Principles and Applications of Time Domain Electrometry in Geoenvironmental Engineering

A.M.O. Mohamed
UAE University, Al Ain, United Arab Emirates
TABLE OF CONTENT

Developments in arid regions research series ii
About the author xv
Preface xvii

Chapter 1
Use of time domain electrometry in geoenvironmental engineering
1.1 Introduction 1
1.2 Time domain electrometry 2
1.3 Geoenvironmental engineering 2
1.4 Environmental monitoring program 3
  1.4.1 Implementation of an environmental monitoring program 3
  1.4.2 Types of EMP 3
  1.4.3 Monitoring program in the EIA methodology 5
  1.4.4 Objectives of project based EMP 6
  1.4.5 Monitoring cost 7
  1.4.6 Reporting and enforcement capability 7
  1.4.7 Monitoring requirements for effective pollution control 8
1.5 Design elements of a monitoring program 8
  1.5.1 Analyze significant environmental issues 8
  1.5.2 Define assessment endpoints 8
  1.5.3 Select environmental indicators 9
  1.5.4 Establish information management system 9
  1.5.5 Develop rigorous sampling design 10
  1.5.6 Establish quality assurance/quality control program 10
  1.5.7 Estimate costs associated with the monitoring program review
    the program periodically 11
  1.5.8 Review the program periodically 11
1.6 Groundwater monitoring 11
  1.6.1 Groundwater protection program 11
  1.6.2 Groundwater detection monitoring 12
  1.6.3 Groundwater compliance monitoring 12
  1.6.4 Groundwater protection standard 13
1.7 Risk management 14
1.8 Land disposal 15
  1.8.1 Regulatory attitudes for land disposal 16
  1.8.2 Design criteria 17
  1.8.3 Closure criteria 17
  1.8.4 Monitoring issues for land disposal practice 19
1.9 Subsurface investigation/monitoring issues 21
  1.9.1 Sampling requirements 21
  1.9.2 An alternative approach-geophysical methods 22
  1.9.3 Remote sensing and geophysics 22
  1.9.4 Direct and indirect measurements 23
Chapter 3
Subsurface monitoring techniques

3.1 Introduction 65
3.2 Direct leak monitoring 66
  3.2.1 Suction lysimeter 67
  3.2.2 Collection lysimeter 67
3.3 Indirect leak monitoring 68
  3.3.1 Soil water potential detection techniques 69
  3.3.2 Soil moisture detection techniques 72
  3.3.3 Solute movement detection technique 77
  3.3.4 Gas detection techniques 81
Chapter 4
Fundamentals of electromagnetics
4.1 Introduction
4.2 Basic quantities of electromagnetics
4.3 Static electric fields
  4.3.1 Fundamental postulates of electrostatics in free space
  4.3.2 Coulomb's law
  4.3.3 Gauss's law
  4.3.4 Electric potential
  4.3.5 Conductors in static electric field
  4.3.6 Dielectrics in static electric field
  4.3.7 Electric flux density
  4.3.8 Dielectric constant
  4.3.9 Dielectric strength
  4.3.10 Capacitance and capacitors
  4.3.11 Electrostatic energy and forces
4.4 Steady electric currents
  4.4.1 Current density and ohm's law
  4.4.2 Electromotive force and kirchhoff's law
  4.4.3 Equation of continuity
  4.4.4 Power dissipation and joule's law
  4.4.5 Resistance calculations
4.5 Static magnetic fields
  4.5.1 Introduction
  4.5.2 Fundamental postulates of magnetostatic in free space
  4.5.3 Vector magnetic potential
  4.5.4 The biot-savart law
  4.5.5 Magnetization and equivalent current densities
  4.5.6 Magnetic field intensity and relative permeability
  4.5.7 Inductances and inductors
4.6 Summary and concluding remarks

Chapter 5
Time-varying fields and maxwell's equations
5.1 Introduction
5.2 Faraday's law of electromagnetic induction
5.3 Maxwell's equations
5.4 Potential functions
5.5 Source free wave equations
5.6 Electromagnetic boundary conditions
5.7 Time harmonic fields
5.8 Time harmonic electromagnetic
5.9 Summary and concluding remarks

Chapter 6
Electromagnetic wave propagation
6.1 Introduction
6.2 Waves in general
6.3 Wave propagation in lossy dielectrics
6.4 Wave propagation in lossless dielectrics
10.2.2 Spontaneous potential curve 286

10.3 Soil resistivity 288
10.3.1 Fundamentals 288
10.3.2 Electric conduction in continuous porous media 288
10.3.3 Point current electrode on homogeneous porous media 289
10.3.4 Buried current electrode in homogeneous porous media 290
10.3.5 Determination of resistivity 291
10.3.6 Apparent resistivity 292
10.3.7 Point-electrode configurations 293
10.3.8 Determination of specific conductivity 294

10.4 Induced polarization 299
10.4.1 Induced polarization phenomenon 299
10.4.2 Time domain IP measures 301
10.4.3 Frequency domain IP measures 302

10.5 Electromagnetic 303
10.5.1 Introduction 303
10.5.2 Electromagnetic induction 304
10.5.3 Electromagnetic permeability 306
10.5.4 Dielectric permittivity 308

10.6 Summary and concluding remarks 309

Chapter 11
Soil magnetic properties

11.1 Introduction 311
11.2 Magnetism in matter 314
11.2.1 Magnetic moments of atoms 314
11.2.2 Magnetization and magnetic field strength 316
11.2.3 Classification of magnetic substances 318
11.2.4 Characterization of magnetic properties 322
11.2.5 Magnetic hysteresis 323
11.2.6 Curie’s law 324
11.2.7 Magnetic property measurement 325
11.3 Magnetic mineralogy of soils 332
11.3.1 Iron and aluminum oxides and hydrous oxides 334
11.3.2 Manganese oxides 340
11.3.3 Titanium oxides 341
11.3.4 Silicon oxides 341
11.3.5 Chromite 341
11.3.6 Limonite aggregates 343
11.3.7 Mineral transformation 344
11.4 Techniques for measuring soil magnetic properties 344
11.4.1 Determinations of soil magnetic parameters 344
11.4.2 Soil magnetic property conversion factors 350
11.5 Magnetic properties of soils 351
11.5.1 Magnetic susceptibility of soils 351
11.5.2 Factors contributing to magnetic susceptibility enhancement 358
11.5.3 Chemistry of (Fe, Al and Mn) and their relations to magnetic susceptibility 361
11.6 Magnetic properties of polluted soils 362
11.7 Chemical and microbiological transformation 364
11.7.1 Types of magnetic bacteria 365
11.7.2 Growth of extracellular bacterial magnetite 366
11.8 Summary and concluding remarks 367
### Chapter 12

**Soil dielectric permittivity**

12.1 Introduction 369

12.2 TDR soil dielectrics 370

12.2.1 Soil dielectric property 370

12.3 Apparent dielectric constant of soil 374

12.4 Frequency dispersion behavior 375

12.5 Mixing models 381

12.6 Dielectric and hydro-geological parameters 387

12.7 In-situ dielectric measurements 389

12.8 Petroleum exploration 389

12.9 Shallow subsurface investigation 393

12.10 Laboratory techniques 395

12.10.1 Measurements with waveguide 395

12.10.2 Measurements with TDR 396

12.10.3 Determination of frequency-dependent permittivity from TDR measurements 397

12.10.4 Determination of frequency-dependent permittivity from frequency domain measurements 401

12.10.5 Impedance measurements 402

12.11 Saturation and wettability effects 402

12.11.1 Wettability 402

12.11.2 Wettability and capillary pressure 403

12.11.3 Wettability and relative permeability 404

12.11.4 Wettability and dielectric property 405

12.12 Summary and concluding remarks 408

### Chapter 13

**Soil moisture content**

13.1 Introduction 409

13.2 TDR system 410

13.2.1 Basic design 410

13.2.2 Further developments 410

13.2.3 Signal input and output for TDR systems 414

13.2.4 Effect of design geometric factors 415

13.3 TDR soil moisture content 418

13.3.1 TDR waveform and waveform analysis 419

13.4 Moisture content prediction models 421

13.4.1 Empirical models 421

13.4.2 Dielectric mixing and physical models 422

13.5 Impact of soil parameters on soil moisture content prediction 424

13.5.1 Soil texture 424

13.5.2 Soil moisture 424

13.5.3 Soil density 426

13.5.4 Pore fluid salinity 426

13.5.5 Soil temperature 429

13.5.6 Soil organic matter 431

13.6 Soil moisture content and pore fluid concentration via Fourier transform 431

13.7 Soil moisture content and pore fluid concentration via eigendecomposition 433

13.8 Soil moisture content via neuro-fuzzy logic 435

13.9 Summary and concluding remarks 437