Def Sci J, Vol 38, No. 2, April 1988, pp 209-216

# Underground Corrosion by Microorganisms Part–I : Analytical Studies of Some Indian Soils

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ABSTRACT

Fourteen types of Indian soils were analysed for their mechanical, physical, chemical, electrical properties and potential corrosion causing microorganisms. An effort to correlate these individual soil properties was also made.

## INTRODUCTION

Soils are known to promote corrosion of buried metallic structures like pipe lines for water, gas, oil, transmission lines, tanks, power cables, etc[1,2]. Factors attributed to this are the presence of moisture, air and electrolytes. Corrosion is also caused by the formation of differential aeration and concentration cells due to soils of different compositions and textures present along the metal structures[3]. Normally in the absence of air, there should be no corrosion under neutral conditions as the oxidant-cum-cathodic depolariser oxygen is absent[4].

However, extensive corrosion has been reported under such conditions due to anaerobic sulphate reducing bacteria[5]. These bacteria, mainly belonging to the genus *Desulfovibro,* perform the role of cathodic depolariser by removing the hydrogen from the metallic surface with the help of enzyme hydrogenase and thus promote the process of corrosion[6-8]. Besides these anaerobes, a number of other soil inhabiting microbes are suspected to play an important role in the process of corrosion of buried structures. In

Received 22 May 1987

order to study the role and extent of corrosion caused by these other soil microorganisms, a survey of fourteen types of soils from different locations of India, representing varying geoclimatic conditions was carried out. Besides isolating the potential corrosion causing microorganisms, the physical, mechanical, chemical and electrical properties of the soils were also determined to study the relevance of these factors with the microbial activity and the rate of corrosion. The analytical data of different soil types has been presented to facilitate future studies in this direction.

## 2. MATERIALS AND METHODS

### 2.1 Soil Sampling

Care was taken to maintain aseptic conditions while collecting the soil samples from the field. A specially designed soil auger with detachable tubes (Fig. 1) was used for sampling.

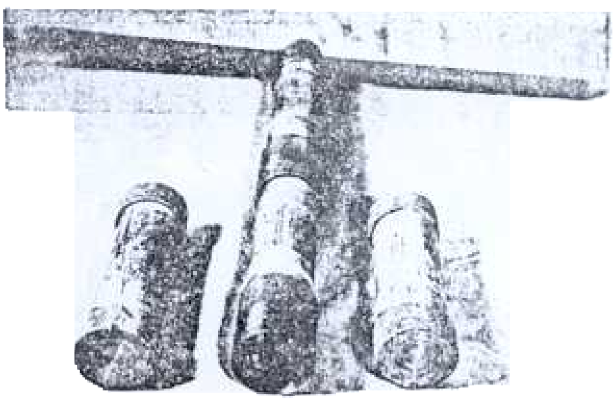

Figure 1. Soil auger with sampling tubes

The components of the auger were sterilised in hot air oven at 180°C for one hour. After cooling, these were wrapped in sterile cotton pads and packed in presterilised polyethylene bags. After assembling in the field, the auger was swabbed with ethyl alcohol and then pushed in the ground upto a depth of 45 cm by working it clockwise and applying manual pressure on the handle. The auger was then gradually withdrawn by working it anti-clockwise. The lower most tube was detached from the main body and its both ends closed with its presterilised metal screw caps. The sealed metal tube was brought back to the laboratory in its sterile wraps.

### 2.2 Determination of Soil Resistivity

If other soil factors, viz. moisture, temperature, texture and electrolyte content are constant there is a correlation between the soil resistivity and the rate of corrosion. This method is considered to be the easiest way of determining the corrosivity of soils[9]. The resistivities of the various soils were measured using Wenner's 4-pin technique[10], which though quite old, is by far the most accurate method of determining the electrical resistivity in the field. The data obtained from each location together with the type of soil as per classification of I.C.A.R., New Delhi[11] is tabulated in Table 1.

Table 1. Soil resistivity data of various types of soils

| Sl. No. | Type | Location | Soil resistivity (ohms/cm) |
|---|---|---|---|
| | Greyish brown, river basin sandy loam impregnated with salt | Kanpur | 4465 |
| 2. | Yellowish brown desert soil | Jodhpur | 7170 |
| | Grey and brown soil of Jamuna basin | Delhi | 6620 |
| | Peat soil | Cochin | 9507 |
| 5. | Red gravelly soil | Mysore | 3503 |
| 6. | Undifferentiated alluvium | Tezpur | |
| 7. | Soil of trap and gneissic origin | Hyderabad | |
| 8. | New coastal alluvium | Puri | 10510 |
| 9. | Sub montane regional soil | Jammu | 4194 |
| 10. | Black regur alluvial soil of valleys | Nagpur | |
| 11. | Laterites old alluvium | Jorhat | 2420 |
| 12. | Saline deltic soil | Digha | 9915 |
| 13. | Coastal alluvium | Madras | 3470 |
| 14. | Marshy saline peat soil | Kandla | 9150 |

## 2.3 Isolation of Potential Corrosion Causing Microflora

The microbiological analysis of the soils was done with the aim of detecting potential predominant corrosion causing/collaborating organisms. Besides anaerobic sulphate reducers, *Thiobacilli,* aerobic acid producing bacteria, fungi and *Actinomycetes* were also isolated in the laboratory using the relevant normal techniques for each type of organism. The anaerobic sulphate reducers viz. *Desulfovibrio desulphuricans* and *Desulfotomaculum* were isolated as per standard techniques[12]. For isolation of *Thiobacilli,* the soils had to be enriched with powdered sulphur at the rate of 1 per cent w/w. After two months of incubation at 35°C and 30 per cent moisture, 5 g of enriched soil from each location was aseptically added to 100 ml of colloidal sulphur agar medium[13] contained separately in 250 ml capacity Erlenmyere flasks. Blanks (without inoculum) were also kept. Four replicates for each soil type were put for incubation at 33°C together with controls. Aliquots from each flasks and control were taken out at weekly intervals and titrated against N/50 NaOH. Regular fall in pH of inoculated samples, development of turbidity, and no change in the controls, confirmed the initiation of growth. This was further confirmed by microscopic examination. The motile bacilli clustered around sulphur granules in characteristic rosettes. Subcultures on Vishanic's and Sauter's media for *Thiobacilli* were made[14] but efforts to obtain colonies on thiosulphate agar[12] did not succeed. In all, only nine locations indicated predominant presence of these bacteria. However, all strains became non-viable within a period of two or three months of their isolation.

The acid producing bacteria and fungi were isolated on a medium having 1 per cent beef extract, 1 per cent peptone, 0.5 per cent NaCl, 2 per cent glucose, 0.5 per cent yeast extract, 1 per cent $CaCO_3$ and 2 per cent agar. The pH was kept at 7.2. A 10 per cent w/v soil suspension in sterile water was used as stock for serial dilutions upto $10^{-6}$. Incubation was at 33°C and observations recorded 24 hourly. Colonies of microbes showing clear zones formed due to solubilisation of $CaCO_3$ were picked up and transferred to nutrient agar and potato dextrose agar media for bacteria and fungi respectively. Kuster and Williams[15] media with 1 per cent $CaCO_3$ as supplement was used for isolation of *Actinomycetes*. The acid producing nature of all the microbes was further confirmed by studying the pH at twenty four-hourly intervals. The various types of organisms isolated from the soils under study are listed in Table 2.

**Table 2. Potential corrosion causing/collaborating microbial isolates from different locations**

| Sl. No. | Location of soil samples | Types of bacterial strains: Anaerobes | | Aerobes | | Fungi | *Actinomycetes* | Total types |
|---|---|---|---|---|---|---|---|---|
| | | *D. Desulfuricans* | *Desulfotomaculum* | *Thiobacilli* | Other acid producers | | | |
| 1. | Kanpur | 1 | | 1 | 6 | 0 | 1 | 10 |
| 2. | Jodhpur | 1 | | 1 | 8 | 4 | 0 | |
| 3. | Delhi | 0 | | 0 | 6 | 1 | 1 | 9 |
| 4. | Cochin | 1 | | 1 | 0 | | | |
| 5. | Mysore | 0 | | 0 | 0 | 0 | 6 | |
| 6. | Tezpur | 1 | | 1 | 1 | 2 | | |
| 7. | Hyderabad | 0 | | 1 | 4 | 3 | | |
| 8. | Jammu | 0 | | 0 | 5 | 3 | 0 | 9 |
| 9. | Nagpur | 0 | 1 | 0 | 5 | 3 | 0 | 9 |
| 10. | Jorhat | 1 | 1 | 0 | 2 | 1 | 0 | |
| 11 | Puri | 0 | 1 | 1 | 5 | 0 | 0 | 7 |
| 12 | Digha | 0 | 1 | 1 | 3 | 0 | 0 | 5 |
| 13. | Madras | 1 | 1 | 1 | 4 | 3 | 0 | 10 |
| | Kandla | 0 | 1 | 9 | 3 | 0 | 0 | 13 |
| | Total | 6 | 14 | 17 | 52 | 21 | 12 | 122 |

## 2.4 Chemical Analysis of Soils

As an individual factor, the soluble salt content of the soils is quite important in the corrosion of sub-soil structures. Besides forming electrochemical cells and supporting corrosion, these salts serve as food for soil microbes and enhance their metabolic activity. However, except for acidic soils, no direct effect of these salts and pH of the soils with the rate of corrosion could be established even after extensive efforts[16]. The soils were chemically analysed[4] for the concentration of chlorides, sulphates, carbonate, nitrate, calcium, magnesium, sodium, potassium and pH values. The percentage of these salts are expressed in mg/l and tabulated in Table 3.

**Table 3. Chemical analysis of soils from different locations (5% soil extracts) (in mg/l of distilled water)**

| Sl. No. | Location | Chloride | Sulphate | Nitrate | Calcium | Magnesium | Sodium | Potassium | pH |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Kanpur | 42.6 | 9.0 | 8.7 | 11.5 | 27.0 | | 5.0 | 8.4 |
| 2. | Jodhpur | 14.0 | | 11.2 | 5.0 | 4.0 | 4.0 | | 7.9 |
| 3. | Delhi | 28.0 | | 4.0 | 14.6 | 6.0 | 4.0 | | 8.4 |
| 4. | Cochin | 14.0 | Traces | 8.5 | 6.0 | 2.0 | 4.0 | | 6.8 |
| 5. | Mysore | 14.0 | | 3.7 | 6.0 | 6.0 | 6.0 | | 7.2 |
| | Tezpur | 14.0 | | 3.7 | 3.0 | 0.97 | 6.0 | | 6.7 |
| | Hyderabad | 14.0 | Traces | 7.5 | 13.0 | 5.0 | 2.0 | | 7.0 |
| | Puri | 28.0 | | 5.5 | 13.0 | 2.0 | 5.0 | 2.0 | 8.3 |
| | Jammu | 28.0 | Traces | 13.5 | 13.0 | 9.0 | 3.0 | | 7.5 |
| 10. | Nagpur | 28.0 | | 10.0 | 12.8 | 4.0 | 2.0 | | 5.4 |
| 11. | Jorhat | 14.0 | | 3.7 | 3.2 | 3.0 | 5.0 | | 9.1 |
| 12. | Digha | 14.0 | | 5.0 | 5.0 | 2.0 | 4.0 | | 6.6 |
| 13. | Madras | 128.0 | Traces | 7.5 | 3.0 | 2.9 | 70.0 | 5.0 | 7.0 |
| 14. | Kandla | 525.0 | -do- | 5.0 | 5.0 | 2.0 | 4.0 | | 8.5 |

## 2.5 Mechanical and Physical Analysis

The physical and mechanical properties of the soils are relevant to its corrosivity as these factors hold a key to soil resistivity, water holding capacity and rate of aeration. The soils are classified as corrosive or non-corrosive on the basis of these properties.

The classification of the soils is based on the differing internal properties, for example, colour, texture and structure. The texture of the soils refers to relative amounts of clay, silt and various grades of sand and gravel which compose the soil mass[17]. The soil samples were subjected to mechanical and physical analysis as per standard-techniques listed below :

| | | |
|---|---|---|
| (i) | Mechanical analysis | IS : 2720 (Pt. II) — 1965 |
| (ii) | Moisture content | IS : 2720 (Pt. II) — 1964 |
| (iii) | Apparent density | IS : 2720 (Pt. XXVIII) — 1986. |
| (iv) | Specific gravity | IS : 2720 (Pt. III) — 1969. |
| (v) | Volume expansion and pore space. | As per method recommended by the metals committee of the Corrosion Advisory Bureau, C.S.I.R., Jamshedpur |

The test data on these properties of soils is tabulated in Table 4.

**Table 4. Mechanical and physical analysis of experimental soils**

| Sl. No. | Location | % coarse sand | % fine sand | % silt | % Caly | Apparent density | % moisture content | % pore space | Sp. gravity | % volume expansion |
|---|---|---|---|---|---|---|---|---|---|---|
| | Kanpur | 0.38 | 58.95 | 16.95 | 15.83 | .4800 | 36.27 | 49.30 | 2.82 | 5.14 |
| | Jodhpur | 13.55 | 43.00 | 34.85 | 8.25 | 1.8900 | 27.16 | 42.70 | 2.82 | 2.68 |
| | Delhi | 1.23 | 94.00 | 03.60 | Negligible | 1.4100 | 36.10 | 50.36 | 2.83 | 1.00 |
| 4. | Cochin | 42.31 | 36.00 | 11.70 | 9.47 | .5138 | 31.20 | 46.34 | 2.73 | 2.88 |
| | Mysore | 29.32 | 26.00 | 7.25 | 32.50 | .2480 | 47.30 | 64.24 | 2.61 | 6.08 |
| 6. | Tezpur | 6.00 | 56.00 | 22.00 | 16.00 | 1.4800 | 33.84 | 49.06 | 2.84 | 1.90 |
| 7. | Hyderabad | 35.87 | 49.26 | 24.68 | 9.19 | 1.4300 | 39.18 | 51.64 | 2.84 | 5.16 |
| 8. | Jammu | 00.95 | 42.80 | 25.18 | 29.82 | 1.2700 | 43.15 | 54.79 | 7.78 | 0.54 |
| 9. | Nagpur | 14.87 | 49.26 | 24.68 | 9.19 | .3400 | 44.78 | 49.56 | 2.46 | 11.72 |
| 10. | Jorhat | Negligible | 56.68 | 42.70 | Negligible | .4700 | 35.21 | 48.56 | 2.69 | 6.60 |
| 11 | Puri | 67.3 | 25.0 | 6.0 | -do- | 1.7400 | 28.87 | 41.7 | 2.99 | Negligible |
| 12. | Digha | 6.0 | 56.0 | 22.0 | 16.0 | .5700 | 32.22 | 50.54 | 3.17 | 0.04 |
| 13. | Madras | 7.32 | 58.0 | 17.73 | 15.92 | .5100 | 34.25 | 49.60 | 2.82 | 6.10 |
| 14. | Kandla | 12.97 | 32.70 | 19.57 | 33.70 | 1.4617 | 32.85 | 45.80 | 2.60 | 3.22 |

## 3. DISCUSSION

Soils vary widely in their physical, chemical and electrical properties. Although these factors are considered important for corrosivity of the soil but many attempts to establish a clear correlation between these factors have not been successful. The studies have however helped to understand more about the individual effect of each factor on the rate of corrosion[18]. The Indian soils have been classified into twenty major types[9]. Out of these, fourteen types of soils were studied for their varying physical, chemical and electrical properties as well as for potential corrosion causing microbes.

Soil resistivity is by far the best criterion for estimating the corrosivity of a given soil in the laboratory, where the vital parameter of moisture[19] can be controlled. However, under field conditions the soil resistivity of the same soil varies due to seasonal fluctuations. Variations upto 50 per cent have been noticed on account of precipitation and 20 per cent due to temperature changes[20]. Texture and electrolyte content of the soils play a significant role in the corrosivity of the soils. Its permeability to air and water is dependent on its particle size. The capillary porosity of the soils causes retention of water and non-capillary porosity causes retention of the air in the soil[17]. Generally poor aeration, high acid value, high electrical conductivity, high moisture and salt content are characteristics of corrosive soils. Dry, sandy and low electrical conductivity soils produce little corrosion[16]. Though the microbial factor is not considered to be as important as others but no sincere effort has been made to study it in great detail. Most of the workers in this field have restricted their investigations to only one or two organisms i.e. *Desulfovibrio desulphuricans, Thiobacillus,* and a few others which are considered to be quite vital for corrosion of underground metal structures[21]. During these studies, which includes all types of potential corrosive soil microorganisms, important observation has been made regarding their corrosivity to metals. Exposures of experimental metal panels to pure cultures of aerobes or anaerobes yielded lower rate of corrosion as against corrosion caused by mixed cultures. It has also been noticed that out of three species of genus *Desulfotomaculum* which have been isolated from the soils, each one prefers identical type of soil for its growth (unpublished work). Similar studies with other isolates are in progress and it is hoped that these microbes may provide us with an answer for establishing a linking factor between the various parameters of the soils and their corrosivity to buried structures.

## 4. CONCLUSION

A number of Indian soils were studied to identify a link between the different soil properties and its corrosivity to the underground metallic structures. Although the individual factors and their impact on the corrosivity of the soils have been studied but no interaction between these parameters could be established so far. The data presented may be of great help for further studies in this field of work in India.

## ACKNOWLEDGEMENTS

The authors are thankful to Dr. B.V. Ramani, Director, DMSRDE, Kanpur for encouragement and interest in the work; to the Director, Defence Laboratory, Jodhpur for carrying out confirmatory soil analysis, and to Dr. J.P. Trivedi, Head Biology Division, for helpful suggestions in preparation of the manuscript.

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