Trends in

Applied Sciences Research

ISSN 1819-3579

Academic Journals Inc.

www.academicjournals.com

Trends in Applied Sciences Research 4 (1): 56-61, 2009
ISSN 1819-3579

Investigation of Failure and Corrosion in Pipelines and Tanks used in Ice-Cream Factory: The Case Study

[1]R. Bazargan-Lari and [2]Y. Bazargan-Lari
[1]Department of Mechanical Engineering, Islamic Azad University, Marvdasht Branch, Iran
[2]Department of Mechanical Engineering, Islamic Azad University, Shiraz Branch, Iran

Abstract: This study describes the reasons of failure and corrosion in pipelines and tanks used in ice-cream factory located in Soltanabad Industrial Region, Shiraz (Iran). The present research shows that the chloride level of the water is an important factor in determining the resistance of stainless steel due to crevice corrosion. Laboratory research shows that for the majority of natural, raw and potable water with pH in the range 6.5 to 8; crevice corrosion of 304/304L is rare below about 200 ppm of chlorides. Also crevice corrosion of 316 to 316L with the same pH is rare below about 1000 ppm of chlorides. Chemical analysis of the water of industrial region shows that it contains 386.36 ppm chlorides. So, the stainless steel pipeline type 304, which is used in the factory did not have any resistance against the crevice corrosion and rapidly corroded from those points which were more susceptible such as welded zone. Since the pipes were corroded around the welded zones, metallographic studies were conducted in this area which revealed that the welds were not of high quality and contained holes in the welded zones as well as imperfections such as lack of diffusion and incomplete penetration. Finally preventing methods of pipelines corrosion is discussed.

Key words: Corrosion, stainless steel, welding

INTRODUCTION

Product quality, health and sanitation issues are major concerns in the food processing industry (Kumar and Anand, 1998). The industry cannot tolerate corrosion in the manufactured product. The industry, therefore, needs to account for corrosion control before production starts(Chmielewski and Frank, 2003). Many researches have been done in different categories of the industrial pipelines such as stress corrosion failure (Valiente, 2001), corrosion fracture (Makarenko *et al*., 2007; (Chernov *et al*., 2002) and Strength of them (Makarenko *et al*., 2005). One of the main reasons for application of stainless steel pipes in food industries is its resistance against the release of iron ions which cause the contamination of water. Stainless steels have been widely used since 1965 in food industrial. 304 and 316 types are used in pumps, valves and shafts where welding is not required. In case the structure needs welding, type L is used, e.g., 316L where the carbon content is lowered to less than 0.03%. Having more than 2 to 3% molybdenuim, type 316L is more resistant to pitting and crevice corrosion than type 304L and is preferred in this regard (Fontana, 1978). One of the most dangerous crevices is the one introduced in the structures during welding which is due to incomplete penetration of the weld metal in the matrix. Precipitates are easily trapped in these kinds of crevices.

Corresponding Author: R. Bazargan-Lari, Department of Mechanical Engineering, Islamic Azad University, Marvdasht Branch, Iran

Moreover, chloride concentration is extremely increased in this area, making it susceptible to under deposit crevice corrosion. In order to prevent this kind of corrosion the welded surface must be completely leveled and the weld metal should diffuse well in to the matrix, leaving no holes or imperfections behind. Increasing the velocity of fluid could also reduce the possibility of crevices made by precipitates and deposits. If the service condition or the system design is such that precipitation is inevitable, it is best to wash these precipitates by high pressure water steam (Tuthill, 1994). Usually, oxidants such as chloride and potassium permanganate are used to extract iron and magnesium from water. In this case a black-colored Fe-Mn precipitate is formed inside the pipe walls. These precipitates are harmless for 304L stainless steels but could participate in the under deposit crevice corrosion of the heat affected zone (Kain *et al*., 1984). When there is susceptibility to crevice corrosion, the first issue considered by engineers is the chloride content of water, because of its important role in decreasing the resistance of stainless steel against this kind of corrosion. The chloride content of water could be easily determined, but it is important to note that other factors such as pH, crevice geometry and the quantity of existing oxidants should be considered as well.

MATERIALS AND METHODS

During plant inspections, information about the pipe and vessel material in ice-cream factory which is located in Soltanabad industrial region on Shiraz, the temperature and kind of fluid running through the pipes and their welding methods were collected. Analyzing the specimens revealed them to be in type of 304 stainless steel. A month after the factory begins its productions, the pipes and vessels carrying water were corroded, whereas ones carrying other fluids remained unchanged and sound. Therefore the temperature, velocity and time of water passage through the pipes were measured. Water passed through a sandy filter before entering the first vessel, after which it passed through a water softener and entered the second vessel. The original water entering the plant, the discharge water from the condenser and the water softener were sampled. The results of analysis are shown in Table 1 and 2. On the other hand, since the corrosion of pipes and vessels were mainly concentrated around the weld fillet (Fig. 1, 2) samples were taken for metallographic studies, results which are shown in Fig. 3 and 4.

Table 1: Chemical analysis of the plant's feed water

Parameters	Concentration of parameters in entering water (ppm)	Concentration of parameters after first water softener (ppm)	Concentration of parameters after second water softener (ppm)
Anions			
F^-	0.40	0.30	0.30
Cl^-	198.70	208.10	203.80
SO_4^{2-}	60.70	44.50	143.20
CO_3^{2-}	0.00	0.00	0.00
HCO_3^-	227.70	213.50	215.80
NO_2^-	0.00	0.00	0.00
NO_3^-	14.80	15.10	25.70
PO_4^{3-}	---	---	---
Cations			
NH_3	---	---	---
Ca^{2+}	64.70	0.00	0.00
Mg^{2+}	34.40	0.00	0.00
Na^{2+}	81.50	88.20	85.00
Cu^{2+}	---	---	---
Fe^{2+}	---	---	---
Ba^{2+}	---	---	---
K^+	2.10	2.40	1.80

Table 2: Chemical analysis of the plant's feed water

Parameters	Concentration of parameters in entering water (ppm)	Concentration of parameters after first water softener (ppm)	Concentration of parameters after second water softener (ppm)
Total hardness ($CaCO_3$)	303.30	0.00	0.00
Permanent hardness ($CaCO_3$)	116.70	0.00	0.00
Temporary hardness ($CaCO_3$)	186.60	0.00	0.00
Calcium hardness ($CaCO_3$)	161.60	0.00	0.00
Magnesium hardness ($CaCO_3$)	141.70	0.00	0.00
Methyl orange alkalinity ($CaCO_3$)	186.60	175.00	176.90
Phenolphthalein alkalinity ($CaCO_3$)	0.00	0.00	0.00
Total alkalinity ($CaCO_3$)	186.60	175.00	176.90
SiO_2	0.75	0.70	0.80
Total dissolved solid	718.00	727.00	688.00
pH	7.20	8.01	8.02
COD (O_2)	---	---	---
BOD (O_2)	---	---	---
Turbidity (NTU)	0.035	0.00	0.00
Electrical conductivity (μmol cm^{-1})	1246.00	1254.00	1267.00
Temperature (°C)	26.20	26.30	26.30

Fig. 1: Corrosion in vessel, around the fillet weld

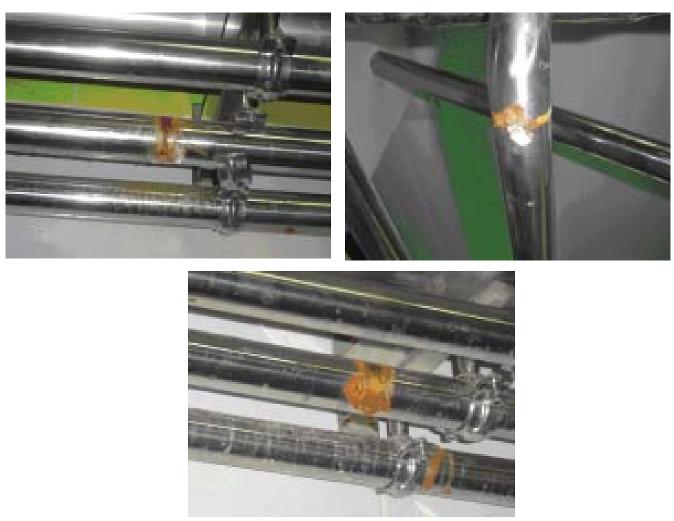

Fig. 2: Corrosion in pipes, around the fillet weld

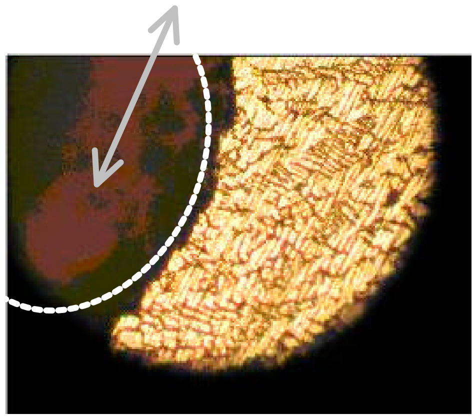

Fig. 3: Microstructure across the fillet weld. Magnification 100x

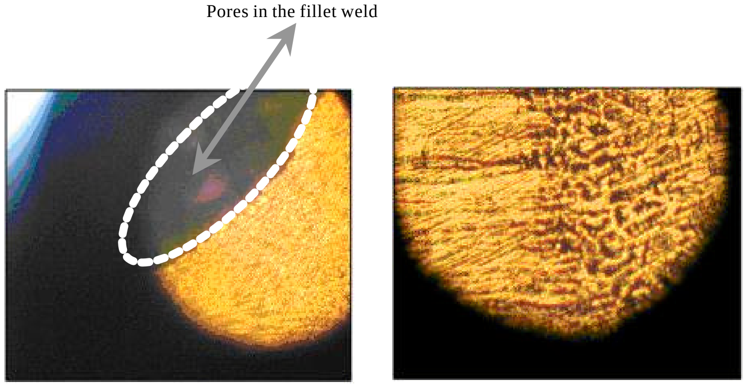

Fig. 4: Metallographic inspection of fillet weld and heat affected zone. Magnification 100x

RESULTS AND DISCUSSION

As earlier described, 304L stainless steels contain less than 0.03% carbon whereas ordinary stainless steels contain approximately 0.08%. In the structures which require welding, type L stainless steels should be used (Kain *et al*., 1984). In this particular plant, this issue was ignored and type 304 stainless steels were used instead of 304L, ever through a large amount of welding was needed in the structures. The best efficiency of stainless steels is in clean and running water with a velocity higher than 1.5-2 ft sec^{-1} (0.5-0.6 m sec^{-1}). In cases where water has a high hardness and for unrefined water it is recommended that the least velocity of water be 3 ft sec^{-1} (1 m sec^{-1}), so that deposition and precipitation is prevented (Tuthill *et al*., 1998). According to the investigations made in the plant, the velocity of water in the steel pipes was 10-12 m sec^{-1} which is a reasonable value as long as the current is flowing and not stagnant. The maximum velocity and turbulence allowed depends in the structure material (e.g., carbon steels or stainless steels or copper alloys). Figure 5 shows the appropriate water velocities according to their different locations (Kain *et al*., 1984). Laboratory studies have shown that in most natural waters with pH of about 6.5 to 8 and chloride concentration of less than 200 ppm, crevice and pitting corrosion of type 304L and 304 stainless steels are rare. In

Velocity-avoid stagnant conditions

- Up to 100 ft sec^{-1} (30 m sec^{-1})-OK
- >3 ft sec^{-1} (1 m sec^{-1}) preferred for raw water with sediment
- 1.2 to 2 ft sec^{-1} (0.5 to 0.6 m sec^{-1}) for finished water

Flow

- Reduced opportunity for bacteria and slime to from growth sites
- Reduces the possibility for microbiologically influenced corrosion

Fig. 5: Velocity/flow for potable water systems (Tuthill *et al*., 1998)

addition, crevice and pitting corrosion of types 316 and 316L in natural waters with pH of about 6.5 to 8 and chloride concentrations of less than 1000 ppm are also scarce (Kobrin *et al*., 1997). Therefore, to be on the safe side, it is recommended to use types 304 and 304L where the chloride concentration is less than 50 ppm and 316 and 316L where the chloride concentration is less than 250 ppm. Application of molybdenuim containing stainless steels or duplex stainless steels is recommended for situations where chloride concentration in water is more than 1000 ppm (Kobrin *et al*., 1997). Tap water usually contains some oxygen. In case this water is deoxidized, stainless steel is able to withstand a significant amount of chloride without undergoing crevice and pitting corrosion (Fontana, 1978). All types of stainless steels are resistant to deoxidized water. No crevice and pitting corrosion occurs in stainless steels exposed to seawater (which contains 18000 ppm chloride) if it is deoxidized. This information shows that type 304L stainless steels are very susceptible to crevice and pitting corrosion in an environment which contains about 3 to 5 ppm residual chloride, whereas more resistance was expected from this type of stainless steels (Kobrin *et al*., 1997). Therefore, in waters containing residual chloride of about 1.8 ppm, type 304 has the best performance (Fontana, 1978). Table 1 and 2 show the chemical analysis of the plant's feed water. This analysis shows a chloride concentration of 198.7 ppm. Thus, according to the above-mentioned discussion and the results obtained, all the pipes and vessels which were made of type 304 stainless steels were susceptible to crevice and pitting corrosion. Corrosion started from weak areas i.e., fillet welds. This phenomenon was also observed in the discharge water coming from first and second water softener, which contained 208.1 and 203.8 ppm chloride, respectively. The latter data show that the water entering the second vessel contains more chloride. As a result, type 304 stainless steel should not be used for this amount of chloride. Type 316L is preferred in this situation and is more resistant. Corrosion occurs rarely in 316L type with a chloride concentration less than 1000 ppm, but in order to ensure safety, it is better to use it in chloride concentration of less than 250 ppm (Tuthill *et al*., 1998). Therefore in this plant, either the chloride content of water should be reduced (by the water softener) or type 316L stainless steels should be used. Moreover, it is recommended to use galvanized steel instead of stainless steel when water contains a large amount of chloride and it is merely for washing purposes (Kobrin *et al*., 1997). Metallographic inspections of the fillet weld and the heat affected zone showed that those welds were not of high quality and contained imperfections such as lack of diffusion, incomplete penetration and pores in the fillet weld (Fig. 3, 4). In this case, pipes should be joined by either Gas Tungsten Arc Welding (GTAW) or Tungsten-Inert-Gas Welding (TIG) where the inert gas eliminates oxygen from the molten puddle so that oxides do not form in the heat affect zone (Tuthill and Avery, 1992). The latter oxides play an important roll in under deposit corrosion. They exist in different colors and shapes. The more and heavier the oxides are, the more important role they play on initiation of localized corrosion. It should be noted that these oxides could not initiate corrosion by themselves and a specific environment is required (Tuthill and Avery, 1992). If water is stagnant for 30 days or more, microbiological corrosion is initiated around the welds. As earlier described, Fe-Mn precipitates which are the results of oxidants such as chloride and potassium permanganate could also be suitable sites for the initiation of localized corrosion around the welds (Tuthill and Avery, 1992). There are different practical methods such as acid pickling the surface of weld, grinding and electropolishing to eliminate and clean the weld of the oxides present in the heat affected zone. Therefore, according to the above discussion there are different methods of corrosion prevention in pipes and vessels of the plant. In case water is only used for washing and not for food products, inhibitors could be used, but application of galvanized steel is more economical and provides higher resistance than stainless steels. Otherwise it is recommended to reduce the amount of chloride in water by modifying the water softener or deoxidizing the feed water of the plant to prevent localized corrosion in the pipes and vessels.

CONCLUSION

In this study, we showed that the main method of solving the corrosion problems in all parts of this factory was reducing the chloride content of water to an acceptable level by modifying the water softener. Beside, two other solutions were suggested. The first one was using stainless steel type L instead of type 304 and another one using high quality welds instead of the previous ones, but these methods weren't feasible according to the economic condition of that factory.

REFERENCES

Chernov, V.Y., V.D. Makarenko, E.I. Kryzhanivs'kyi and L.S. Shlapak, 2002. On the causes of corrosion fracture of industrial pipelines. Mater. Sci., 38: 880-883.

Chmielewski, R.A.N. and J.F. Frank, 2003. Biofilm formation and control in food processing facilities. Comprehens. Rev. Food Sci. Food Safe., 2: 22-32.

Fontana, M.G., 1978. Corrosion Engineering. 3rd Edn., McGraw-Hill, New York.

Kain, R.M., A.H. Tuthill and E.C. Hoxie, 1984. The resistance of types 304 and 316 stainless steel to crevice corrosion in natural water. J. Mater. Energy Syst., 5: 205-211.

Kobrin, G., S. Lamb, A.H. Tuthill, R.E. Avery and K.A. Selby, 1997. Microbiologically influenced corrosion of stainless steel by water used for cooling and hydrostatic testing. Int. Water Conf., 58: 504-516.

Kumar, C.G. and S.K. Anand, 1998. Significance of microbial biofilms in food industry: A review. Int. J. Food Microbiol., 42: 9-27.

Makarenko, V.D., O.V. Antselovich, M.S. Bakharev, K.A. Murav'ev and A.I. Kalyanov, 2005. Improving the strength of industrial pipelines. J. Chem. Petroleum Eng., 41: 221-224.

Makarenko, V.D., V.A. Petrovskii, I.O. Makarenko, V.Y. Chernov and V.V. Ob'edkova, 2007. Corrosion fracture of equipment within wells and pipelines at western siberia oil deposits. J. Chem. Petroleum Eng., 43: 120-124.

Tuthill, A.H. and R.E. Avery, 1992. Specifying stainless steel surface treatments. Adv. Mater. Process., 142: 34-38.

Tuthill, A.H., 1994. Stainless steel piping. J. Am. Water Works Assoc., 86: 63-67.

Tuthill, A.H., R.E. Avery, S. Lamb and G. Kobrin, 1998. Effect of chlorine on common materials in fresh water. Mater. Perform., 37: 52-56.

Valiente, A., 2001. Stress corrosion failure of large diameter pressure pipelines of prestressed concrete. Eng. Fail. Anal., 8: 245-261.