STUDY ON THE CORROSIVE NATURE OF SOIL TOWARDS THE BURIED-STRUCTURES

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Abstract: This work is focused to investigate soil parameters such as moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulfate contents those affect the corrosive nature of soils toward the buried-galvanized steels and cast-iron pipelines used to supply the drinking water in Kathmandu Valley. It is found that the twenty three soil samples collected from the study areas are "mildly corrosive" to "non-corrosive" nature towards the buried-galvanized steels and cast-iron pipes used to supply the drinking water in Kirtipur areas of Kathmandu Valley.

Keywords: Chloride content; Oxidation-reduction potential; Resistivity; Soil corrosivity; Sulfate content.

INTRODUCTION

Soils can be corrosive for the buried-structures like galvanized-steels and iron-cast pipelines used to supply the drinking water from reservoirs to consumers. Mitigating measures taken into account during design and construction while the effects of corrosive soil can cause structural failure of the buried-structural materials. An understanding of the corrosivity of a particular soil can minimize such soil corrosion of the buried-structural materials. The study of the soil corrosion of buried-structural materials is importance, because millions of miles of the buried steels or iron–pipelines are used to supply the drinking water, gas, oil and so on in the world. Corrosion control of these buried-structural materials necessitates a huge amount of money for regular maintenance and replacement. The corrosion rate of the buried-structural materials is mainly influenced by six different soil parameters like moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulfate contents[1-3]. Estimation of such soil parameters can give an indication of the soil corrosivity towards the buried-structural materials like galvanized steel and cast-iron pipes.

Numerous studies on soil corrosion on the buried-structures have carried out[4-19]. It has been reported that the corrosion behaviour of galvanized steels and bare steels after exposure for thirteen years in different soils of USA by Danison and Romanoff in early of 1950s[4,5]. It was reported that the corrosion of mild steel increased when soil moisture content exceeds 40% and suggested that the maximum corrosion rates occur at saturations of 60–85%[4]. Soil resistivity has the largest effect on the observed maximum average pitting corrosion rate on the surface of the buried-pipelines[6]. Many buried-structural materials, such as galvanized water supply pipelines, natural gas and crude oil pipelines have been corroded by soils all around the world[4-7,10,13,16,18]. It has been reported that the aggressiveness of soil towards the drinking water supply pipeline used in Toronto city of Canada was affected by soil properties such as resistivity, pH and the presence of sulfate-reducing bacteria[10]. Study on Nigeria pipeline of crude oil (along the Obrikom–Ebocha areas) showed that the soil resistivity value decreased with increasing the moisture content and temperature[13]. It has been reported that the sandy and gravel soils have a high resistivity (more than 6000 ohm.cm) and therefore, considered to be "mildly corrosive" or "excellent corrosion resistance" for the galvanized steels and cast-iron pipes, while a clayey soil with a resistivity less than 1000 ohm.cm is generally considered to be "highly corrosive" for the buried-galvanized steels[1-3]. Soils having high resistivity (i.e., low conductivity) are generally least corrosive for the buried-structural materials.

It has been reported that soil is generally considered "mildly corrosive" if the sulfate and chloride in soils are below 200 ppm and 100 ppm, respectively, with pH of 5–9 and the resistivity greater than 5,000 ohm.cm[1-3,8,9]. The presence of sulfate more than 200 ppm in soils can pose a major risk for the buried-structural materials[8-11], because it can readily be converted to highly corrosive sulfides by anaerobic sulfate-reducing bacteria. Maslehuddin *et al.* (2007) studied the effect of chloride concentration in soil on the corrosion behavior of reinforcing steels[15].

The of city supply water is mostly through the buried galvanized steels and cast-iron pipelines in

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Kathmandu Valley. For the purpose of security and safety all such water supply pipelines are generally buried beneath the earth surface to a depth of about 1 meter. The repeated failure as a result of corrosion of the buried water supply pipelines in Kathmandu Valley is observed for a long time. In this context, it is very urgent to investigate the effects of different soil parameters that affect the corrosive nature of soils on the buried-galvanized steel and cast-iron pipelines used to supply the city water in Kathmandu Valley.

The main objectives of this study are to know the effect of soil parameters on the corrosivity of such buried-structural materials and to specify the corrosive nature of soils of Panga-Kirtipur-Tyanglaphant areas of Kirtipur Municipality.

EXPERIMENTAL METHODS

Twenty three soil samples were collected from Panga-Kirtipur-Tyanglaphant areas of Kitipur Municipality. The Panga-Kirtipur-Tyanglaphant area is located within the latitude of 27^{o} 40’ 05”–27^{o} 41’ 30” N and within the longitude of 85^{o} 16’ 10”–85^{o} 17’ 10” E as shown in Fig. 1. All soil samples were taken from the depth of about 1 meter from the ground level for the real location of the buried-pipelines for the purpose of the supply of drinking water. The distance between two samples was taken about 300 to 500 meters. The soil sample was taken in an air tight polyvinyl bag so that the moisture remained same for a period of moisture content analysis in the laboratory.

Moisture content in soil was determined using weight loss method in accordance with the ASTM D4959-07 standards[20]. A digital pH meter was used to determine the pH of 1:2 soil-water suspension of each soil samples in accordance with the ASTM G51-95 (2012) standards[21]. The conductivity bridge was used to determine the electrical conductivity of the 1:2 soil-water suspension in accordance with the ASTM G187-05 standards[22]. The soil resistivity (bulk/saturated paste) was calculated from the conductivity. The oxidation-reduction potential (ORP) of the soil samples was measured with the help of a digital potentiometer in accordance with the ASTM G200-09 standards[23]. The platinum wire and saturated calomel electrodes (SHE) were used as working and reference electrode, respectively. The recorded ORP values vs SCE was converted to reference value of the saturated hydrogen electrode (SHE). Argentometric titration was used to determine the amount of chloride content in soil. Chloride content in the 1:2 soil-water suspension was determined by titrating the soil suspension against standard silver nitrate solution using potassium chromate as an indicator. Gravimetric method was used to estimate the amounts of sulfate content in soil samples. The details of these all methods are discussed in elsewhere[24,25].

Fig. 1: ***Location map of the Panga-Kirtipur-Tyanglaphant sampling sites of Kirtipur Municipality of Kathmandu district.***

RESULTS AND DISCUSSION

Moisture content in soil

The moisture content in soil is one of the most important parameters of soil corrosion towards the buried-structural materials. The moisture content in the collected soil samples was in the range of 15 to 48%. Among these twenty three soil samples, five samples have less than 20%, while sixteen samples have 20-40% and only two samples have more than 40% moisture content (Table 1). It is considered that the soil samples holding less than 40% moisture content are probably due to the mixture of sand and clay or sandy soils. These results revealed that all the soil samples are assumed to be “mildly corrosive” to “non corrosive” towards the buried-galvanized steels and cast-iron pipelines.

Soil pH

All twenty three soil samples collected from the study area are neutral or slightly alkaline in nature showing the pH values in the range of 6.4-7.9 as presented in Table 1. Among these twenty three soil samples, fifteen are neutral (6.4-7.4) and eight are slightly alkaline (7.5-7.9) in nature. Therefore, all twenty three soil samples analyzed in this research work are assumed to be “mildly corrosive” to “non-corrosive” nature towards the galvanized steels and cast-iron pipelines.

Soil resistivity

The soil resistivity (saturated paste resistivity) is actual “bulk resistivity” of soil influences by types of soil, moisture content, concentration of different dissolved salts, degree of compactness and temperature so on. Since the soil resistivity was not measured in the sampling sites, all these affecting factors except types, moisture content and dissolved salts are changed from their in-situ values. Hence, in this research work, all efforts were made to insure uniformity among the resistivity tests performed in the laboratory. All soil samples were tested at room temperature at 25^{0}C

Table 1: Soil parameters of Panga-Kirtipur-Tyanglaphant areas of Kirtipur Municipality.

S.N.	*Sample Name*	*Moisture Content (%)*	*Soil pH*	*Soil Resistivity (ohm.cm)*	*ORP (mV vs SCE)*	*Chloride (ppm)*	*Sulphate (ppm)*
1	PKT1	25	6.4	45,500	514	21	65
2	PKT2	32	7.4	10,100	424	50	171
3	PKT3	32	6.9	11,600	341	27	74
4	PKT4	36	6.9	15,900	441	23	86
5	PKT5	29	6.7	43,500	400	23	50
6	PKT6	21	7.1	62,500	439	16	41
7	PKT7	35	7.6	25,000	442	30	64
8	PKT8	30	7.6	13,900	425	30	124
9	PKT9	34	7.4	5,000	441	68	138
1	0PKT10	32	7.1	25,600	392	16	77
11	PKT11	36	7.0	23,300	401	24	65
12	PKT12	46	6.9	6,100	332	56	273
13	PKT13	48	7.1	3,300	446	90	143
14	PKT14	20	7.6	20,800	383	35	110
15	PKT15	17	7.7	17,900	385	33	110
16	PKT16	15	7.8	18,500	441	47	82
17	PKT17	19	7.6	23,800	307	68	67
18	PKT18	18	7.5	26,300	395	38	82
19	PKT19	16	7.9	20,800	418	42	102
20	PKT20	30	7.2	10,200	342	55	192
21	PKT21	32	7.2	10,400	361	52	165
22	PKT22	24	7.1	13,200	344	64	137
23	PKT23	30	7.1	10,000	331	67	137

which was remained constant and an effort was made to compact the soils to the same degree into the square soil box.

Table 1 shows the soil resistivity value of all twenty three soil samples collected from study areas. Only one sample has less than 5,000 ohm.cm soil resistivity, two have 5,000-10,000 ohm.cm, ten have 10,000-20,000 ohm.cm, seven have 20,000-30,000 ohm.cm and three soil samples have above 40,000 ohm.cm soil resistivity among these twenty three soil samples. These results revealed that most of the soil samples collected from the study areas are "mildly corrosive" to "essentially non-corrosive" in nature for the buried-structural materials based on the ASTM[9] and NACE[26] standards. It is meaningful to mention here that the soil corrosivity towards the buried-structural materials was classified into six groups (i.e., essentially non-corrosive, mildly corrosive, moderately corrosive, corrosive, highly corrosive and extremely corrosive) as shown in Table 2[8,9,26].

Oxidation-reduction potential of soil

The measurement of the oxidation–reduction potential (ORP) of soils is significant to explain the soil corrosivity towards the buried–structural materials, because it determines partially the stability of the materials. In general, an anaerobic soils having low ORP less than about 100 mV vs SHE are not helpful for formation of passive oxide layers on the surface of the materials, because the anaerobic soils do not contain any free oxygen which is necessary for the passivation of the buried–iron/steels[33]. Furthermore, the ORP of a soil indicates whether or not a soil is capable of sustaining sulfate-reducing bacteria (SRB), which contribute greatly to the corrosion problem. A low ORP indicates that oxygen content in the soil is low. Consequently, the condition is ideal for the proliferation of the sulfate-reducing bacteria, the greater the sulfide content in soils by reducing sulfate to sulfide. This is possible only the ORP is less than zero or negative values[26].

The ORP value of all twenty three soil samples collected from the study areas is higher than 300 mV vs SHE as presented in Table 1. Among these twenty three soil samples, twelve samples have ORP values in the ranges of 300-400 mV vs SHE, ten samples have 401-500 mV vs SHE and only of soil sample has more than 500 mV vs SHE ORP. These results revealed that all soil samples collected from the study areas of Kirtipur are belonged to "mildly corrosive" to "non corrosive" for the buried-structural materials based on the Johes' classification (as given in Table 3)[27].

Chloride content in soil

The contribution of chloride ions to soil corrosivity towards the buried-materials is very significant, because it also participates directly in pit initiation on the surface of stainless steels. Chloride ion is not only promoting the pitting corrosion of stainless steels, but it also inhibits the passivity of the buried-structural materials. In addition, the presence of chloride content tends to decrease soil resistivity[1].

The chloride content in all twenty three soil samples collected from the present study areas is found to be below 100 ppm. Among these twenty three soil samples, fourteen soil samples have less than 50 ppm of chloride content, while eleven samples have between 50-100 ppm chloride content as presented in Table 1. These results revealed that soils of Panga-Kirtipur-Tyanglaphant areas are considered to be "mildly corrosive" to "non-corrosive" towards the galvanized steels and cast-iron pipelines used to supply the drinking water in the areas, because the soils containing less than 50 ppm chloride content and more than 10,000 ohm.cm soils resistivity are categorized "non-corrosive" soils towards the buried-structural materials[8,9,26].

Sulfate content in soil

Sulfate content in soil is generally harmful for the buried-structural materials, as it participates directly in the electrochemical reactions that take place during corrosion process. It participates directly in pit initiation of stainless steels and also increases the soil conductivity. The soil containing less than 200 ppm of sulfate is considered as "mildly corrosive[8,9,26]. Sulfate content in all twenty three soil samples collected from Panga-Kirtipur-Tyanglaphant area is found to be less than 200 ppm except one soil sample (that is, PKT12) as presented in Table 1. These results revealed that all most all soil samples of Panga-Kirtipur-Tyanglaphant area of Kathmandu Valley are considered to be "mildly corrosive" to "non-corrosive" towards the galvanized steels and cast-iron pipelines.

Table 2: Relationship between soil resistivity, chloride and sulphate content and soil corrosivity towards the buried–structural material [8,9,26].

Soil Parameter	Soil Corrosivity Rate
1. Soil Resistivity (ohm.cm)	
> 20,000	Essentially non–corrosive
10,000–20,000	Mildly corrosive
5,000–10,000	Moderately corrosive
3,000–5,000	Corrosive
1,000–3,000	Highly corrosive
< 1,000	Extremely corrosive
2. Chloride Content (ppm)	
< 100	Mildly corrosive
3.Sulphate Content (ppm)	
< 200	Mildly corrosive

Table 3: Rating of soil corrosivity based on the oxidation–reduction potential of soils[27].

Oxidation–reduction Potential (mV vs SHE)	Soil Corrosivity
>400	Non–corrosive
201–400	Mildly corrosive
100–200	Moderately corrosive
<100	Severe corrosive

CONCLUSIONS:

Twenty three soil samples from Panga-Kirtipur-Tyanglaphant area of Kathmandu district were collected to investigate the soil corrosivity towards the buried-galvanized steels and cast-iron pipes used to supply the drinking water in the study areas. Following conclusions are drawn from the above results and discussion.

1. Most of the collected soils from Panga-Kirtipur-Tyanglaphant area are sandy or mixture of sand and clay which are assumed to be "mildly corrosive" to "non-corrosive" towards the galvanized steels and cast-iron pipes used to supply the city drinking water.
2. Most of the soils of the study areas are nearly neutral to slightly alkaline which is in the range of "mildly corrosive" to "non-corrosive" for the underground galvanized steels and cast-iron pipelines.
3. Based on the soil resistivity, it is found that all the soil samples collected from Panga-Kirtipur-Tyanglaphant area are categorized to "mildly corrosive" or "essentially non-corrosive" towards the buried-galvanized steels and cast-iron pipelines.
4. All the soil samples collected from Panga-Kirtipur-Tyanglaphant area of Kathmandu Valley have the oxidation-reduction potential value in the range

of 300-512 mV vs SHE, which support the fact that these soils are "mildly corrosive" or "non-corrosive" towards the buried-galvanized steels and cast-iron pipelines.

5. The chloride content in all twenty three soil samples are within the upper limits (i.e., less than 100 ppm) for the corrosivity of soils towards the buried-structural materials.
6. Sulfate content in twenty two soil samples (except one soil sample) is within the upper limits of 200 ppm for "mildly corrosive" towards the buried-galvanized steels and cast-iron pipelines.
7. It can be advised to the related authorities or local people that simple modification of the soils by using cheapest non-conducting materials like gravel or sand around the buried water supply galvanized and cast-iron pipelines is necessary before undergrounding them in the study areas of Kathmandu Valley to increase the life time of the pipelines.

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