Testing of Bentonite Clay Contaminated Flood Waters and Industrial Waste Waters

C. Vipulanandan Ph.D., P.E.
Honorable Daniel Wong Endowed Professorship
"**Smart Cement**" Inventor and Text Book
"**Vipulanandan Rheological Model**"
"**Vipulanandan Failure Model**"
Chief Editor – Advances in Civil Engineering
Director, Center for Innovative Grouting Material and Technology (CIGMAT)
Director, Texas Hurricane Center for Innovative Technology (THC-IT)
Professor of Civil and Environmental Engineering
University of Houston, Houston, Texas 77204-4003

Abstract

Based on the applications and conditions, waste waters can be contaminated with fine clay particles. Also during flooding soil on the surface is eroded and flood waters carry various types of sediments including clays clogging various manholes and also depositing clays in the ship channels and port affecting various operations. Also during hydraulic fracking the water will be contaminated with very fine clay particles from various formations and impacting the recycling of the fracking fluids. Also industrial wastewaters will also have fine clay particles. Also rules and regulations are being updated by the U.S. EPA and other agencies. Hence it is important to develop new technologies to real-time monitoring system for the operations including monitoring the water quality at all levels of supplies, treatment and recycling operations. A two-probe method has been developed and the preliminary investigation was on characterizing the clay contaminated water and based on the results electrical resistivity and electrical resistance was identified as the critical monitoring parameters. Also the sensitivity of resistivity with the waste water contaminated with bentonite clay contents were investigated.

1. Introduction

The water used for domestic, commercial and industrial operations around the world amounting to over 2.4 trillion gallons per day. Source of fresh water supply includes ground water, rain water, reservoirs and rivers. Use of groundwater is leading to ground settlement and countries are limiting its use especially along the coastal regions because of sea level rises.

Water reclamation (also called wastewater reuse or recycling) is the process of converting many types of wastewaters into water that can be reused for other purposes. Reuse may include irrigation of gardens and agricultural fields or replenishing surface water and groundwater (i.e., groundwater recharge) also recycling in industries. Reused water may also be directed toward fulfilling certain needs in residences (e.g. toilet flushing), businesses, and industry, and could even be treated to reach drinking water standards. This last option is called either "direct potable reuse" or "indirect potable" reuse, depending on the approach used.

Reclaiming water for reuse applications instead of using freshwater supplies can be a water-saving measure. When used water is eventually discharged back into natural water sources, it can still have benefits to ecosystems, improving streamflow, nourishing plant life and recharging aquifers, as part of the natural water cycle.

Reusing wastewater as part of sustainable water management allows water to remain as an alternative water source for human activities. This can reduce scarcity and alleviate pressures on groundwater and other natural water bodies. Another potentially positive aspect is the nutrient content in the wastewater, which might reduce the need of other fertilizers.

Drawbacks or risks often mentioned include the content of potentially harmful substances such as bacteria, heavy metals, organic pollutants (including pharmaceuticals, personal care products and pesticides) and fluorides. Irrigation with wastewater can have both positive and negative effects on soil and plants, depending on the composition of the wastewater and on the soil or plant characteristics.

In recent years the rules and regulations are being updated by the U.S. EPA and other agencies and theses have to be taken into account. Water/wastewater reuse, as an alternative water source, can provide significant economic, social and environmental benefits, which are key motivators for implementing such reuse programs. Specifically, in agriculture, irrigation with wastewater may contribute to improve production yields, reduce the ecological footprint and promote socioeconomic benefits.

Barriers to implementation of Recycling Wastewaters

Recycle (reclaimed) water is considered safe when appropriately used. Reclaimed water planned for use in recharging aquifers or augmenting surface water receives adequate and reliable treatment before mixing with naturally occurring water and undergoing natural restoration processes. Some of this water eventually becomes part of drinking water supplies.

A 2005 study titled "Irrigation of Parks, Playgrounds, and Schoolyards with Reclaimed Water" found that there had been no incidences of illness or disease from either microbial pathogens or chemicals, and the risks of using reclaimed water for irrigation are not measurably different from irrigation using potable water.

A water quality study published in 2009 compared the water quality differences of reclaimed/recycled water, surface water, and groundwater. Results indicate that reclaimed water, surface water, and groundwater are more similar than dissimilar with regard to constituents. When detected, most constituents were in the parts per billion and parts per trillion range. DEET (a bug repellant), and caffeine were found in all water types and virtually in all samples. Triclosan (in anti-bacterial soap & toothpaste) was found in all water types, but detected in higher levels (parts per trillion) in reclaimed water than in surface or groundwater. Very few hormones/steroids were detected in samples, and when detected were at very low levels. Haloacetic acids (a disinfection by-product) were found in all types of samples, even groundwater. The largest difference between reclaimed water and the other waters appears to be that reclaimed water has been disinfected and thus has disinfection by-products (due to chlorine use).

A 2012 study conducted by the National Research Council in the United States of America found that the risk of exposure to certain microbial and chemical contaminants from drinking reclaimed water does not appear to be any higher than the risk experienced in at least some current drinking water treatment systems, and may be orders of magnitude lower.[38] This report recommends adjustments to the federal regulatory framework that could enhance public health protection for both planned and unplanned (or de facto) reuse and increase public confidence in water reuse.

1.2. History

From the beginning of the Bronze Age (ca. 3200–1100 BC), domestic wastewater (sewage) has been used for irrigation and aquaculture by a number of civilizations including those that developed in China and the Orient, Egypt, the Indus Valley, Mesopotamia, and Crete (Andreas et al. 2018). In historic times (ca. 1000 BC−330 AD), wastewater was disposed of or used for irrigation and fertilization purposes by the Greek and later Roman civilizations, especially in areas surrounding important cities (e.g., Athens and Rome). In more recent times, the practice of land application of wastewater for disposal and agricultural use was utilized first in European cities and later in USA. Today, water reclamation and reuse projects are being planned and implemented throughout the world. Recycled water is now used for almost any purpose including potable use. This paper provides a brief overview of the evolution of water reuse over the last 5,000 years, along with current practice and recommendations for the future. Understanding the practices and solutions of the past, provides a lens with which to view the present and future.

1.3.Engineered Wastewater Treatment Systems

The development of modern methods of sewage treatment can be traced back to the mid nineteenth century in England and Germany. The large population in London and the limited area available for treatment in sewage farms, broad irrigation, or intermittent filtration led to renewed interest in more intensive methods of treatment before discharging the treated effluent to land and hence to freshwater bodies. Methods of treatment that were used included large septic tanks, contact beds, and trickling filters. Where sufficient land was available intermittent sand filters were also used.

1.4.Changing Views of Water Reclamation and Reuse

Many things have changed in the water reclamation and reuse field in the contemporary period (1900 AD-present), but especially so during the last three decades. One of the most relevant changes is the recognition of the importance of reclaimed water in an integrated water resources management plan. Reclaimed water has become a new, additional, alternative, reliable water supply source right at the doorstep of metropolis for numerous uses in the diverse environment. This approach has even been recognized by the United Nations through the World Water Development Report 2017 (UNESCO, 2017) focusing on wastewater as a resource. Moreover, successful stories on water reuse have expanded the frontier from agricultural and landscape irrigation and restricted urban uses to a variety of uses including potable reuse (Crook, 2010; Mujeriego, 2013; Tchobanoglous et al., 2014).

1.5. World Health Organization (WHO)

The World Health Organization has recognized the following principal driving forces for wastewater reuse:

1. increasing water scarcity and stress,
2. increasing populations and related food security issues,
3. increasing environmental pollution from improper wastewater disposal, and
4. increasing recognition of the resource value of wastewater, excreta and greywater.

Water recycling and reuse is of increasing importance, not only in arid regions but also in cities and contaminated environments.

Already, the groundwater aquifers that are used by over half of the world population are being over-drafted. Reuse will continue to increase as the world's population becomes increasingly urbanized and concentrated near coastlines, where local freshwater supplies are limited or are available only with large capital expenditure. Large quantities of freshwater can be saved by wastewater reuse and recycling, reducing environmental pollution and improving carbon footprint.[9] Reuse can be an alternative water supply option.

1.6. EPA Guidelines

Water reuse (also commonly known as water recycling or water reclamation) reclaims water from a variety of sources then treat and reuse it for beneficial purposes such as agriculture and irrigation, potable water supplies, groundwater replenishment, industrial processes, and environmental restoration. Water reuse can provide alternatives to existing water supplies and be used to enhance water security, sustainability, and resilience.

Water reuse can be defined as planned or unplanned. Unplanned water reuse refers to situations in which a source of water is substantially composed of previously-used water. A common example of unplanned water reuse occurs when communities draw their water supplies from rivers, such as the Colorado River and the Mississippi River, that receive treated wastewater discharges from communities upstream.

Planned water reuse refers to water systems designed with the goal of beneficially reusing a recycled water supply. Often, communities will seek to optimize their overall water use by reusing water to the extent possible within the community, before the water is reintroduced to the environment. Examples of planned reuse include agricultural and landscape irrigation, industrial process water, potable water supplies, and groundwater supply management.

1.7. Water Reuse Regulations in the United States

EPA does not require or restrict any type of reuse. Generally, states maintain primary regulatory authority (i.e., primacy) in allocating and developing water resources. Some states have established programs to specifically address reuse, and some have incorporated water reuse into their existing programs. EPA, states, tribes, and local governments implement programs under the

Safe Drinking Water Act and the Clean Water Act to protect the quality of drinking water source waters, community drinking water, and waterbodies like rivers and lakes. Together, the Safe Drinking Water Act and the Clean Water Act provide a foundation from which states can enable, regulate, and oversee water reuse as they deem appropriate.

1.8. US Geological Survey (USGS)

What is continuous real-time water quality (RTWQ)

In the United States, USGS is involved in monitoring the quality of water in streams around the country. Real-time water quality refers to in-stream water-quality measurements done at selected points and made available on the web in real-time. Water-quality measurements are recorded in time intervals as small as 5 minutes to hourly and are often referred to as continuous. These time-dense (continuous) stream data are made available on the Web in near real-time (updated 4-hour intervals or less) (available at http://waterdata.usgs.gov/nwis). Providing these data in real-time informs the various users of stream conditions and public safety.

Real-time water quality information is made possible because of improvements in sensor and data recording technology since the first in-stream sensors were developed in the 1950-60s to directly measure or compute concentrations of many water-quality constituents. Sensors that measure water-quality properties or constituent concentrations are available for specific conductance, pH, water temperature, turbidity, dissolved oxygen, and nitrate. Typical probes (pH, dissolved oxygen, turbidity, dissolved organic matter, conductivity, temperature, chloride and algae (blue-green)) used by USGS for point measurements are shown in Figure 1.

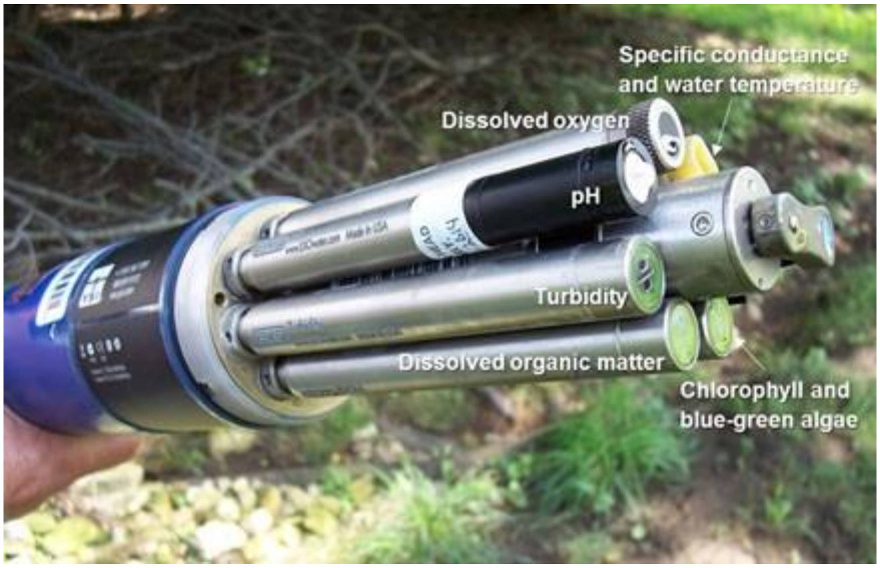

Figure 1. Probes used by USGS for monitoring

1.8.2. Why continuous and real time?

Continuous real-time information is a vital asset that helps safeguard lives and property and ensures adequate water resources for a healthy economy. Continuous real-time water-quality data are needed for decisions regarding drinking water, water treatment, regulatory programs, recreation, and public safety. Additionally, increased data-collection frequency provides an improved understanding of factors that affect water quality.

Advances related to monitoring technology are enhancing our understanding of water-quality issues. These advancements include, for example, innovation and new water-quality sensors, monitors (multiple sensors in a single probe), data recorders, and transmission equipment. In-stream water-quality sensors provide continuous measurements (typically, every 5-60 minutes) of water-quality conditions that may vary widely over short periods of time, such as before, during, and after storms or during tidal fluctuations. When these data are available in real time, water management officials can be notified of these changes and are able to respond by altering treatment or collecting additional data. Additionally, real-time measurements for temperature, conductance, and turbidity can be statistically related to other important properties, such as indicator bacteria that are more costly and difficult to monitor and analyze. Continued development, testing, and deployment of a new generation of real-time sensors for water quality have the potential to greatly increase the level of information available.

2. Objectives

Overall objective is to investigate to identify the electrical parameter to monitor the clay contaminated water in the field. The specific objectives are as follows:

(1). Identify the critical electrical parameters to monitor the bentonite clay contamination of water in the field

(2). Experimentally verify the sensitivity of the monitoring parameter for various concentrations of clay contamination.

(3). Develop model to predict the real-time monitoring parameters with the clay types and contents.

3. Literature review

3.1. Sources of Wastewaters

Sources of water for potential reuse can include municipal wastewater, industry processes and cooling water, stormwater, agriculture runoff and return flows, and produced water from natural resource including oil extraction activities. Also another area is in chemical industries and also hydraulic fracking. These sources of water must be adequately treated to meet “fit-for-purpose specifications” for a particular next use.

3.2. Reuse

Recycled wastewater can be used in multiple applications. Fit-for-purpose specification are the treatment requirements to bring water from a particular source to the quality needed, to ensure public health, environmental protection, or specific user needs.

(a). Environmental restorations

The use of reclaimed water to create, enhance, sustain, or augment water bodies including wetlands, aquatic habitats, or stream flow is called "environmental reuse". For example, constructed wetlands fed by wastewater provide both wastewater treatment and habitats for flora and fauna.

(b). Groundwater recharge

It includes aquifer recharge for drinking water use; Augmentation of surface drinking water supplies; Treatment until drinking water quality.

(c). Agriculture

There are benefits of using recycled water for irrigation, including the lower cost compared to some other sources and consistency of supply regardless of season, climatic conditions and associated water restrictions. When reclaimed water is used for irrigation in agriculture, the nutrient (nitrogen and phosphorus) content of the treated wastewater has the benefit of acting as a fertilizer. This can make the reuse of excreta contained in sewage attractive.

The irrigation water can be used in different ways on different crops:

- Food crops to be eaten raw: crops which are intended for human consumption to be eaten raw or unprocessed.
- Processed food crops: crops which are intended for human consumption not to be eaten raw but after treatment process (i.e. cooked, industrially processed).
- Non-food crops: crops which are not intended for human consumption (e.g. pastures, forage, fiber, ornamental, seed, forest and turf crops).[21]

There can be significant health hazards related to using untreated wastewater in agriculture. Wastewater from cities can contain a mixture of chemical and biological pollutants

(d). Potable

Perhaps the most important future trend in the field of water reuse, especially in large metropolitan areas, is potable reuse (PR). As the name implies, PR involves the reuse of wastewater for human consumption following various treatment interventions. It should be noted that the US EPA acknowledged the importance of and highlighted the increased interest in pursuing potable water reuse, in its recently issued 2017 Potable Reuse Compendium (US EPA and CDM Smith, 2017) as a supplement the previously published Guidelines for Water Reuse (US EPA/USAID, 1992; US EPA, 2004, 2012). There are two types of planned PR: (a) indirect potable reuse (IPR), and (b) direct potable reuse (DPR).

Indirect potable reuse

Indirect potable reuse (IPR) means the water is delivered to the consumer indirectly. After it is purified, the reused water blends with other supplies and/or sits a while in some sort of storage, man-made or natural, before it gets delivered to a pipeline that leads to a water treatment plant or distribution system. That storage could be a groundwater basin or a surface water reservoir.

Direct potable reuse

Direct potable reuse (DPR) means the reused water is put directly into pipelines that go to a water treatment plant or distribution system. Direct potable reuse may occur with or without "engineered storage" such as underground or above ground tanks. In other words, DPR is the introduction of reclaimed water derived from domestic wastewater after extensive treatment and monitoring to assure that strict water quality requirements are met at all times, directly into a municipal water supply system. Direct potable reuse is also called "toilet to tap".

(e). Irrigation

Irrigation of public parks, sporting facilities, private gardens, roadsides; Street cleaning; Fire protection systems; Vehicle washing; Toilet flushing; Air conditioners; Dust control.

(f). Commercial

Irrigation of public parks, sporting facilities, private gardens, roadsides; Street cleaning; Fire protection systems; Vehicle washing; Toilet flushing; Air conditioners; Dust control.

(g). Domestic

Can be used for Vehicle washing; Toilet flushing; Air conditioners and as external coolants.

(h). Industrial (Chemical and Petroleum)

There are multiple applications such as Processing water; Cooling water; Recirculating cooling towers; Washdown water; Washing aggregate; Making concrete; Soil compaction; Dust control.

This will also include the oil and gas industries where recycled water is used for hydraulic fracking and also extracting oil from formations.

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4. New Technology

Real-Time Monitoring

Point-to- point versus Along the Length Monitoring

Figure 2 Schematic of Monitoring (a) Point-to-Point and (b) Along the Length

Current monitoring by the USGS is done point to point along the pipeline. There could be accumulation of contaminants around the measuring probes, Also there could be fungus growth around the probes. Also in addition to the water quality, the pipeline infrastructure also needs to be monitored. New two probe real-time monitoring technology has been developed to that can be used to monitor the not only the water quality along the length also the changes in the measuring probes and also the condition including corrosion along the pipelines.

Vipulanandan Impedance Model

Equivalent Circuits

Identification of the most appropriate equivalent circuit to represent the electrical properties of the waste waters are essential to further understand its properties and also to measure the wastewater quality in pipes, storage facilites and treatment processes. In this study, an equivalent circuit to represent the wastewater was required for better characterization through the analyses of the Impedance Spetroscopy (IS) data. There were many difficulties associated with choosing a correct equivalent circuit. It was necessary somehow to make a link between the different elements in the circuit and the different regions in the impedance data of the corresponding sample. Given the difficulties and uncertainties, researchers tend to use a pragmatic approach and adopt a circuit which they believe to be most appropriate from their knowledge of the expected behavior of the material under study and demonstrate that the results are consistant with the circuit used.

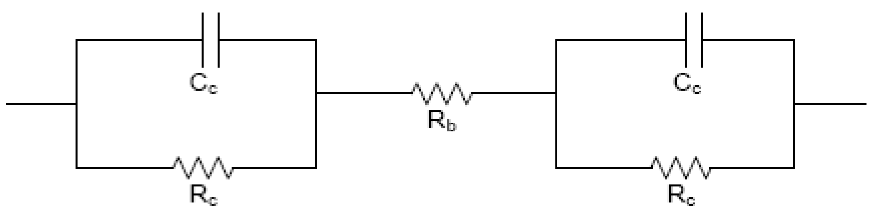

Figure 3. Equivalent Circuit for the Two-Probe CASE-2

In the equivalent circuit for CASE-2 in Figure 3, R_b is the resistance of the bulk material and this case the wastewaters. The R_c and C_c are the resistance and capacitance of the two wires used for the measurement of waste waters. Both contacts are represented with the same resistance (R_c) and capacitance (C_c) if they are identical and if not they will be different. The total impedance of the equivalent circuit for CASE-2 (Z_2) is as follows:

$$Z_2(\sigma) = R_b(\sigma) + \frac{2R_c(\sigma)}{1+\omega^2 R_c^2 C_c^2} - j\,\frac{2\omega R_c^2 C_c(\sigma)}{1+\omega^2 R_c^2 C_c^2}. \qquad (1)$$

$$= R_2 + j\,X_2 \qquad (2)$$

The term R_2 in Eqn. (2) represents the real part of the impedance (Z_{real} of Z_2) and X_2 represents the imaginary part of the impedance (Z_2). When the frequency of the applied signal was very low, $\omega \rightarrow 0$, $Z_2 = R_2 = R_b + 2R_c$, and when it is very high, $\omega \rightarrow \infty$, $Z_2 = R_2 = R_b$ and X_2 will be equal to zero (Vipulanandan 2020) . In CASE-2, if the impedance is measured at very high frequency it will measure the resistance (R_b) of the wastewater and eliminates the effects of the contacts and also it is frequency independent. Hence it is important to verify the CASE for wastewaters by performing tests.

Testing

Wastewater Characterization

In order to characterize the wastewater, cylindrical molds of 4" height and 2" in diameter were with the two probed inserted into the mold as shown in Figur 4(a). The probes were connected to the LCR to measure the impedance with frequency varying from 20 Hz to 300 kHz as shown in Fighre 4(b). At least three samples were tested under each condition.

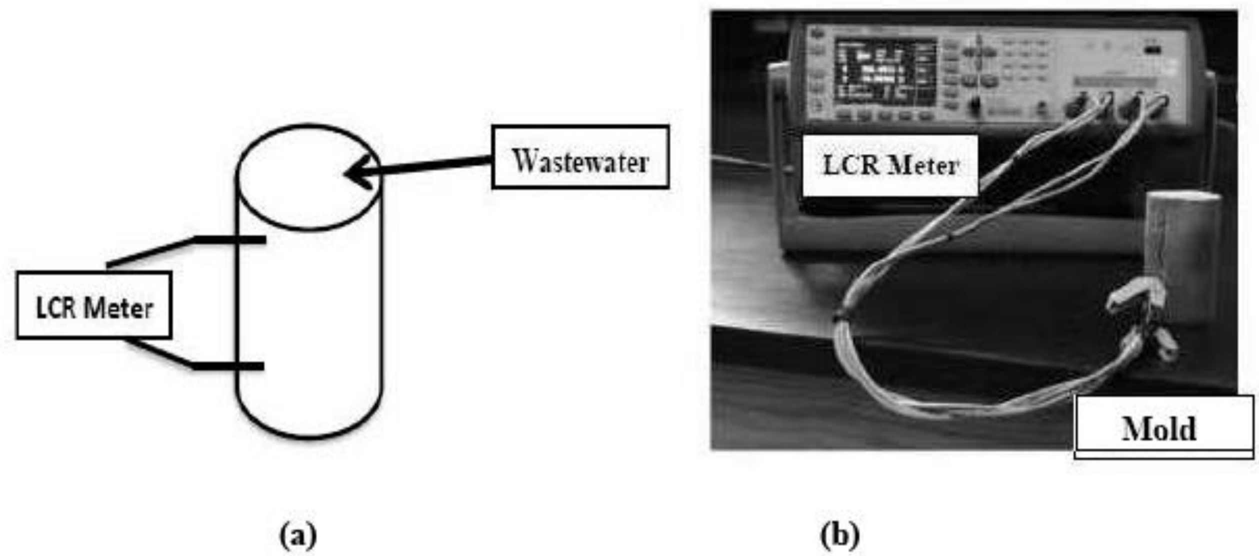

Figure 4 Characterizing of wastewaters (a) Instrumented mold and (b) Connected to the LCR meter.

The typical impedance-frequency response of wastewater with and without clay contamination is shown in Figure 5. The frequency was varied from 20Hz to 300kHz and it represented the CASE -2 (Vipulanandan 2020). With higher frequencies the impedance reaches a limiting value, representing the CASE-2. Vipulanandan Impedance model was used to predict the experimental results.

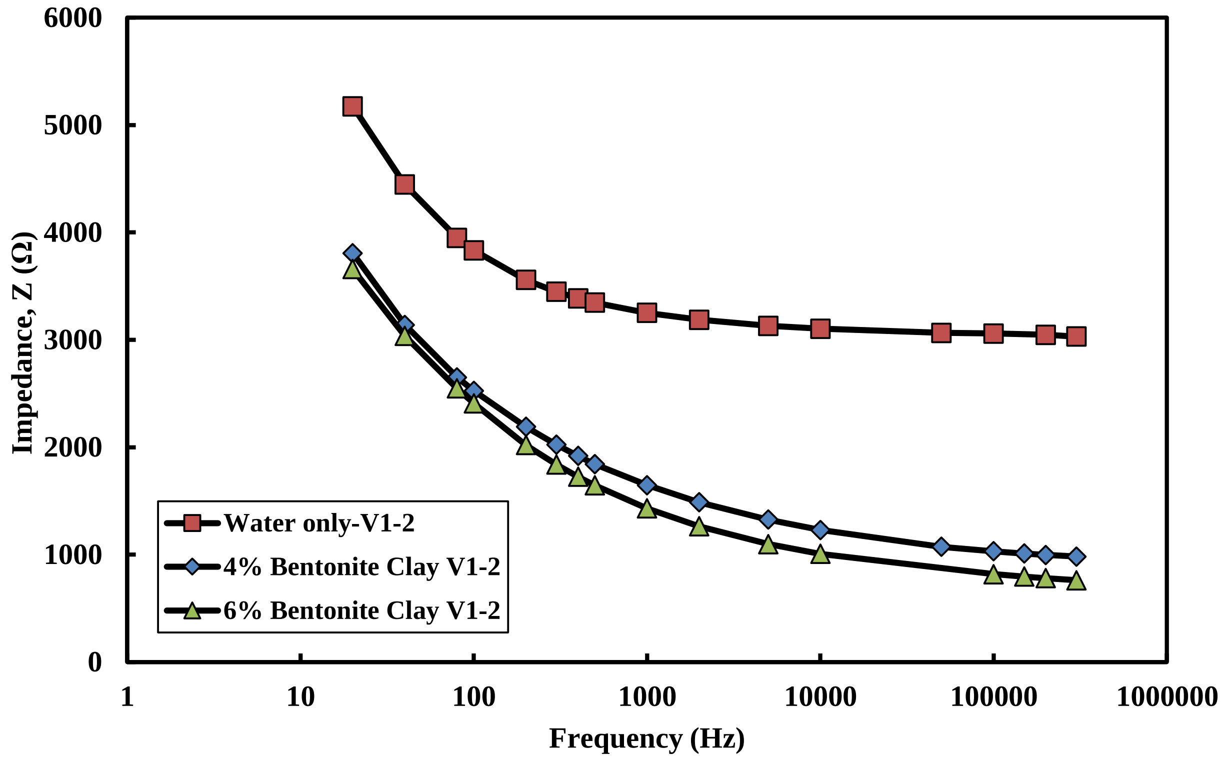

Figure 5 Typical Impedance-Frequency Response of Water contaminated with Various Amounts of Bentonite Clay

Resistance (Volume Measurement)

The new two probe method was used to measure the resistance of the wastewater between the two probes with the varying clay contents. As shown in Figure 5, the resistance reduced with the clay content. It has been proven from experiments that change in resistance (ΔR) to the initial resistance (Ro) is equal to the resistivity change (Δρ) to the initial resistivity (ρo) (resistivity is a wastewater property).

$$\frac{\Delta R}{R_o} = \frac{\Delta \rho}{\rho_o} \quad (3)$$

Addition of clay (X) reduced the resistance (R at frequency of 300 kHz) as shown in Figure 5. Adding 4% bentonite clay changed the resistance (ΔR) from 3031Ω to 982 Ω, a change of 67%. With the addition of 6% bentonite clay, the resistance changed by 75%. This clearly shows the sensitivity of the monitoring parameter resistance. Also with the bentonite clay contamination the resistivity and pH of the water reduced.

Vipulanandan Correlation Models

For resistivity following relationship was used and the equation is as follows:

$$R = R_o - \left[\frac{X}{A+BX}\right] \quad (4)$$

The experimental data was used to predict the relationship as shown in Figure 6 using Eqn. (4). The Statistical parameters such as root mean square error (RMSE) and coefficient of determination (R^2) shows how well Vipulanandan Correlation Model predicted the experimental results (Table 1).

Table 1. Correlation Model Parameters for Resistance and bentonite Contents (Eqn. (4))

	Bentonite
A	**0.000558**
B	**0.000344**
Ro	**3050 Ω**
RMSE	**10.96 Ω**
R^2	**1.0**

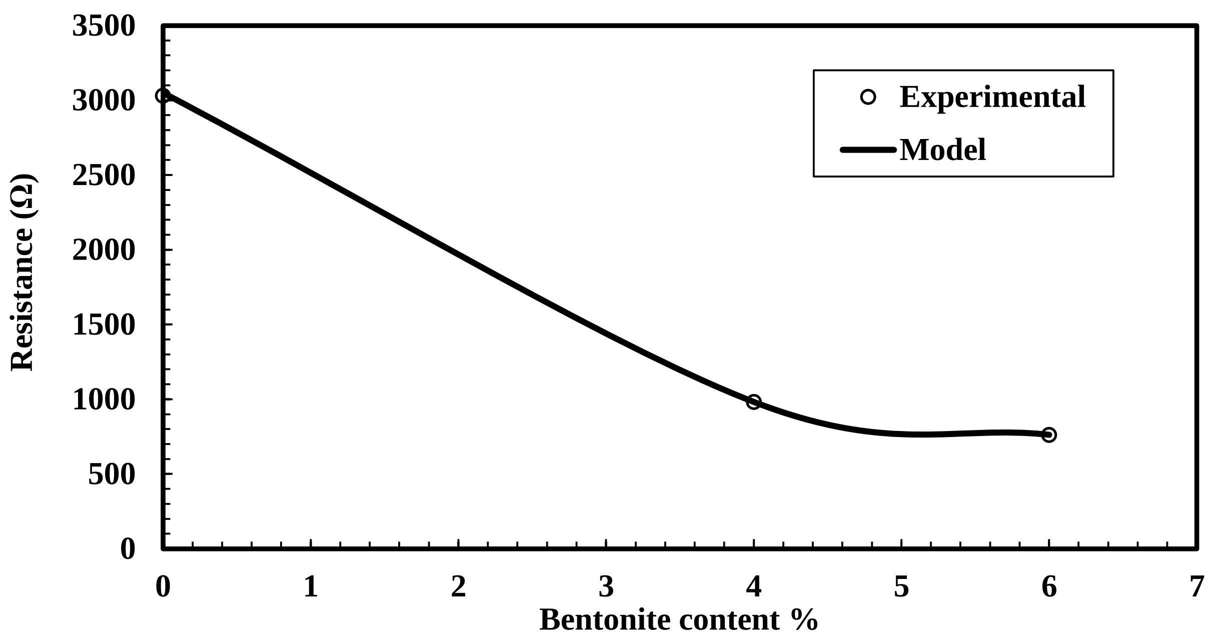

Figure 6 Correlation Resistance and the Bentonite Clay Content

5. Conclusions

In order to identify the field monitoring parameter clay contaminated water was characterized using the two probe method and alternative current (AC). Based on this study following conclusions are advanced:

(1). By charactering the water contaminated with the bentonite clay, the resistivity and resistance were identified as the critical electrical parameter to real-time monitor in the field.

(2). It is important to real-time monitor the quality of the clay contaminated wastewaters before, during and after treatment and changes in resistivity and resistance can be used for real-time monitoring.

(3). Preliminary study on the bentonite clay contaminated water using the two-probe method along the length measurement showed very sensitive response.

(4). Vipulanandan Correlation Model was used to predict the changes in the resistivity and resistance with the clay content. Model predicted the experimental results very well.

6. Acknowledgement

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