associated with fire protection systems. Some of these factors are increased awareness, movement from thick to thinner pipe, decreased disinfectant in the water supply, and increased inspections of the FPS. It has been determined through large amounts of literature that much of the present corrosion is a result of microbial influence. Various distinct characteristics can be used to identify the role microbes play in the corrosion process. Numerous types of field tests have been developed to identify the severity and presence of the microorganisms. Common metals show an increased degradation effect due to microbial activity, however titanium is one metal not affected by microbiologically influenced corrosion. Biocides and other treatment methods have been developed to aid in the reduction of microbial influenced corrosion in piping systems.

MIC is a process that has the ability to affect an organization in numerous ways. Developing effects may be observed in a short period of time or take years to develop. This problem has been known to affect various industries and most recently fire protection systems. Fire protection systems must be maintained properly to reduce risks associated with the fabrication of microprocessors. The key to managing this problem is to acknowledge that MIC is a threat to the organization and then minimize the problem through identification, testing, and best practice preventative controls. The minimization process should make water-based fire protection systems inhospitable and inaccessible to microbiologically influenced corrosion.

Chapter III

Methodology

Introduction

The purpose of this study was to determine if Company XYZ is using best practices to minimize the occurrence of microbiologically influenced corrosion. The focus of the research was to collect and consolidate biocorrosion-related information associated with water-based fire protection systems in Company XYZ's semiconductor fabrication facilities. The three major objectives of this study were to:

- Develop a protocol to detect and identify MIC characteristics.
- Investigate MIC controls that Company XYZ have in place to minimize outbreaks of MIC.
- Compare current proactive MIC controls within Company XYZ to best practices for controlling MIC as determined by recent literature. The comparison will determine if Company XYZ is using best practices to control MIC problems.

The methods and procedures used to identify risks to Company XYZ and appropriate control systems are explained under the following headings of a) method of study, b) population and samples, c) data collection techniques, d) procedures followed, and e) method of analysis.

Method of Study

A review of literature was completed to identify the means of MIC formation, characteristics, tests used to indicate the presence, treatment controls, and current best practices. Information was obtained from recent articles in professional journals, books, and direct contact with venders/consultants who are involved with the treatment and prevention of MIC.

This information was used to develop a telephone survey questionnaire to determine if semiconductor facilities owned and run by Company XYZ are using best practices to minimize risks associated with the presence of MIC. The survey questionnaire was used as guidance in phone interview with Company XYZ. Most phone interviews were with on-site fire engineers or mechanical engineers that have an understanding of the water-based fire protection system. The telephone interviews were used to determine if the contacted facilities are integrating best practices for controlling MIC into their organization. The results of the survey were analyzed and used to determine if activities, tasks, and conditions are being performed to reduce and control the actual risks associated with MIC. The interview survey form investigated the current methods used to control MIC outbreaks by interviewing facilities of Company XYZ located around the United States to determine if best practices are currently being used to regulate and control this problem.

Data Collection Techniques

The telephone survey questionnaire was chosen as the data collection instrument because of ease of use and ability to accurately represent an organizations MIC presence, control activities, and conditions. The survey can also aid in the identification of MIC controls a facility may have in place to minimize an outbreak. The study focuses on semiconductor facilities in the United States, therefore a phone interview seemed to return the largest amount of information about MIC in a practical amount of time. The survey is based off of key factors that literature suggests as best practices for a successful MIC control program. The survey has a variety of questions to give an indication and a better understanding of the potential for MIC occurrence and possible controls each facility has in place.

Appendix A contains the telephone survey questionnaire form. Because the questionnaire deals with professionals in high profile positions within Company XYZ, a willingness to participate consent form was required and can be found in Appendix B. Extreme care was taken to ensure complete confidentiality during this study. The survey questionnaires were coded in order to render the information worthless to people not associated with the study. After the study was completed all confidential information was destroyed to minimize the possibility of adverse affects to the surveyed individuals. A copy of this paper was also sent, via e-mail, to all interested persons that were surveyed and or contacted for information.

Procedures Followed

The following steps were followed to conduct this study:

1. The purpose of this study and significance were developed and approved in March 2000 through the writing of a scholarship paper presented to the Semiconductor Safety Organization (SSA).
2. A review of literature was completed. From this review a survey questionnaire was developed and became the data-collecting instrument.
3. The survey questionnaire was reviewed by selected graduate instructors and the Protection of Human Subjects in Research Committee within the graduate college at the University Wisconsin Stout. Revisions of the survey instrument were completed and used in the interviews.
4. A contact person from Company XYZ at each semiconductor manufacturing facility was identified. These facilities are located throughout the United States.
5. The contact individuals at Company XYZ were then contacted, via telephone, and interviewed.
6. Specific information was gathered by direct contact with risk control professionals (environmental, health, and safety) within Company XYZ. These individuals have an understanding and background of their organization's water-based fire suppression

systems. Additionally venders/consultants who are involved with the treatment and prevention of MIC were also contacted.

7. During the interview written notes were taken. The interviews followed the survey questions. Other questions were also integrated into the interview when specific topics were addressed.
8. Ten telephone survey questionnaires were completed.
9. All interviews were finished on August 19 of 2000.
10. Data analysis was completed on September 22 of 2000.
11. Conclusions and recommendations will be presented to all interested interviewees by November of 2000.

Method of Analysis

The results of the surveys were analyzed by hand and compared to best practices as determined by the review of literature. The responses were also used to identify and/or change gaps the facilities may have with regards to the formation, presence, test, best practices, and control of MIC.

CHAPTER IV

Results and Discussion

Introduction

The methods used to accomplish this study were; 1) review of literature, 2) development of a telephone survey questionnaire, and 3) administering the telephone survey interview. The survey was administered to Company XYZ, which is a major semiconductor organization that produces microchips throughout the country and world. The survey was conducted by contacting persons from US facilities having a title of fire engineer, mechanical engineer, or facilities maintenance. A total of six sites were analyzed within Company XYZ covering various geographic locations across the United States.

An analysis of the survey forms was conducted to determine if Company XYZ has integrated a best practice approach for controlling microbiologically influenced corrosion within their risk minimization process. The following information has been utilized to analyze the survey and interview results. This information is presented as it relates to the objectives of this study.

Objective One:

The first objective was to develop a protocol to detect and identify MIC characteristics. This part of the study was accomplished in the review of literature and therefore has no significant data from the sampling survey.

Objective Two:

The second objective was to investigate MIC controls that Company XYZ is using to minimize outbreaks of MIC at facilities across the United States. The review of literature provided a guideline to develop the survey form and information regarding best practices an organization should have in place to minimize all affects of MIC. The following section presents an analysis of current information gathered from the phone survey questioner regarding the measures used by Company XYZ to control an out break of MIC.

It was found from the survey questionnaire that 50% of Company XYZ's manufacturing sites located in the United States have a corrosion problem within the FPS, however these corrosion problems are not believed to be specifically caused by MIC. The facilities that reported a corrosion issues are unsure of the contributing factors causing the corrosion. All site locations reported that there are no substantial corrosion problems in their geographic location. Sites that reported corrosion problems showed evidence of leaky pipes, pinhole leaks, thinning of the walls, and groves found on the inners of the piping. One site identified tubercle growths in the piping. After further lab analysis the tubercles were identified as positive to the presence of MIC. Facilities that reported corrosion typically replace 2-4 sections of pipe every year and are usually not tested for the presence of MIC.

Different sites reported varying times of inspection, but all stated that the inspections are based off of the National Fire Protection Association (NFPA) recommendations, therefore some inspections are daily, weekly, monthly, quarterly, annually, and as recommended. Water samples are at least taken quarterly. All sites report that multiple samples are taken from fire hydrants, risers, line ends, inspectors test valve, and from incoming city water. All facilities receive their water from municipalities, which commonly treat the water to drinking standards. All water-based suppression systems are closed loop systems that have backflow preventors to ensure no contaminated water or chemicals will backflow into the city water system. Further treatment of the water at all facilities is done by mixing stabilizing chemicals at the fire storage tanks or injection of chemicals into the FPS at the fire pumps. Only two facilities were able to provide information regarding the stabilizing chemicals injected into the FPS. One facility uses a form of bromine that was unspecified and the second facility uses sodiumhexamedaphosphate. Fifty percent of the facilities reported occasional rotten egg smell in the fire system water. The piping in the FPS cover millions of square feet of floor space at all facilities. This floor space is made of at least one fabrication facility as well as other buildings on site. No contacts provided an exact square footage based dimension of their facility, but each claimed that it is in the millions of square feet at each site location.

All facilities have a combination of welded and grooved systems made up of mostly steel piping. One facility uses PVC in half of the underground piping. No one from any facility could report the total hardness, dissolved oxygen, total iron, or amount of residual chlorine characteristics present in the firewater. Some of the personnel are unsure if all of those chemical constituents are tested. This is mainly due to facilities contracting out this type of work. Therefore if water seems to be stable, then Company XYZ does not always hear about it. Company XYZ takes the idea that no news is good news.

No sites within Company XYZ have a written MIC program in place that specifically deals with the minimization of this risk through best practices, however there has been a push from corporate division to create and implement a MIC program to protect the FPS from a MIC invasion. While all site locations do treat and monitor the FPS water, none have initiated a best practices approach to ensure no losses in the fabrication areas as a result of MIC.

Objective Three:

The third objective is to compare the current MIC controls of Company XYZ to best practices of minimizing and controlling MIC as determined by recent literature. The following section will compare information regarding Company XYZ, which was gathered from the phone survey, to information presented in the review of literature concerning best practices approach for reducing an organization's risk to MIC.

When comparing Company XYZ to best practices as determined by a review of literature there are many similarities as well as differences. A comparison of data collected will be made to five sections of the review of literature. Those sections are 1) Formation of MIC, 2) Characteristics of MIC, 3) Tests Used to Indicate the Presence of MIC, 4) MIC Treatment Controls and, 5) Current Best Practices.

Formation of MIC

The FPS at each site is a closed loop system resulting in a low flow rate through the piping. This does not allow a constant movement of water or delivery of biocides throughout the entire system. Best practices states that mechanical disturbance can greatly reduce the ability of MIC to initiate formation on the inner walls of the piping. Closed sprinkler systems are potentially at a higher risk for developing MIC. Also because the piping is made up of both welded and grooved sections the welded areas have a higher probability of developing MIC in heat-affected zone according to literature.

Characteristics of MIC

Within the facilities that reported a corrosion problem there were similar characteristics of MIC. Leaky pipes, pinhole leaks, thinning of the walls, and groves found on the inner walls of the piping are all potential indicators of MIC, however they do not totally verify the presence of MIC.

Because data regarding water characteristics in the FPS was unattainable, a comparison between current best practices and the current status of water within Company XYZ cannot be made, however best practices states that it is important to constantly maintain, check, and adjust the chemical composition within the water. The review of literature also states that natural minerals and combinations of chemicals present in the system may also contribute to a corrosion process.

Resent literature shows that draining and refilling a FPS can reintroduce new nutrients and bacteria into the system. Unfortunately in the semiconductor industry, retooling is an ongoing process that constantly requires adjustment of the FPS in order to protect the tools and investment in the fabrication area. Contacted individuals stated that draining a system is a common occurrence when repairing or adjusting the FPS. Managing the draining and refilling of a FPS as well as the firewater may help to minimize MIC activity.

Tests Used to Indicate the Presence of MIC

Currently, Company XYZ takes water samples but does not use a MIC specific test to monitor the bacteria count within the FPS. It is suggested that organizations incorporate a MIC testing procedure to track the trends of the bacteria in the FPS. This would allow a change within the system to be seen as well as identification of specific bacteria groups.

MIC Treatment Controls

The only treatment control currently being used by Company XYZ is the mixing and injection of biocides or stabilizing chemicals into the FPS. Specifically, one facility injects a form of bromine, which can become an oxidizer at the right concentration and contribute to the corrosion of the piping. While controlling the water source is a very important step of a best practice program for controlling MIC, it is only a small element in the big picture. Because each FPS is different it is difficult to determine the correct concentration and chemicals that need to be integrated into all areas of the system to ensure control of unwanted bacteria. While no facility reported the presence of biofilm, all facilities did assume that the biocides being used are penetrating into the various layers of the biofilm aiding in the control of MIC. The review of literature shows that the first step in minimizing any MIC problem is through a pipe cleaning method. No cleaning has ever been initiated at any site owned by Company XYZ.

Current Best Practices

When comparing Company XYZ to current best practices, it can be determined that Company XYZ could greatly improve as it relates to utilizing known best practices. Company XYZ has never addressed the potential problem of MIC in the preplanning stage of fab construction. The only similarity between Company XYZ and best practices is the idea of taking water samples from various piping locations within the FPS. No real in-depth treatment plan has been developed at any Company XYZ site to minimize or prevent this problem. Company XYZ does try to stabilize the ingoing water, but it is likely that this is not enough to control and manage any outbreak of MIC.

Summary

While the survey analysis identified fabrication facilities with the greatest potential to be affected by MIC, it also illustrated specific activities, tasks, and conditions contributing to the risks associated with MIC. The analysis of the survey questionnaires, which represent a cross-sectional representation of the individual sites, highlights the controls that are currently being used as compared to the ones that are available to minimize MIC problems through a best practice approach. The phone surveys also demonstrated the perception the fire engineers, mechanical engineers, and facility maintenance personnel have regarding the protocols and systems they feel should be implemented and evaluated. The information gathered and presented may be applied to the development or at least refinement of a best practices approach to minimize and mitigate MIC within a FPS.

CHAPTER V

Summary, Results, and Recommendations

Summary

Restatement of the Problem

Microbiologically influenced corrosion (MIC) is a distinct type of corrosion where microscopic organisms influence the corrosion process (Bshart, 1998). MIC has emerged in the last several years as a major cause of corrosion problems in fire protection systems. It has been determined that MIC attacks have affected the integrity of all metals with the exception of titanium (Schultz, 1991). It has been estimated that 10-30% of corrosion in all piping around the country is a result of MIC (Bshart, 1998). Because semiconductor organizations deal with high risk and high dollar investments it is extremely important to control and protect the company's assets. MIC has the potential to reduce the effectiveness of the fire protection system leaving an organization with a greater chance of loss, therefore this problem can be considered a serious risk if uncontrolled.

The purpose of this study is to determine if best practices are currently being used to minimize the effects of microbiologically influenced corrosion with in Company XYZ. The objectives of the study are to:

1. Develop a protocol to detect and identify MIC characteristics.
2. Investigate MIC controls that Company XYZ has in place to minimize outbreaks of MIC.
3. Compare current proactive MIC controls within Company XYZ to best practices for controlling MIC as determined by recent literature. This comparison will determine if Company XYZ is using best practices to control MIC problems.

Based on the information in this study organizations should take steps toward investigating and implementing solutions for microbiologically influenced corrosion before it is too late.

Methods and Procedures

A review of studies completed by a variety of researches from recent published articles found in professional journals, books, as well as direct contact with venders/consultants who are involved with the treatment and prevention of MIC were used to complete this study. This information was used to; 1) determine identifiable MIC characteristics 2) develop a survey questionnaire, and 3) evaluate methods of MIC control as it relates to best practices. The survey was completed with the use of phone to produce a total investigation into six targeted facilities resulting in a 100% return of useful information. Specific people with certain job titles from each facility were interviewed to produce the most accurate information possible.

Major Findings

The analysis of the results collected from survey and interviews are summarized and presented as they relate to each of the study objectives.

Objective one: Identifying MIC Characteristics

1. Numerous types of aerobic and anaerobic bacteria can contribute to the degradation of a FPS.
2. If the environment is suitable for continuous development, the biofilm may begin to develop tubercle growth in as little as five to seven days.
3. The overall biocorrosion reaction involves three separate but important reactions between metals, solutions, and microorganisms.
4. MIC can have a variety of identification/warning characteristics.
5. In-house field tests often report unrealistic information regarding the presence and growth of MIC.

6. The only metal not affected by MIC is titanium.
7. It is difficult for most biocides to penetrate biofilm deep enough to destroy and control the cellular division of the bacteria.

Objective two: Facility Evaluation

1. The interview responses found that 50% of the facilities are affected by some type of corrosion.
2. Company XYZ has a minimal MIC control plan in place to ensure that their FPS is working properly.
3. Facilities that have corrosion problems typically replace 2-4 sections of pipe per year.
4. All facilities treat the incoming water, which is from the municipality, with a stabilizer and/or bacteria inhibitor.
5. All FPS service numerous building and are often drained and refilled.
6. The FPS is made out of steel with some areas being constructed of PVC.
7. The facilities that are affected by corrosion have side-effects of pinhole leaks and tubercle build up.

Objective three: Best Practices

1. Best practices states that penetration and removal of biofilm and tubercle growth within the pipes is necessary before a MIC control program can be affective through the introduction of biocides into a FPS.
2. If possible, it is important to be proactive in the minimization of MIC through the design phase of construction ensuring that construction of the FPS has been handled properly and water quality tests have been evaluated to allow an understanding of any problem that may be present.

3. Organizations should develop a MIC control program which includes FPS inspections, analysis of data, corrosion evaluation, water analysis, inspection procedures, continuous system monitoring, decision for repair or replace, and proper maintenance procedures.
4. Companies should adjust all chemical characteristics associated with any feed-water water quality and biocides that are in use to meet the needs of the FPS, which is based on a continuous testing of the system.

Because microbiologically influenced corrosion has many varying factors, it is very difficult to pinpoint one specific best practice to minimize this problem. Organizations must investigate, analyze, recommend, and implement the proper control programs.

Conclusions

The early identification and use of adequate controls can effectively reduce the presence of MIC in any FPS (Moisidis and Ratiu, 1996). The conclusions of this study will be discussed as they relate to the major findings.

Exposure risks and controls

It was found that 50% of Company XYZ's fabrication facilities were affected by some form of corrosion. The control systems that are in place are very minimal and do not directly address the potential problem of MIC infestation. No one facility can specifically say or conversely deny that they have this problem and it is under control. Bacteria is everywhere so there is always possible exposure to a form that may initiate MIC formation and increase potential risk. Controls used at each facility do not address numerous aspects of best practices as determined by the review of literature and cannot be relied upon to minimize the associated risks of MIC.

Recommendations

Recommendations Related to this Study

The results of this study indicate that the current MIC control program utilized by Company XYZ is inadequate and a bare minimum at best. Their plan addresses the potential problem in a reactive way, rather than taking a proactive approach, unfortunately the issues revolving around MIC are complex and still somewhat unknown. Company XYZ management must further investigate this possible problem with in their facilities in order to better understand the associated risks. A redesigned best practice internal control program needs to be created and introduced into the preventative maintenance procedures of the organization. This program must include:

1. Understanding the problem
   - Understand how MIC can affect various susceptible areas in the FPS (sprinkler heads, hydrants, valves, as well as identified impaired or inoperable areas).
2. Inspections of the FPS
   - Walk-through inspections should be performed at least once a year to identify, confirm, locate, and define any corrosion activity as well as determine locations for additional inspections, sampling, and testing.
   - Visual inspections of pipes, elbows, and tee fittings should be performed to identify surface corrosion, wall cracks, and leaking joints.
   - A more in-depth inspection may involve metallurgical examinations, ultrasonic wall thickness scans, and analysis of corrosion deposits in the damaged areas. These inspections will aid in identifying grooves, pitting, and uniform corrosion of the inner walls.
3. Chemical analysis of the water and piping

- Organizations should perform a system condition assessment to determine the severity of the corrosion. The assessment should investigate the water, microorganism, pipe metallurgy, pipe thickness, and system flow tests.
- Water samples and corrosion deposits can be used to perform a biological assessment to correlate to the system characteristics such as: corrosiveness, pH, dissolved salts, suspended solids, biological activity and quantity, oxygen concentration, and mineral scale deposits.
- Water and pipe analysis from the risers, cross mains, inspector's test connections, ends of remote branch lines, and hot-spots should be performed in order to determine problem areas. By testing the FPS a baseline can be created to compare any fluctuation in the system.

4. Determination of bacteria type
    - Make-up/source water tests should be performed to help indicate specific bacteria and chemical factors that are present or aid in the in MIC formation.
    - In-house test kits or reliable laboratories should be used to determine specific bacteria types. By knowing the type of bacteria specific treatment strategies can be manipulated to properly control MIC.
5. Knowing past history of the system
    - Consolidate any known plant corrosion information and pinpoint identified hot-spots within the FPS.
6. Investigating pipe cleaning methods
    - If removal of biomass or scaling is needed, hydrolazing, flushing, cathodic protection, and chemical treatments should by analyzed to determine best results.

- Removing dirt, oils, and other material, which may harbor bacteria, provide food to microbes, or shield bacteria from biocides will help to control MIC.

7. Understanding water treatment/adjustment issues
   - Specific stabilizing chemicals must be investigated to determine the effectiveness of inhibiting the MIC process.
   - Investing in a treatment delivery system will inject the proper recommended concentration of chemical(s) into the source water entering the FPS.
8. Continuous monitoring
   - This includes conducting continuous corrosion testing, determining the ongoing corrosion rate, measuring microorganism populations, measuring biocide levels, and determining if the water supply is a contributing factor of corrosion.
   - The effectiveness of all treatments should be evaluated to determine if the corrosion activity is decreasing.
   - A good monitoring program will track microbes, oxygen, pH, total iron, and residual chemicals. Installation of monitoring corrosion coupons will allow early detection of MIC and ensure that the treatment is continuous and effective in controlling MIC.
9. Minimization of other associated risks
   - Chemical treatments/reactions need to be investigated for each new proposed modification to ensure chemical compatibility of existing treatments and employee safety. This will minimize side-effects associated with the implementation or modification of any existing processes.

Management must also clearly designate the responsibility in relation to implementing all sections of a best practice MIC control program to ensure that the potential problems associated with MIC are minimized.

Recommendations for Future Study

Areas of further study include:

1. Types and methods of chemical control on specific types of bacteria.
2. Pipe degradation time with known bacteria population.
3. An updated comparison of on-site MIC test kits.

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Appendix A

FPS Survey Questionnaire

1. Initials of interviewee
2. Is there a corrosion problem?
3. Does your geographic region have corrosion issues?
4. Is there a MIC problem in your facility?
5. What are the corrosion side-effects if any?
6. Do you have a written program in place to deal with MIC issues? If so explain.
7. How often is the FPS inspected?
8. What visual corrosion effects are present?
9. How often are pipes replaced?
10. Is there a rotten egg smell to the water?
11. If samples (water/metal) are taken where are they taken from (location)?
12. Is there water treatment process prior to entering the FPS? If so explain.
13. What chemical compositions are used for cleaning, flushing, or stabilizing of the water (i.e. biocides)?
14. What is the source of water (municipal, well, treated or untreated)?
15. Is the FPS an open or closed loop?
16. What is the size of facility (square feet)?
17. How many building are serviced by FPS?
18. How old is the FPS (number of years)?
19. What is the FPS pipe material (steel, brass, other)?
20. What is the system constructed of (welded, screwed, grooved)?

21. How large is your storage tank?

22. What is the max flow rate and PSI from the storage tank?

23. Are there backflow preventors?

24. What is the sprinkler coverage area (square feet)?

25. What is the water pH and how is it controlled?

26. What is the total harness level?

27. What is the total dissolved oxygen?

28. What is the total iron in the water?

29. Is there residual chlorine present?

30. What is the chemical compositions of deposits in the FPS?

31. What types and numbers of bacteria are present?

32. Are you or have you been in litigation over this any corrosion related problem? (Y/N)?

Appendix B

Consent Form

I understand that my participation in this study is strictly voluntary and I may discontinue my participation at any time without any prejudice. I understand that the purpose of this study is to investigate best practices in the minimization of microbiologically influenced corrosion in fire protection systems in the semiconductor industry. I further understand that any information collected in the study about me or the organization I work for will be held in the strictest confidence and will not be part of my permanent record. I understand that at the conclusion of this study all records, which identify individual participants and organizations, will be destroyed. I also give the interviewer permission to initialize my signature in order to proceed with the collection of research information due to distance between the two of us.

Signature or initials of participant: ________________________________date:_______

Signature of interviewer and guardian:______________________________date:_______

NOTE: Questions or concerns about participation in the research or subsequent complaints should be addressed first to the research advisor and second to Dr. Ted Knous, Chair, UW-Stout, Institutional Review Board for the protection of Human Subjects Research, 11 HH, UW-Stout, Menomonie, WI 54751, (715) 232-1126.