Study of Iron Pipe Corrosion in Municipal Water Distribution System and Its Effect

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Abstract
Deterioration could lead to destruction of materials with chemical or electrochemical reaction as corrosion. Corrosion is one of the most complicated and costly problems facing in municipal drinking water utilities. A large number of parameters affected pipe corrosion, including water quality and composition, flow conditions, biological iron activity, and corrosion inhibitors. Corrosion scales play an important role in modifying water quality in drinking water distribution systems. The corrosion scales from old water pipe lines were analyzed for their structure and composition. This paper mainly studied the deposits found in water distribution system of Municipal and protection of corrosion methods as well as to preventive measurements of the iron pipe corrosion. The corrosion scales had a shell-like, enveloping layer, covering porous deposits of iron oxide phases. Catastrophic failures are obtained in water distribution systems, so major layer will be occurred. The ground water samples were drawn from the area and subjected to physical and chemical analysis and the analysis results were used to evaluate in laboratory works.
Keywords: electrochemical, corrosion, iron pipes

1. Introduction

Municipal is using cast iron pipes to transport potable water for several years, now days the iron pipe corrosion is a major problem in water distribution piping system. The majority of distribution system pipes are composed of iron material; cast iron (38%), ductile iron (22%), and steel (5% [4]. Iron corrosion is an extremely complex process because of the large variability in distribution system conditions; a particular factor may be critical in one system but relatively unimportant in another system. Moreover, corrosion itself has several different manifestations and can be evaluated in many ways. In our studies on iron pipe corrosion have focused on different aspects of iron corrosion; pipe degradation measured by weight loss, oxygen consumption or corrosion current, scale formation measured by head loss or scale deposition, and by product release measured by iron concentration, color, staining, turbidity, or number of customer complaint [7].

While most people in urban cities of the country have access to piped water, Municipal still rely on groundwater for domestic use. Industrial effluents, if not treated and properly controlled can pollute ground water. Therefore, the ground waters generally have poor quality water in the affected areas. Depending upon its specific chemistry, water can promote scaling, corrosion or both. Scaling is one of the most critical water quality issues in Municipal. [18]

Scale can be formed from a variety of dissolved chemical species but two reliable indicators are hardness and alkalinity. Calcium carbonate is the most common form of scale deposition attributable to ground water used in residential geothermal heat pump systems. Two indices commonly used in the water treatment plant to evaluate the nature of a water source. [22] The Municipal drinking water comes from the ground water from wells have usually been insufficiently long contact with carbonate containing sediment. Dissolving of a material by a corrosive liquid is called chemical corrosion. The material continues to dissolve until either it is consumed or the liquid is saturated. The removing of metal atoms from a solid material as the result of an electric circuit is called electrochemical corrosion. In this form of corrosion, metal atoms lose electrons and become ions thus forming a byproduct. Electrochemical corrosion occurs most frequently in aqueous mediums, in which ions are present in water or moist air. In this process, an electric circuit is created and the system is called an electrochemical cell [29]. Corrosion is one of the most common problems affecting domestic water supplies. Iron and steel pipes have been used in Municipal water distribution systems for over many years. The main source of Iron pipe corrosion are particulate matter transported by water, dissolve oxygen, microbial activity, chlorides, sulphate and physicochemical reactions both at the pipe wall interface and within the water bulk. Most water distribution systems buildup of iron corrosion products inside the iron pipes. Corrosion scale/deposits not only restrict the flow of water but degrade the quality of water. The scales are porous deposits that are comprised of iron hydroxide phases. Some ways in which Iron pipe corrosion scales can adversely affect the water quality in drinking water distribution pipes are [20].

2. Methods and Materials
2.1. Materials
Material used to water analysis were steel pipe anode, copper cathode , water sample from internal corroded iron pipe line, and soil in box container (water path), conductor (metal path) between our pipe anode , direct

source (DC power source) of electric current with the rectifier or transformer and gray cast iron.

2.2. Chemicals

Chemicals used for laboratory water test were: phenolphthalein (p-solution); distilled water for preparing solution; sodium thiosulphate (t-solution); Calcium Hardness indicator; buffer solution; 0.02N H_2SO_4; 0.01M EDTA and methyl orange solution.

2.3. Equipment used in the laboratory for water testing

Equipment used in the laboratory for water testing were: measuring cylinder; PH meter; turbidity meter; conductive meter; 800ml beaker; glass road (string rod) and test-tube.

2.4. Cathodes Protection Equipment

The basic equipment used for cathodes protection work includes: corrosion and cathodes protection, galvanic anodes, or impressed current anodes and a rectifier, junction boxes where multiple anodes may come together, test stations for electronic access to cathodically protected structures, shunt resistors used for measuring current by application of Ohm's law, variable resistors used to adjust current throughout, a high-impedance (10 mega ohm minimum) portable voltmeter and wire leads.

2.5. Methods

There are three common methods used to control corrosion on pipelines are protective coatings and linings, cathode protection and materials selection [21] [25].

Coatings and lining: are principal tools for defending against corrosion. They are often applied in conjunction with cathode protection systems to provide the most cost-effective protection for pipelines [4].

Materials selection: refers to the selection and use of corrosion-resistant materials such as stainless steels, plastics, and special alloys to enhance the life span of structure such as a pipeline. Materials selection personnel must consider the desired life span of the structure as well as the environment in which the structure will exist. Corrosion inhibitors are substances that, when added to particular environments decrease the rate of attack of that environment on a material such as metal or steel reinforced concrete [6].

Cathodes protection: it is a technology that uses direct electrical current to counteract the normal external corrosion of a metal pipeline. Cathodes protection is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell [9].

2.5.1. Set up of cathode protection for pipe lines

Anodes are arranged in a ground beds either distributed or in a deep vertical hole depending on several designs and field condition factors including current distribution requirements. The output direct current negative terminal is connected to the structure to be protected by the cathode protection. The rectifier output direct current positive cable is connected to the anodes [8]. The alternative current power cable is connected to the rectifier input terminal the output of the impendence current cathode protection system should be optimized to provide enough current to protect the target structure. An impudence current cathode protection system for pipe line consist of the direct current power source often an alternative current powered transformer rectifier and an anode. Arrow of an anode buried in the ground (the anode ground bed). The direct current power source typical have a direct current output of up to 50 Ampere and 50volt depending up on the size of pipe line, the coating quality, the positive direct current output terminal would be connect via cables to the anode array while another cable would connect the negative terminals of the rectifier to the pipe line [25].

2.5.2. Water quality test

Water makes about 90 % of the final product and thus its quality directly affects the quality of the finished product. The quality parameters related to water can be physical and chemical and or micro biological among which the following is the common ones [24].

Turbidity: is the amount of particulate matter that is suspended in water. Turbidity was measured by turbidity meter.

Color: indicates the presence of decomposed organic material from natural or manmade sources and was measured by spectrophotometer.

Test and odor: are the result of decay of organic matter or intrusion of industrial and human wastes and were noticeable as water temperature increased.

Total Dissolved Solid (TDS): is the measure of inorganic salts and small amounts of organic matters present in a solution in water and was given in mg/l.

Electrical Conductivity: is a measure of the ability of water to conduct an electric current and was expressed in micro Siemens per centimeter. It was related to the concentration of TDS and major ions.

PH: is a measure of alkalinity or acidity of the water sample and is important to control corrosion and water treatment processes. PH of iron pipe was measured by PH meter.

Water hardness: sampling location was at corroded iron pipe water.
   I.   100ml distilled water was measured and added to beaker.
   II.   1ml hardness buffer was added
   III.   Two level of hardness indicator was added.
   IV.   Hardness was checked while the sample was turned to red
   V.   As buffer solution 12-15 drop of $10\%NH_3$ buffer was added.

Alkalinity: the following procedures were used.
100ml was taken; 3 drop T- solution was added; 3 drop m-solution was added; color change from colorless to light green was observed; using $0.02NH_2SO_4$ was titrated; color change from light green to pink was observed; then volume of $0.02NH_2SO_4$ was measured.

Conductivity of water: is an indirect measurement for finding the total dissolved solids in a water body in the conductivity of water sample (micro semien per centimeter) at 25^0C.

Dissolved oxygen: it was measured by dissolved oxygen meter.

3.   Result and discussion

The concentration of ions increased as the pH value of both of water sample were increased.
The total hardness of the corroded water as $CaCO_3$ is 188.1mg/l. It was hard water based on the hardness of municipal was 303 PPM $CaCO_3$. It showed that very hard water regarding to the outside of the country distributed water such as municipal water system.

3.1. Water Quality

In order to reach a better view on the variation of the treated water quality from the water treatment parameters and how they affected water stability, selected results from the determination of water quality parameters were discussed below. Alkalinity in water is due to the presence of weak acid systems that consume hydrogen ions produced by other reactions or produce hydrogen ions when they are needed by other reactions allowing chemical or biological. The Water quality parameters compared with Municipal and WHO drinking water standards are shown table1, where the treated water is within these standard [18].

Table1: Water quality parameters compared of municipal and WHO drinking water standards

Parameter	Municipal water	Corroded water	Average	Drinking standard	
				Municipal	WHO
Temperature (ºC)	24	39	31.5	25	-
AlkalinityasCaCO$_3$ (mg/l)	100	180	140	125-500	30-500
Calcium as Ca (mg/l)	120	188.1	154	75	75
PH	7.20	8.16	7.6	6.5-8.5	7-8.5
TDS(mg/L)	600	876.36	738.18	1000	500

The primary source of alkalinity was the carbonate system, although phosphates, silicates, borates, carboxylates and other weak acid systems. Alkalinity was required in the coagulation process for the reaction of aluminum sulphate. From the recorded data the variation in alkalinity ranged between 100 mg/l to 180 with average 140 mg/l as CaCO3. Corrosively of water decreased as the alkalinity increased where it was necessary to provide a stable pH throughout the distribution system for corrosion control of metal pipes. Low iron corrosion rated and iron concentrations in the distribution systems have been associated with higher alkalinities. Calcium is the second most prevalent constituent in most surface waters and is generally among the most prevalent three or four ions in ground water [18].

Total dissolved solids (TDS) in water were due to inorganic salts. Principally these inorganic constituents were calcium, magnesium, sodium, and potassium salts of bicarbonate, chloride, sulfate, nitrate and phosphate. These compounds originate from weathering and leaching of rocks, soils and sediments. Also some of these compounds are added to the water in the treatment plants. From the recorded data the variation concentration of TDS ranged between 600 to 876.36 mg/l with an average of 738.18 mg/l. higher water temperatures accelerated the rate of corrosion by increasing the rate of the cathode reaction. The chemical reaction rate generally is doubled for every 8˚C increase in temperature [18].

3.2.   Corrosion rate calculation

It is the speed at which metal deteriorates in specific environment. The rate of corrosion depended upon: environmental condition; type of metal and condition of metal; weight loss; the decrease metal weight during the reference time period; density of metal; area of the pipe initial and time. To calculate the corrosion rate from metal loss, RC (rate of corrosion) [23].

$$RC \ (millimeter/year) = 87.6 * \left(\frac{weight}{density * area * time} \right)$$

Given=1.30 cm, A=$\frac{\pi D2}{4}$=1.325cm^2

CP= corrosion potential=300 mv

W=28,691.55mg

Time=1year=8760hr

RC=87.6 *($\frac{W}{D*A*T}$)= 87.6 *($\frac{28691.55}{8.02*1.325*8760}$)=27micro ampere (µA), sample from municipal water distribution of cast iron pipe. Where, w=weight loss in mg, d= density in g/cm^3, A=area of sample in cm^2, T=time of exposure of pipe

Rate of corrosion for most metals increased with any increment of dissolved oxygen so the corrosion of pipe was increased [29].

3.3. Cathodes protection by impressed current

Impressed current systems typically use a power source known as a rectifier. The rectifier converts AC power to DC power and provides adjustability to the system. Rectifiers were commonly equipped with meters to read current and voltage outputs. Circuit breakers, lightning arrestors and fuses were used to protect the unit from power surges and faults. Shunts were calibrated resistors used to measure current flow [30].

Table2: Impressed current systems

S.no	Applied Current	Potential	Resistance	Days
1	3.18	0.836	0.22	1
2	3.33	0.899	0.2702	2
3	3.35	0.588	0.179	3
4	3.36	0.598	0.1780	5
5	3.37	0.604	0.1794	7
6	3.35	0.5159	0.15476	9
7	3.36	0.500	0.1492	11
8	3.38	0.4022	0.11904	13

Table3: corroded pipe and resistance

S.no	Applied Current	Potential	Resistance	Day
1	3.34	0.67	0.1497	1
2	3.351	0.542	0.162	2
3	3.354	0.598	0.178	3
4	3.3654	0.698	0.208	5
5	3.3665	0.799	0.238	7
6	3.3673	0.897	0.267	9
7	3.368	0.931	0.277	11
8	3.373	0.9469	0.281	13

Figure1: electrode potential and time
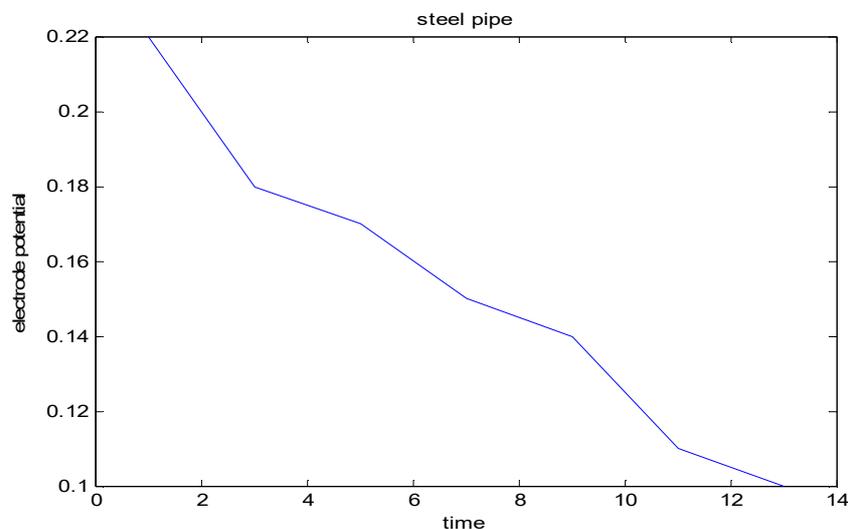
From the above figure it has been concluded that as time increased electrode potential increased, as it

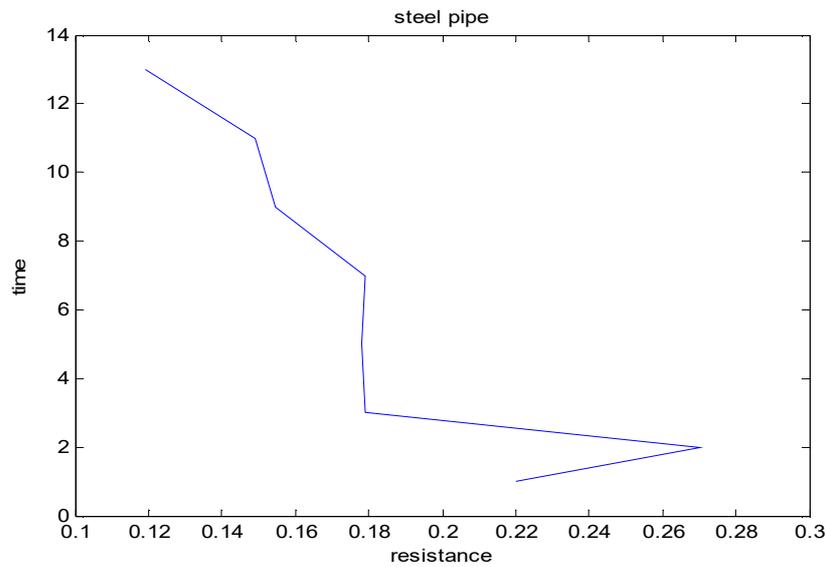increased ions concentration as a result of corrosion reaction.

Figure2: comparison of resistance and time relationship in corrosion reaction

From the above figure it has been concluded that as time increased resistance decreased, as it increased ions concentration as a result of corrosion reaction.
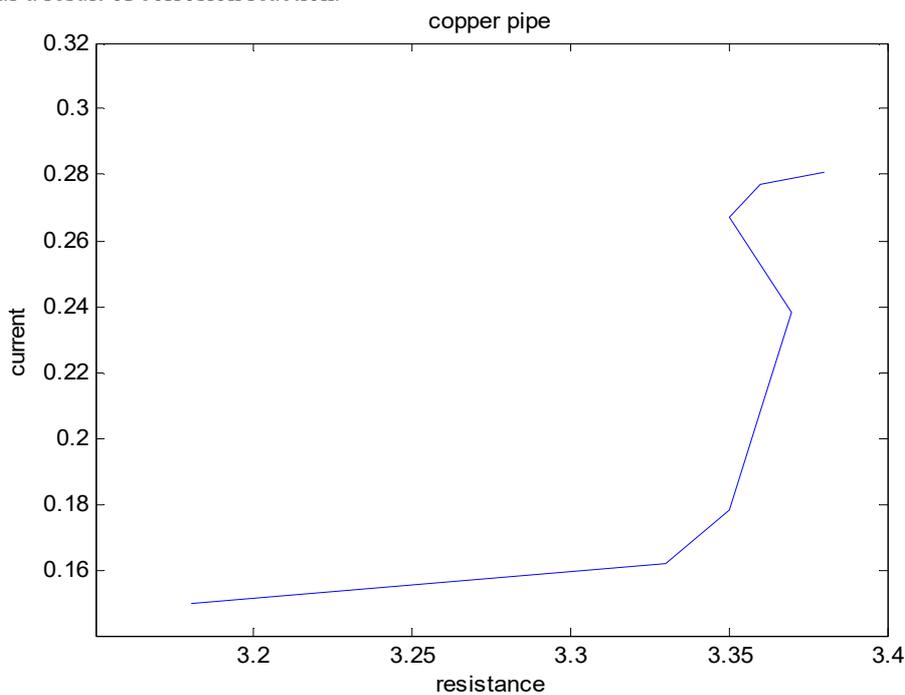

Figure3: comparison of current and time relationship in corrosion reaction

From the above figure it has been concluded that as time increased current increased, as it increased ions concentration as a result of corrosion reaction.

4. Conclusion

The Municipal drinking water came from the ground water. This water was more hard water; so our experimental result showed that 188.1Mg/l as CaCO3 and the pH of the water was 8.16 from the corroded pipe sample at 28.9 ^{0}C temperature. In low alkalinity and low pH water, elevating the pH to between 7 and 8 would beneficial in alleviating iron corrosion. Iron corrosion increased if the pH of the hard water was taken above 8 in the corroded iron pipe. So in the experiment was focused on cathode protection to decrease corrosion of iron pipe in drinking water distribution. Iron corrosion is an extremely complex process in underground iron pipe line. Because of the large variability in distribution system conditions; a particular factor may be critical in one system but relatively unimportant in another system. Moreover, corrosion itself has several different

manifestations and can be evaluated in many ways. In our studies on iron pipe corrosion have focused on different aspects of iron corrosion. Pipe degradation was measured by weight loss, oxygen consumption, corrosion current, color, turbidity. Corrosion problems in humans in the short term damages the liver and kidneys over time. Corrosion can cause physical and mental development problems in children. In adults, it can lead to high blood pressure and kidney problems so our study was starting based on the problem. The total cost of corrosion for the drinking water and sewer systems includes the cost of replacing aging infrastructure, the cost of unaccounted for water, the cost of external coatings, and the cost of cathode protection. So; the corrosion management was part of the overall management system, which should be concerned with the development, implementation, review and maintenance of the corrosion.

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A large number of parameters affected pipe corrosion, including water quality and composition, flow conditions, biological iron activity, and corrosion inhibitors. Corrosion scales play an important role in modifying water quality in drinking water distribution systems. The corrosion scales from old water pipe lines were analyzed for their structure and composition. This paper mainly studied the deposits found in water distribution system of Municipal and protection of corrosion methods as well as to preventive measurements of the iron pipe corrosion. The corrosion scales had a shell-like, env Pipes in water distribution systems may change as they age. The accumulation of corrosion byproducts and suspended particles on the inside wall of aged pipes can increase pipe roughness and reduce pipe diameter. To quantify the hydraulic effects of irregular accumulation on the pipe walls, eleven aged pipes ranging in diameter from 0.020-m (0.75-in) to 0.100-m (4-in) and with varying degrees of turberculation were located and subjected to laboratory testing. Using EPANET 2, the importance of correcting pipe diameters when modeling water distribution systems containing aged pipes was investigated. Correcting the pipe. iii. Internal corrosion of drinking water distribution systems and home plumbing systems has long been a recognized issue facing the drinking water industry—one that has many health, water quality, and economic implications. This manual was written with the intent to provide a practical overview of internal corrosion issues, to identify appropriate corrosion response and control methods, and to develop corrosion control monitoring programs. Corrosion of distribution system piping may lead to pipe and valve failures resulting in increased water losses. Several studies of low-alkalinity waters have found that iron and zinc were the principal corrosion by-products of galvanized plumbing (Dangel 1975; J.M. Montgomery 1982). The corrosion scales from old water pipe lines were analyzed for their structure and composition. This paper mainly studied the deposits found in water distribution system of Municipal and protection of corrosion methods as well as to preventive measurements of the iron pipe corrosion. The corrosion scales had a shell-like, enveloping layer, covering porous deposits of iron oxide phases. Catastrophic failures are obtained in water distribution systems, so major layer will be occurred. The ground water samples were drawn from the area and subjected to physical and chemical analysis and the anal