Assessment of Corrosion Behavior of Copper Pipelines System under Flowing Condition

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Abstract. A simulated environmental condition for a closed loop copper piping system that involve temperature and flow changing was investigated for the character of corrosion products. Two identical copper closed-loop piping system were constructed in this work. Both systems were filled with 3% sodium chloride solution and run for about eleven months. Both systems were heated to a temperature of 80 °C for eight hours a day and for 5 days a week and the rest of the time the temperature kept at room temperature of 23 ± 2 °C. During the heating process, the solution in one pipe system was in stagnation condition while the other was flowing at input velocity of 0.27 m/s. The corrosion products created in both piping systems were evaluated by pourbaix diagrams, visual observation, light and Scanning Electron Microscopes. The experiment confirmed the essential contribution of flow on corrosion product behavior.

Keywords: Corrosion product, Piping system, Temperature, Stagnation, Flow.

1. Introduction

Copper has excellent electrical and thermal conductivity, very good corrosion resistance to many environment, more potential than of hydrogen (corrosion will take place mainly due to oxidation) and good resistance to corrosion in neutral solutions (freshwater and seawater). For all that, copper pipelines have always been an excellent option for transferring water for many years in different industries and household water distribution system. Copper is sometimes used in seawater piping in a limited flow velocity of 1.2 m/sec to avoid corrosion-erosion [1]. Many structural failures were reported for copper piping system [2-3] which led to unsafe copper contamination in drinking water [4]. This encourages researches to farther study and analysis the corrosion of copper in piping systems. Many researchers have focused on the effect of copper and a particular corrosive environment such as SO_2, NO_2 and $NaCl$ at different humidity and temperatures [5-7].

Different corrosion product phases such as cuprite (Cu_2O), paratacamite ($Cu_2Cl(OH)_3$), posnjakite ($Cu_4SO_4(OH)_6 . 2H_2O$) and brochantite ($Cu_4SO_4(OH)_6$) can be created in water solutions. While Mendoza et al. [8] and Milosev et al. [9] confirmed that corrosion product phases formed on the metal surface changed its morphology and degree of crystallization in presence of chlorides under rainy atmospheres. Also, Sirvastava et al. [10] proved the damage of the protective cuprous oxide layer in chloride, sulphide and ammonia salts. Sandberg et al. [11] used the E / pH diagrams for evaluate the stability of copper corrosion products in natural sea water (3% of NaCl) and in different chloride concentrations at room temperature. Also, Kuznicka [12] investigated the failure of copper tubes heat exchanger carrying industrial water at low

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temperature. He found that the loss of stability of protective cuprous oxide layer due to corrosion-erosion in the present of solid particles and chlorides was the cause behind that failure.

To represent and simulate the real life application and usage of piping systems, many factors can affect the corrosion resistance of copper such as composition of the copper, type of fitting and joining, temperature flow and concentration of corrosive environment. These factors can lead to different types of corrosions and erosion, and therefore farther investigation regarding these factors should be addressed and considered. The aim of this study is to investigate the effects of flow on the corrosion products of copper piping system under sodium chloride environment in a long term experiment.

2. Materials and Methods

Two commercial copper pipes (99.5 $\pm$ 0.48 Cu) with different diameters, of 16 mm and 18 mm, were used to construct two identical pipeline systems as in figure1. The pipes of each system were connected by three different types of joints: soldering (sectors 2, 5 and 11), brazing (sectors 4, 6and 8) and by pressure fitting (sectors 3 and 9). These procedures were maintained throughout the entire testing time of eleven months.
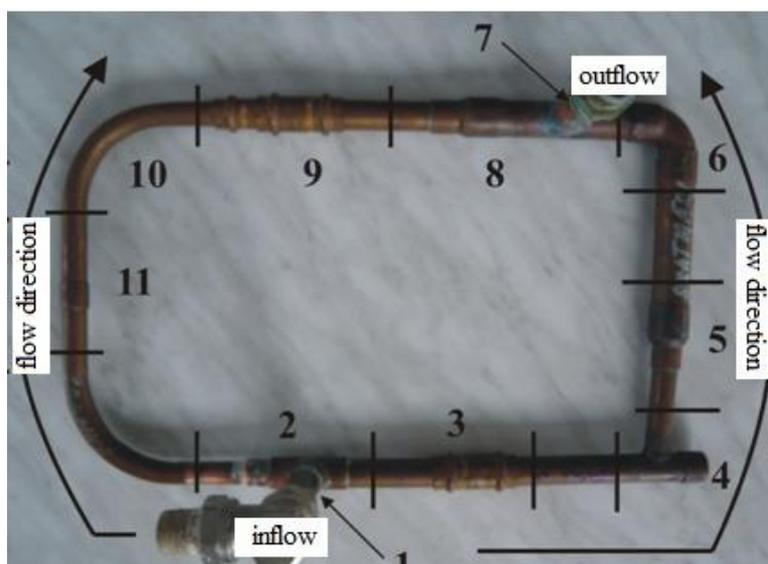

Figure 1 Pipeline system with flow directions of sodium chloride.

In each pipeline system, 3% of NaCl in distilled water was used to be the corrosive solution running inside the pipelines. This solution was running for 8 hours per day at temperature 80 ℃ then 16 hours at 23 ± 2 ℃. In one pipeline system (system A), the solution inside the pipe was flowing at input velocity of 0.27 m/s for the 8 hours period. Inlet of the sodium chloride solution can be seen in Figure 2 as in sector 1 while the outlet was marked as in sector 7. As recommended by the manufacturer, a flow velocity of 0.3 m/sec for pure copper was applied on the pipeline of system A. The other pipeline system (system B) was exposed to the same corrosive solution yet in stagnant condition. These procedures were maintained throughout the entire testing time of eleven month.

To evaluate and asses the corrosion behaviors, two samples representing the stagnation and flowing conditions were selected from the same sector (sector 2) at the two pipeline systems. Samples were longitudinally sectioned as shown in Figure 2. Evaluation of the corrosion products and copper samples were further considered using the constructing pourbaix diagrams as well as the light and the electron micrographs.
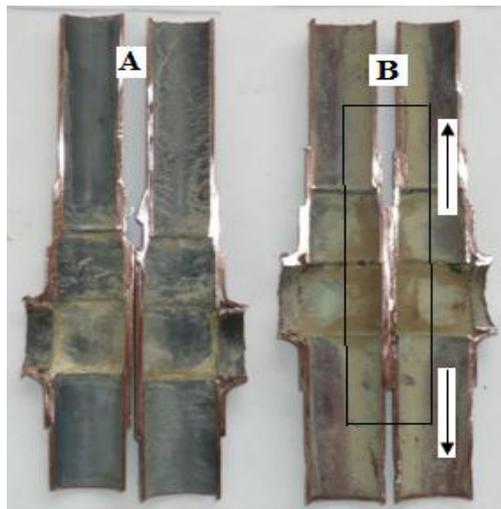
Figure 2 Corrosion products in sector 2 at (a) stagnant condition bottom and top (b) flowing condition bottom and top respectively.

3. Results

To get information about corrosion product in the experimental solution at temperature 25 and 80 ℃, Pourbaix diagram were constructed. The E – pH diagram for Cu-Cl-H_2O system was obtained using HSC Chemistry V.5.1 software (producer Outokumpu Research, Oy Pori Finland). The diagrams were constructed for molar equivalent of 3 % NaCl solution at 25 ℃ and 80 ℃, respectively, and the results can be seen in Figure 3 and 4.

Corrosion products is not substantially influenced by temperature, but at higher temperature (80 ℃) the creation of complex compounds $CuCl_{12}$ $3Cu(OH)_2$, CuCl and $CuCl^{(+a)}$ are shifted more to acid area (low value of pH) and the immunity area is shifted to lower values of potential. This indicates that at higher temperature of 80 ℃, the corrosion rate of copper increases. The ions (Cu^+) in Cu_2O are oxide in aqueous environment (in the potential range from -0,15V to +0,521V) to form CuO (Cu^{+2}) which have black color. Also, in the chloride solution the CuCl is originated in aqueous solution and hydrolyze to soluble chloride (blue- greenish).

The corrosion products generated in different conditions on copper surfaces vary according to visual inspection as can be seen in figure 2. In stagnant condition, a uniform, homogenous and excellent adhesive dark-gray layer with a little green tone film was formed on the inner sides of copper pipeline. The top and bottom sides of the stagnant pipeline system have the same visual layers. Pipes in flowing condition form adhesive corrosion products that are blue-greenish and yellow brown in color. In the top side of this pipe corrosion products were locally fallen down. This difference in corrosion product formation is due to the rate of chemical reactions and access of reactants that take placed on the pipe surface. This indicates dissimilarity of corrosion processes that take place at different locations on the pipe.
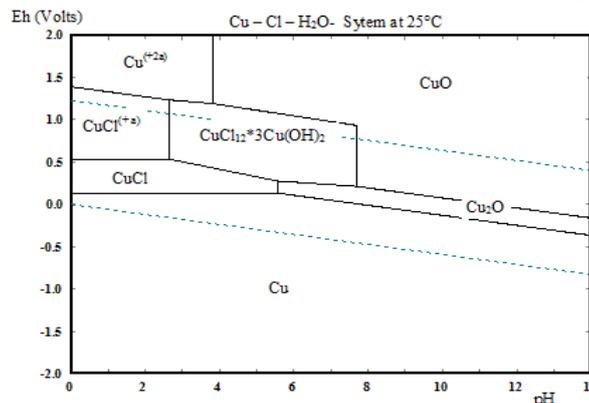

Figure 3 E – pH diagram E – pH diagram for Cu-Cl-H_2O system at temperature 25 ℃.
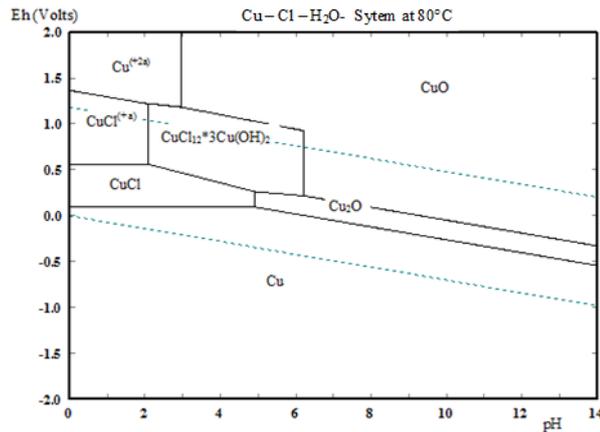
Figure 4 E – pH diagram E – pH diagram for Cu-Cl-H$_2$O system at temperature 80 ℃.

Light microscope was used to evaluate and to compare the corrosion mechanism of copper in both flowing and stagnation conditions, Figure 5. It was revealed that the corrosion in the flowing conditions initiated and increased with a tenfold progress rate more than that observed in the stagnation conditions. The grains were chipped off due to the flow of sodium chloride during the long period of the experiment.

The surface corrosion products were also examined by SEM in stagnation condition, figure 6. Corrosion products over both bottom and top parts of the pipe in stagnation conditions show similar attitude. A Semi-quantitative chemical analysis was conducted by SEM on a 60x60 micron scanning area focusing on the elements: Cu, O, Cl and Sn (Tin is presented on the system by soldering) which can be seen in EDX results. Only negligible traces of chlorides (0.02 wt. %) were observed over the examined area. Both bottom and top sides of pipe were found to have similar chemical contents. Different outcome was observed for specimen in the flowing condition, figure 7, where oxygen (65.63 wt. %) and chlorine (Cl$^-$ ions 1.82 wt. %) were found to be the main influential elements acting on the copper surface. The basal oxide layer was cracked with the formation of a greenish Cu$_2$Cl(OH)$_3$ layer.
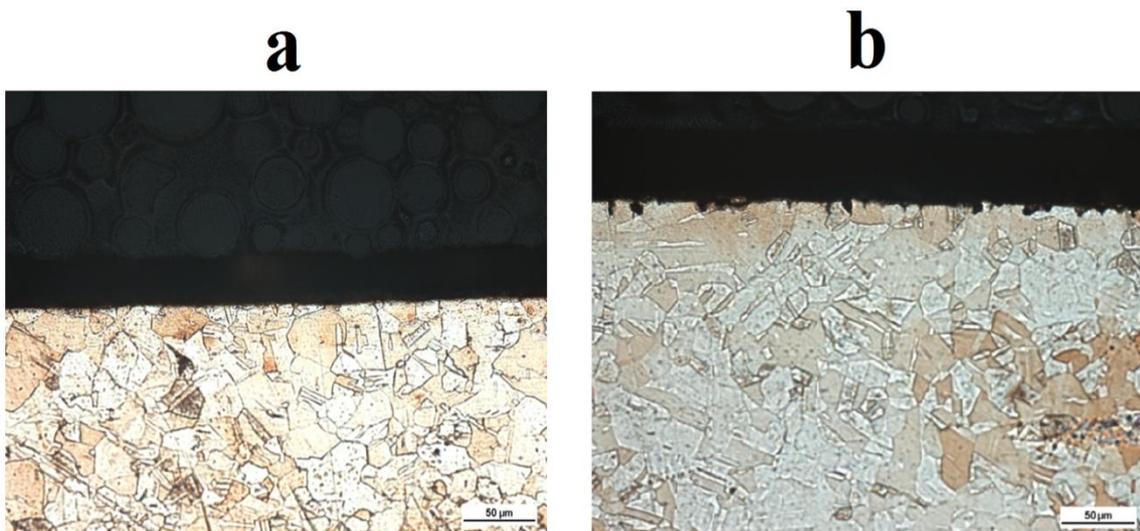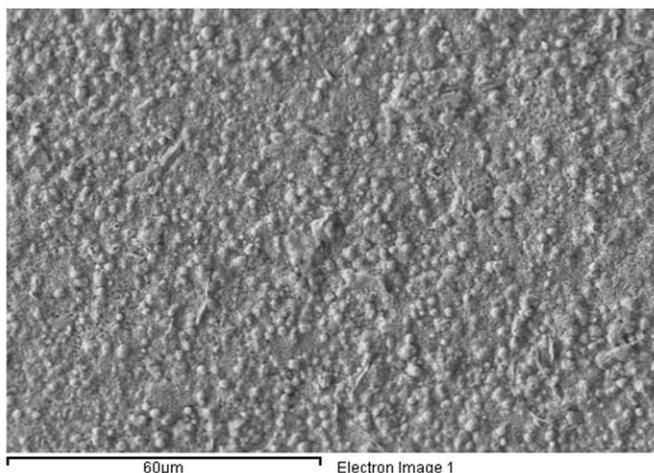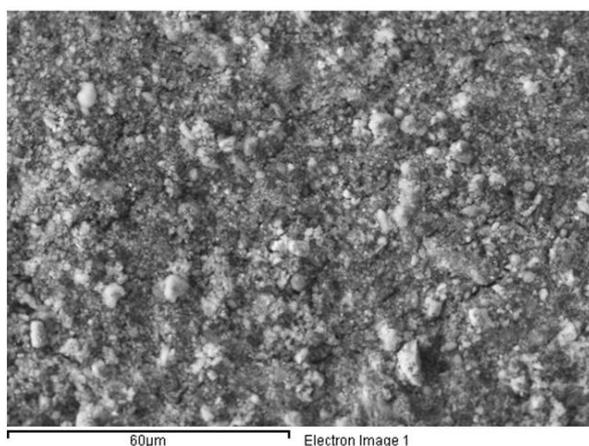

Figure 5 Corrosion attack at sector 2 in (a) stagnation and (b) flowing conditions.

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Element	Weight%	Atomic%
O K	2.44	10.71
Cl K	0.02	0.04
Cu L	61.72	68.10
Sn L	35.82	2.16

Figure 6 SEM and EDX analysis: corrosion products, oxygen distribution and chemical analysis for stagnation condition.

Element	Weight%	Atomic%
O K	65.63	88.87
Cl K	1.82	1.11
Cu L	25.74	8.78
Sn L	6.80	1.24

Figure 7 SEM and EDX analysis: corrosion products, oxygen distribution and chemical analysis for flowing condition.

4. Conclusions

Flow of the sodium chloride solution inside copper pipes accelerates chemical reaction that produced corrosion compounds due to increase access of reactants into the pipe surface. In flowing condition, thickness of corrosion product is larger and content of oxygen and chlorine is higher than in stagnant condition. Corrosion products in stagnant condition are smooth, homogenous and have good adhesive property to the pipe surface.

Hydrolysis of the corrosion products created on the copper pipe surface in flow condition is fast process and poor adhesion properties of those products are the main reasons fallen particles into the solution. This makes copper corrosion products loss its protective properties against corrosion.

The fallen particles from the top side of the copper pipe were accumulated on the bottom side. And due to the flowing condition, mechanical damage of the bottom side of the copper pipe was induced.

The loss of stability of protective cuprous oxide layer due to corrosion-erosion in the present of solid particles and chlorides is the main cause of fast damage of copper pipes in flow environment.

The content of tin in corrosion products in the stagnation condition is due to dissolution of soldering in chloride solution. After this dissolution, tin was attached to the copper in strong adhesion way.

5. Acknowledgements

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