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Failure Analysis of Heat Exchanger Tube Due to Corrosion

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Abstract*— *In order to "Investigate the failure of Heat Exchanger material due to corrosion, fundamental corrosion factor has been studied. This material has been diffused probably affected as corrosion.

This research report presents the result of an investigation of the corrosion failure and discusses the corrosion parameters of three materials such as Mild steel, Aluminum alloy and stainless steel by making calculation of corrosion rate inside the laboratory.

The Tafel extrapolation method of galvanic corrosion measurement is used for the galvanic current of similar or dissimilar material. In galvanic couple the results obtained by using Gamry software. The specimen immersed in 5% $Nacl_2$ solution for obtaining good result of corrosion rate and these specimens tested inside laboratory from college of engineering Pune. This process much more sensitive and faster than more traditional method for measuring corrosion rate such as weight loss.

Result shows that the material of 304 stainless steel has higher corrosion resistance as compare to Aluminum alloy and Mild steel. It is prove with graphically and mathematical calculation.

The aim of this research project is to suggest the best material to Heat Exchanger of Dairy plant. Which has higher corrosion resistance?

Finally it was found that, the basic principal to calculate corrosion rate, depends upon the Faraday's law. It states that "The tendency of each material when dipped inside electrolyte solution (5% of $Nacl_2$). There is evolution of atoms. "Hence the rate of evolution of atoms at anode side is nothing but rate of corrosion and these calculated by using Gamry Software.

I. INTRODUCTION

Heat Exchanger are device that facilitate the exchange of heat between two fluid that are at different temperature while keeping them from mixing with each other

There are four type of heat exchanger failure such Mechanical Failure - Metal Erosion, Steam Hammering , Chemical Failure- Uniform Corrosion, Pitting , SCC, Mach + Chemical Failure - Corrosion Fatigue, Erosion Corrosion, Others Failure - Scale, Mud ,Algae Fouling

The most popular application of electro chemical corrosion techniques is determination of the rate of Uniform corrosion, the two electro chemical techniques for corrosion rate determination are open circuit potential & Tafel Plot. The ASTM B117 salt Spray test was conducted in the engineering material solution, salt spray chamber, This test use full to calculate corrosion rate by eye inspection .

Basically corrosion may be defined as loss of metal or disintegration of metal by chemical or electrochemical reaction with environment. It is generally easier to understand why corrosion occur. As most metal exist in nature (in ores & minerals) as compound such as oxide, sulfides sulfates etc. because metal extracted from these ores after expanding lot of energy, hence natural of metal change as alloy, the metal have natural tendancy to revert back to its natural thermodynamically stable state .This is the basic reason for metallic corrosion. The mild steel tube of heat exchange becomes corrosive due to following points:

1) Due to continuous flow of steam or water scale is obtained inside the tube.
2) If scale is increased then heat required is more hence increases fuel cost.
3) Pressure of tube suddenly increases & failure occurs.
4) Algae production is serious damage to failure of tube ,
5) Due to production of algae there is direct effect on flow of water inside tube.
6) Due to present of Algae, % of oxygen increases & corrosion occurs.
7) If scale & algae not remove then internal diameter becomes less & back pressure increase on machine.
8) Scale is obtained inside the tube due to dirty water.
9) To remove this scale acidic or inorganic chemicals are used, but after removal of Algae e acid is present hence acid corrosion takes-places

A) The acid theory: - This theory suggests that the presence of acids (such as carbonic acid) corrosion is obtain.
This theory applicable to rusting of iron in the atmosphere, according to this theory rusting of iron is due to the continuous action of oxygen ,carbon dioxide & moisture as below:-

$Fe + O + 2CO_2 + H_2O \rightarrow Fe\ (HCO_3)_2$
$2\ Fe\ (HCO_3)_2 + H_2O + O \rightarrow 2\ Fe\ (OH)CO_3 + 2\ CO_2 + 2\ H_2O$
$2\ Fe\ (OH)\ CO_3 + 2H_2O \rightarrow 2\ Fe\ (OH_3) + 2CO_2$

B):- Direct chemical attack: **-** This is also known as dry corrosion. Direct chemical attack by dry gases on a metal at atmospheric temp. is rather uncommon. However, when corrosion take place by direct chemical attack, a solid film of corrosion product is usually formed.

C):- Electrochemical corrosion:- This theory explains the indirect or wet corrosion.

According to this theory all metal have tendency to pass into the solution.

When immersed in a solution of its salt is measured in terms electrode potential. Hence essential requirements of electrochemical corrosion are:-

1) Formation of anodic and cathodic area
2) Electrical contact between the cathodic and anodic part to enable the production of electron.
3) An electrolyte through which the ion can diffuse or migrate.

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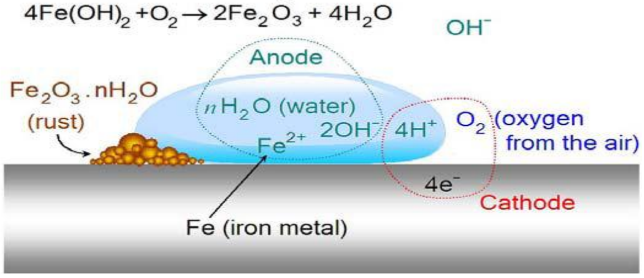
This theory has successfully explained the corrosion of metal, which are in contact with a more "noble' metal or alloys.

$Fe \rightarrow Fe^{2+} + 2e^-$

$O_2 + 4e^- + 2H_2O \rightarrow 4OH$

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$

$4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3 + 4H_2O$



II. MATERIALS

Here mild steel material used for study of failure tube due to corrosion and calculate corrosion rate. As well as following material used depending upon design requirement.

1. MILD STEEL
2. ALUMINIUM ALLOYS (2024)
3. STAINLESS STEEL

Comparatives Parameters.

I. Mild Steel

AISI TYPE	%C	%P	%Si	%Mn	%Cu	Tensile Strength(Mpa)	Tensile (%) Elongation
M.S.	0.18-0.25	0.035	0.04	0.60-1.25	0.2	300-350	26-30

II. Aluminum Alloy (2024)

AISI TYPE	% C	% Cr	% Fe	% Mg	% Mn	% Zn	% Ti	% Si	Tensile strength (Mpa)	Tensile (%) Elongation
2024	3.8	0.1	0.5	1.2	0.3	0.25	0.15	0.5	85-96	35-40

III. Stainless Steel (304)

AISI TYPE	%C	%Cr	%Ni	% Other	Tensile strength(Mpa)	Tensile (%) Elongation
304	0.08	18-20	10	Mn,Si	515	40

Objective

1. To determine the corrosion rate in terms of time according to reliability. For salt spray test of mild steel, aluminum alloy and stainless steel.
2. Using Gamry software calculated corrosion rate of above three specimens on the basic principal of Faraday's law.
3. To determine the effect of corrosion of different material and investigation of a material having less corrosive for the heat exchanger in Dairy plant.
4. To determine the parameters which are useful for calculating corrosion? Such as density, equivalent weight, corrosion current for each specimen mathematically.
5. To study the importance of the curve between Gamry current of cathodic and anodic potential with resultant Ecorr & Icorr.

III. METHODOLOGY

1. Salt Spray Test Machine

For salt spray test machine make sample of 50×50mm of material

The Specimen Suspended between 15 to 30^0C from the vertical.

Specimen cannot be contact with each other.

Temperature 35^0c pressure 69 to172 KN/m^2, pH of solution 6.5.

Make electrolyte solution $NaCl_2$ 6 gm in 200 ml water.

Salt fog shall be such that for each 80 cm^2 of horizontal collecting.

Take recording of Visual inspection at every 24 Hours.

Wash specimen in clean water of Temperature below 38^0c to remove salt.

2. Gamry Instrument

Prepare sample of 10×10 mm of salt spray specimen.

Make soldering of copper wire to each sample and insulate it.

Connect the cell cable leads to the appropriates electrode.

Select the script; you want to run, such as DC Corrosion or Tafel.

Plot for experiment menu.

Name the data output file.

Specify parameter value and save.

Start the experiment and activate the potentiostat.

While the experiment is running plotted data will be display at the conclusion for experiment an "Experiment done" massage is displayers

The F2 (Skip) Button.

Salt spray Machine

Gamry Software Machine

Calculation of Corrosion Rate Using Gamry Instrument

Corrosion Rates

- CR = 0.12 (Icorr x EW)/ d
- For units of Corr. Rate in mils per year, Icorr in mA.cm-2
- EW is the equivalent weight, d is the density of the metal.
- Icorr data available from lab testing.

Material: - Mild Steel

Corrosion Rate = 0.12 Icorr.E.W./ ρ

E.W. = Atomic Weight / Valancy

E.W. = 55.847 / 3 = 18.61

E.W. = 18.61, Density = 7.8 gm/cm^3

1. Corrosion Rate (mpy) (MS-00) = 0.12 x 12.10 x 18.61 / 7.8
 = 3.46 at Zero hours (Fresh Sample)

2. Corrosion Rate (mpy) (MS-01) = 0.12 x 58.50 x18.61 / 7.8
 = 16.74 at 12 hours

Material: - Aluminum Alloy (2024)
E.W. = 26.981 / 3 = 8.99
E.W. = 8.99, Density = 2.69 gm/cm^3
1. Corrosion Rate (mpy) (AB-00) = 0.12 x 10.51 x 18.61 / 7.8
= 3.01 at Zero hours (Fresh Sample)
2. Corrosion Rate (mpy) (AB-01) = 0.12 x 12.30 x 8.99 / 2.69
= 4.93 at 12 hours

Material: - Stainless steel (304)
E.W. = 15.72
Density = 8.0 gm/cm^3
1. Corrosion Rate (mpy) (SS-00) = 0.12 x 0.3844 x 15.72 /8.0
= 0.090 at Zero hours (Fresh Sample)
2. Corrosion Rate (mpy) (SS-01) = 0.12 x 0.5204 x 15.72 /8.0
= 0.120 at 12 hours

Result obtained by Gamry software of Mild Steel & Aluminum Alloy (2024).

Parameter	Value
Beta A	133.7e-3 V/decade
Beta C	50.80e-3 V/decade
Icorr	12.10 µA
Ecorr	-689.0 mV
Corrosion Rate	3.285 mpy
Chi Squared	11.02
Data File	ms fresh.
Fit Status	The difference between Eoc and Ecorr is large. Your sample may have changed.

Parameter	Value
Beta A	54.70e-3 V/decade
Beta C	415.6e-3 V/decade
Icorr	10.60 µA
Ecorr	-878.0 mV
Corrosion Rate	2.874 mpy
Chi Squared	24.27
Data File	aluminium.

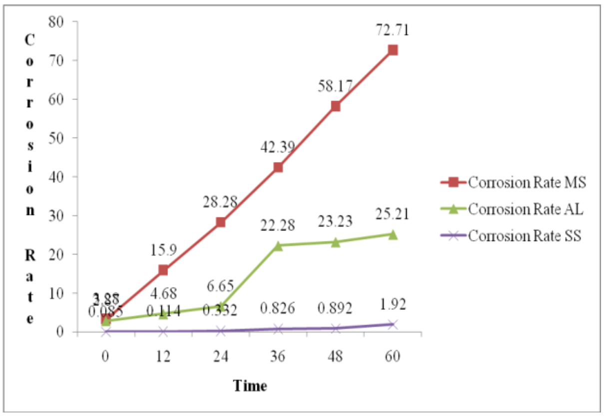
IV. EXPERIMENTAL ANALYSISS AND COMPARISION

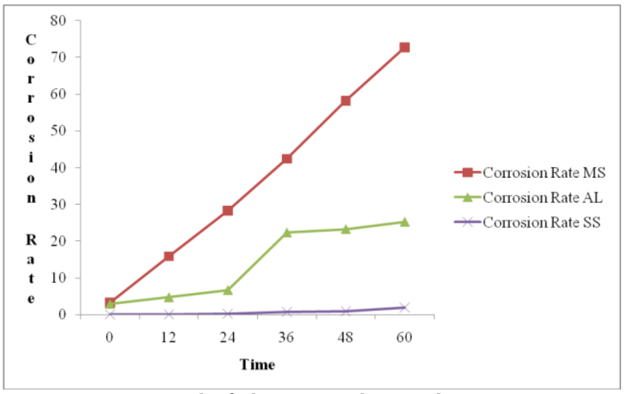
Comparison table of data obtained from Gamry Software Machine

Time (hours)	Corrosion Rate (MS)	Corrosion Rate (Al. alloy)	Corrosion Rate (S.S.)
0	3.28	2.87	0.085
12	15.9	4.68	0.114
24	28.28	6.65	0.332
36	42.39	22.28	0.826
48	58.17	23.23	0.892
60	72.71	25.21	1.920

II. Comparison Table of Mathematical Calculation of Corrosion Rate

Time (hours)	Corrosion Rate (MS)	Corrosion Rate (Alum. alloy)	Corrosion Rate (S.S.)
0	3.46	3.01	0.090
12	16.74	4.93	0.120
24	29.77	7.01	0.350
36	44.63	23.46	0.870
48	61.24	24.46	0.939
60	69.07	26.86	2.026





Comparative Graph of Three Materials According to Corrosion

V. CONCLUSION

1. The polarization resistance method measures the instantaneous corrosion rates as compared to other methods on which metal loss is measure over a finite period of time. Instantaneous means that each reading on the instrument can be translated directly into corrosion rate.
2. The experiment can be completed in a matter if minutes and the small

Polarizations from the corrosion potential do not disturb the system. This permits rapid rate measurements and can be used to monitor corrosion rate in various process streams.

3. This technique may be used for accurately measuring very low corrosion rates (less than 0.1 mpy). The measurements of low corrosion rates as especially important in food processing industries where trace impurities and contamination are problems.
4. Electrochemical corrosion rate measurements may be used to measure the corrosion rate of structures that cannot be visually inspected of subjected to weight loss tests.
5. Corrosion failure is major problem in heat exchanger tube hence many plant is shutdown permanently.
6. Rust never rest but it controlled using plating and coating.
7. Electro chemical corrosion rate are able to measure using Gamry Instrument.
8. Salt spray machine useful to calculate corrosion rate in hours.

REFERENCES

www.gamrysoftware.com

[1] Ahmed Y. Musa, Abu Bakar Mohamad, Abdul Amir H. Kadhum, and Eng Pei Chee, "Galvanic corrosion of aluminum alloy and copper in 1.0 M nitric acid," *Int. J. Electrochem. Sci*., vol. 6, pp. 5052-5065, 2011.

[2] M. Abu-Zaid, "A Fouling evaluation system for industrial heat transfer equipment subject to fouling," *Int. Communications in Heat and Mass Transfer*, vol. 27, issue 6, pp. 815-824, 2000.

[3] Bernard S. Covino, Jr., Sophie J Bullard, Stephen D. Cramer, Gordon R. Holcomb, Małgorzata Ziomek-Moroz, Michael S. Cayard, and David A. Eden, "Understanding the Operation and Use of High Temperature Electrochemical Corrosion rate Probes," InterCorr International Inc., 14503 Bammel North Houston, Suite 300 Houston , TX 77014.

[4] T. R. Bott, *Fouling of Heat Exchanger*, Elsevier Science B.V.-Amsterdam, the Netherlands, pp. 517, 1995.

[5] M. Bohnet, "Fouling of heat transfer surface," *Chemical Engineering Technology*, vol. 10, issue 1, pp. 113-125, 1987.

[6] Brooks and C. R. Choudhury, *A Metallurgical Failure Analysis*, New York. McGraw-Hill, USA, pp. 413, 1993.

[7] Edward Curran, CEO, Curran International

[8] Ehteram A. Noor, Aisha H. Al- Moubaraki, "Thermodynamic study of metal corrosion and inhibitor adsorption processes in mild steel/1-methyl-4[4 (-X)-styryl pyridinium iodides/hydrochloric acid systems," *Materials Chemistry and Physics*, vol. 110, pp. 145–154, 2008.

[9] Ezi, C. W. I., Owate, I.O. And Abumere, O. E., "Comparative analyses of corrosion rates of subsurface storage tanks (metals) with some mechanical properties," *Scientific Research and Essay*, vol. 2, issue 6, pp. 184-190, 2007.

[10] Hamid Saadatmanesh, Member, ASCE

[11] István Vámos, Petrik SZKI, Budapest, Hungary; vamos@petrik.hu

[12] Irene Carrillo, Benjamin Valdez, Roumen Zlatev, Margarita Stoycheva, Michael Schorr, ´and Monica Carrillo "Corrosion inhibition of the Galvanic Couple Copper –Carbon Steel in reverse osmosis water," *Hindawi Publishing Corporation International Journal of Corrosion*, vol. 2011, Article ID 856415, 2011.

[13] J.R. Rossum

[14] K. F. Khaled, "New synthesized guanidine derivative as a green corrosion inhibitor for mild steel in acidic solutions," *Int. J. Electrochem. Sci.*, vol. 3, pp. 462–475, 2008.

[15] Marvin P. Schwartz, "Four types of heat exchanger failure," International Telephone & Telegraph Corp., Skokie, IL.

[16] M. S. Abd-Elhady, C. C. M. Rindt, J. G. Wijers b, and A. A. van "Steenhoven, Removal of Particles from a Powdery Fouled Surface due to Impaction," *Proceedings Heat Exchanger Fouling and Cleaning: Fundamentals and Applications*, 2003.

[17] Mohammadreza Tavakkolizadeh and Hamid Saadatmanesh, "Galvanic corrosion of carbon and steel in aggressive environments," *Journal of Composites for Construction*, volume 5, issue 3, 2001.

[18] Mohd Yuhazri, Y, Jeefferie, A.R., Haeryip Sihombing, and Siti Rahmah, S., Effect of parameter controlled in tin coating on the mild steel substrate," *International Journal of Engineering Science and Technology (IJEST)*, vol. 3, no. 3, pp. 2113-2117, 2011.

[19] Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[20] N.D. Alexopoulosa, P. Papanikosb, "Experimental and theoretical studies of corrosion-induced mechanical properties degradation of aircraft 2024 aluminum alloy," *Materials Science and Engineering* A 498(1), pp. 248-257, 2008.