DETERMINATION OF ELECTROCHEMICAL POTENTIAL OF PRODUCED-WATER-MUD SYSTEMS

Joshua Muroi
McCoy School of Engineering, Midwestern State University

ABSTRACT

This study investigates the electrochemical behavior of produced-water-based mud systems when subjected to applied electrical conditions. A series of controlled experiments were conducted using a series of mud solutions to evaluate their current response, power absorption, and associated chemical changes. Results indicate that ionic composition plays an important role in governing system behavior with divalent ions such as calcium (Ca^{2+}) significantly enhancing power absorption compared to monovalent systems (Na^{+}). Additionally, measurable shifts in pH suggest that electrical input induced chemical variation within the fluid. These findings establish a framework for understanding how produced water-mud solutions interact with electrical energy. This work further stands to influence industrial fluid design, treatment processes, and emerging energy-interaction applications.

INTRODUCTION

Produced water is an unavoidable byproduct of oil and gas production and represents one of the largest waste streams in the harvestation of hydrocarbons. As reservoirs mature, water production can exceed hydrocarbon output, with estimates suggesting globally over 200 million barrels of water are produced daily alongside oil and gas operations (Bailey et al., 2000). In many cases, several barrels of water are produced for every barrel of oil and stands to contribute to significant economic and environmental burdens associated with treatment, handling, and disposal. The prevalence of these challenges have driven increasing interest in identifying alternative strategies for produced water management, within the realms of reuse and value recovery.

Produced water, often in the form of brine, is characterized by high salinity and complex ionic composition, including dissolved species such as sodium, calcium, and chloride ions. When dissolved in water, these salts dissociate into charged ions that enable electrical conduction through ionic transportation mechanisms. This intrinsic property of these ions suggests that produced water is not merely to be considered a passive waste stream, but rather as a medium which is capable of interacting with electrical energy.

Previous work by Elsharafi et al. (“Energy from Saltwater”, Midwestern State University) demonstrated that wastewater-based mud systems can conduct electrical energy, and that conductivity was strongly influenced by salt concentration and soil composition. Their findings showed that increasing salinity enhances voltage output due to the increased availability of charge-carrying ions while dilution reduced electrical response. Furthermore, clay-based systems exhibited higher voltage output than sandy systems, likened to the effects of tighter particle packing and improved pathways for charge transport (Elsharafi et al., Midwestern State University). These results highlight the combined influence of ionic content and structural properties on the electrical behavior of brine mud systems.

Despite these findings, existing studies primarily focus on the ability of these mud systems to conduct and retain electrical charge, with limited investigation into how produced-water-based muds interact with externally applied electrical energy. In particular, the relationships between fluid composition, electrical absorption, and associated chemical changes remains insufficiently understood. The awareness and adequate investigation of this information gap is critical for advancing in the characterization of produced water as an electrochemically active system.

This study builds upon prior work by experimentally investigating the response of produced-water-based mud systems under controlled electrical loading. By systematically varying ionic composition and measuring current, power absorption, and pH variation, this work aims to establish clearer relationships between fluid chemistry and electrochemical behavior. The findings provide insight into how produced water-mud interacts with a direct current, and supports the broader objective of considering produced water as a functional medium with potential applications in fluid design, treatment processes, and emerging energy-interaction technologies.

Statement of Theory and Definitions:

Electrical Conductivity - ability of a material to conduct electric current via ion movement.
Ohmic Behavior - a linear relationship between voltage and current, indicating resistive conduction
Resistance - opposition to current flow in a material
Power - electrical energy transferred per unit time
Electrochemical System - a system where electrical energy drives chemical reactions (or vice versa)
Electrolysis - chemical decomposition driven by applied electrical current
pH - a measure of how acidic or basic a substance is
Open Circuit Voltage (OCV) - the natural voltage of a system without external load

EXPERIMENTAL WORK

Six distinct produced-water-based clay mud formulations were prepared to systematically investigate the influence of ionic composition on electrical response. Each formulation was thoroughly mixed in order to ensure homogeneity, and attempting to avoid sedimentation or particle aggregation which could negatively influence conduction pathways. The mud samples were maintained at room temperature for the duration of the experiments.

During testing, the mud sample was mixed into a standardized container equipped with a pair of parallel electrodes, inserted at fixed spacing in order to maintain consistent electrical field conditions across all tests. A direct current (DC) voltage was applied to the electrodes in incremental steps of 2V ranging from 1V to 11V. To simulate different load conditions, external resistors of 1kΩ, 10 kΩ, 47 kΩ, and 100 kΩ were connected in series with the mud system.

At each voltage and resistor combination, the voltage across the resistor was measured using a digital multimeter. From there, calculations were made to determine the voltage dropped across the electrodes (ultimately across the mud solution) by subtracting the voltage dropped across the load resistor from the supplied voltage. This is in keeping with the law of series circuits, that voltage is shared among resistors. Power absorption for each condition was calculated according to $P = VI$, where V is the applied voltage and I is the measured current. In addition, pH measurements were taken both before and after electrical loading to assess any induced chemical changes within the fluid. Each experimental condition was replicated three times to ensure reproducibility, and average values were reported. Figure 1 shows the schematic wiring diagram of produced-water-mud experimental setup.

Equipment and Materials

- Voltage power supply
- Steel electrodes
- Produce water samples
- Digital Multimeter (DMM)
- pH meter

PROCEDURE

1. 70 grams of clay rich soil was mixed with 100 ml of 1 of 6 produce-water samples
2. The solution is mixed thoroughly, being sure to break up any lumps present in the mixture.
3. The pH of the solution is measured before electrical testing.
4. Two electrodes of identical material and dimensions were placed inside the mud solution at a distance of 6cm. The electrodes are lowered until approximately 1cm away from the bottom face of the mud container.
5. The circuit was assembled as depicted below. After double-checking connections, the circuit was supplied with 1V.
6. The system was allowed time to settle, and the voltage reading across the electrodes was recorded. The voltage supply is then incremented by 2V taking voltage measurements across the electrodes until 11V.
7. Steps

RESULTS AND DISCUSSION

The electrical behavior of the mud formulations was evaluated by measuring the current response under varying applied voltage conditions. Across all samples, current increased with applied voltage, consistent with Ohmic behavior in conductive media. While salinity was not directly measured in the present study, prior work done by Elsharafi et al. (Midwestern State University) demonstrated that mud systems with higher salt concentrations exhibit greater current response at equivalent voltage levels, whereas lower salinity systems show reduced conductivity.

The dissociation of dissolved ionic compounds typically found in produced water are as follows. Salts such as sodium chloride (NaCl) and calcium chloride ($CaCl_2$) dissociate in aqueous solution into ions (Na^+, Ca^{2+}, and Cl^-), which serve as charge carriers when an electric field is applied. The presence of divalent ions, particularly Ca^{2+}, introduced an additional level of complexity due to their higher charge relative to monovalent ions such as Na^+. This difference in ionic charge has the potential to influence conductivity, ion mobility, and overall energy transfer within the system. As a result, variations in ionic composition contribute not only to differences in current response, but also to the way energy is absorbed and distributed within the mud. While the present results confirm that both sodium and calcium chloride influence electrochemical behavior of the system, the extent of their individual contributions has not been quantitatively isolated, indicating a need for further controlled investigation. Figures 2 through 5 and tables 1 and 2 show the results of this research.

To further characterize system behavior, power absorption was calculated using the measured voltage and current values, with the results presented in Figure 2 as the average power absorbed as a function of applied voltage. A consistent trend was observed across all mud samples, where power absorption increased nonlinearly with increasing voltage. This indicates that as the electrical driving force increases, the system facilitates greater energy transfer through ionic conduction. However, it is necessary to distinguish that increased power absorption does not imply energy storage or generation. Instead, the absorbed energy is dissipated within the system, primarily through resistive heating and electrochemical processes.

From an engineering perspective, this behavior highlights the potential to tune the energy interaction properties of produced-water-based fluid systems through compositional control. While higher salinity systems exhibit enhanced conductivity, they also demonstrate increased energy dissipation, which may influence their performance in electrically active environments. This trade-off between conductivity and dissipation is an important consideration in the design and application of such systems, particularly where electrical interactions are present.

Additional insight into the electrochemical nature of the system is provided by measured pH variations before and after electrical testing. These changes indicate that electrochemical reactions occurred during voltage application; likely involving ion migration, electrolysis or localized redox reactions within the fluid.

The presence of these reactions confirm that the system is not purely resistive, but also exhibits coupled electrical and chemical behavior under applied loading. This has important implications for long-term system performance, as repeated or sustained exposure to electrical fields may alter the chemical and physical properties of the mud over time.

Overall, the results demonstrate that produced-water-based mud systems actively interact with applied electrical energy in a predictable and tunable manner. Increased ionic concentration enhances both conductivity and power absorption, while fluid structure contributes to the stability and efficiency of charge transport. It is important to emphasize that, although these systems exhibit measurable electrical response, they do not function as power sources or energy storage mediums. Rather, they behave as electrochemically active, energy-dissipating media. This distinction is critical when considering practical applications.

CONCLUSION

This study investigated the electrochemical behavior of produced-water-based mud systems under applied voltage conditions. The results demonstrate that these systems exhibit a measurable and consistent electrical response, characterized by increasing current with applied voltage and corresponding increases in power absorption. While the magnitude of this response varied across formulations, the observed behavior confirms that produced-water-based muds actively interact with electrical energy through ionic conduction mechanisms.

Further investigation is required to quantify the individual contributions of specific ionic compounds to the electrochemical behavior of produced-water-based mud systems. In particular, controlled studies isolating sodium chloride and calcium chloride concentrations would enable a more precise understanding of how monovalent and divalent ions influence conductivity, power absorption, and electrochemical activity.

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Table 1. Electrical Summary of Mud Formulations

Mud	Average Current (mA)	Max Current (mA)	Average Power (W)	Max Power (W)	Average Mud Resistance (Ohm)
Mud_2_Blue	1.303	8.776	1.68E-03	1.41 E-02	9.91E+03
Mud_2_Pink	1.302	8.645	1.71E-03	1.51E-02	1.10E+03
Mud_3_Blue	1.279	8.579	1.82E-03	1.56E-02	8.10E+03
Mud_3_Pink	1.305	8.645	1.70E-03	1.51E-02	1.00E+04
Mud_4	1.279	8.486	1.84E-03	1.63E-02	6.41E+03
Mud_5	1.045	5.364	1.17E-03	6.76E-03	6.71E+03

Table 2. Average pH change in mud solution after electrical testing

Mud	Average Delta pH
Mud_2_Blue	-0.105
Mud_2_Pink	0.22
Mud_3_Blue	0.075
Mud_3_Pink	0.06
Mud_4	0.355
Mud_5	-0.22

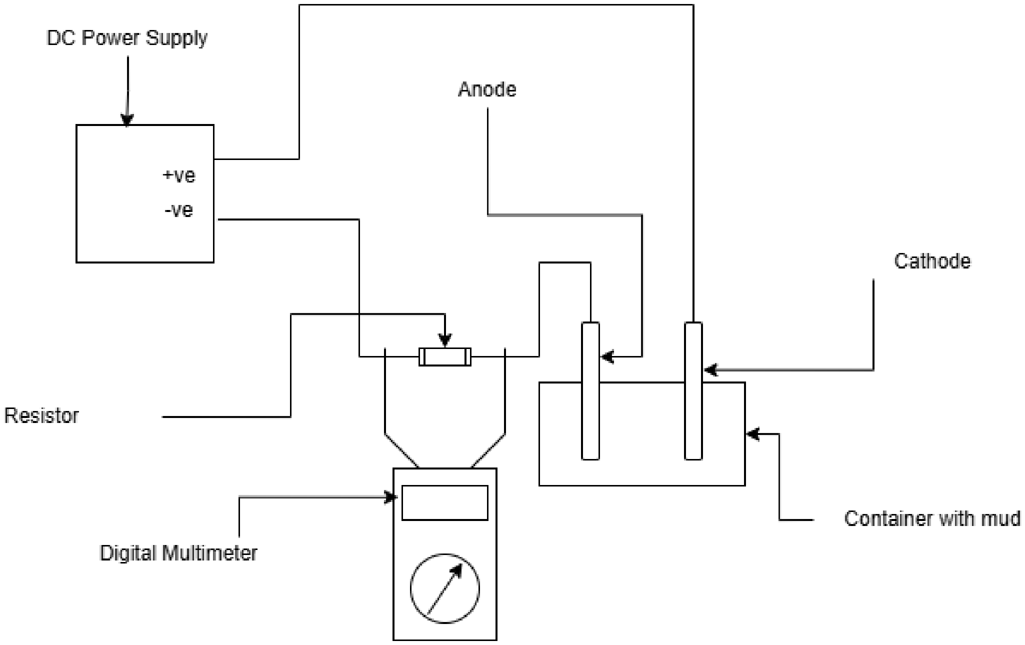

Fig 1. Schematic wiring diagram of produced-water-mud experimental setup.

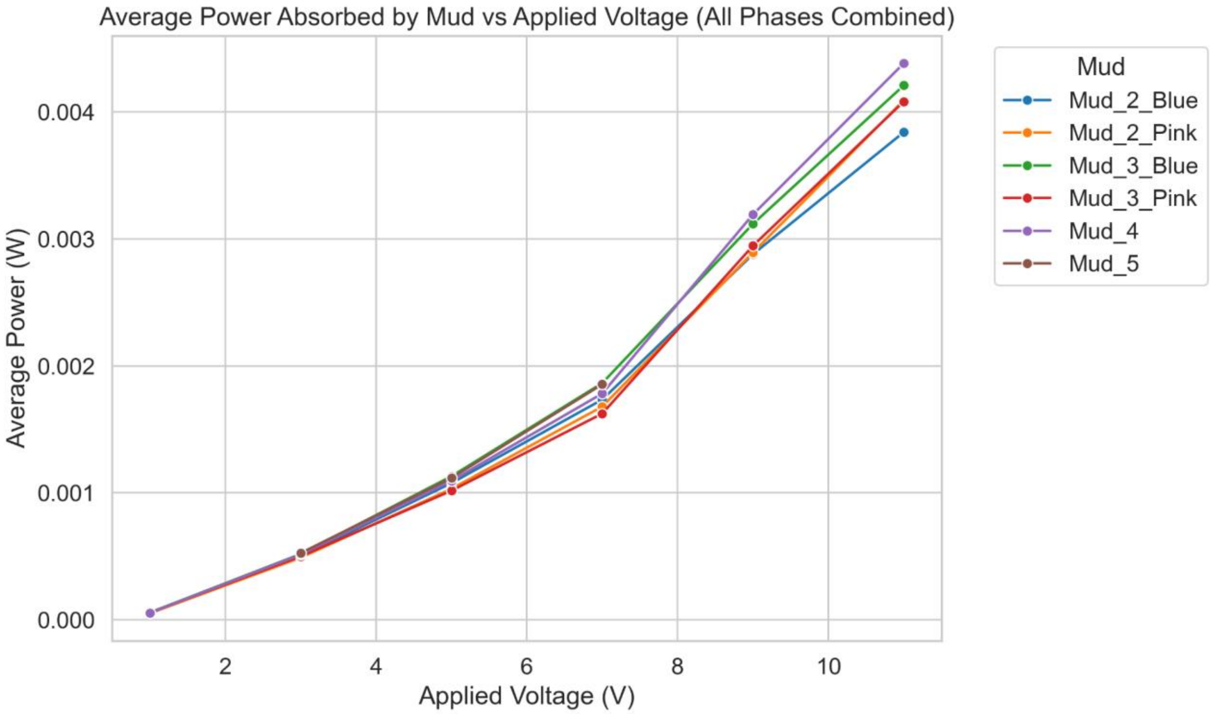

Fig 2. Average power absorbed by mud solution versus applied voltage.

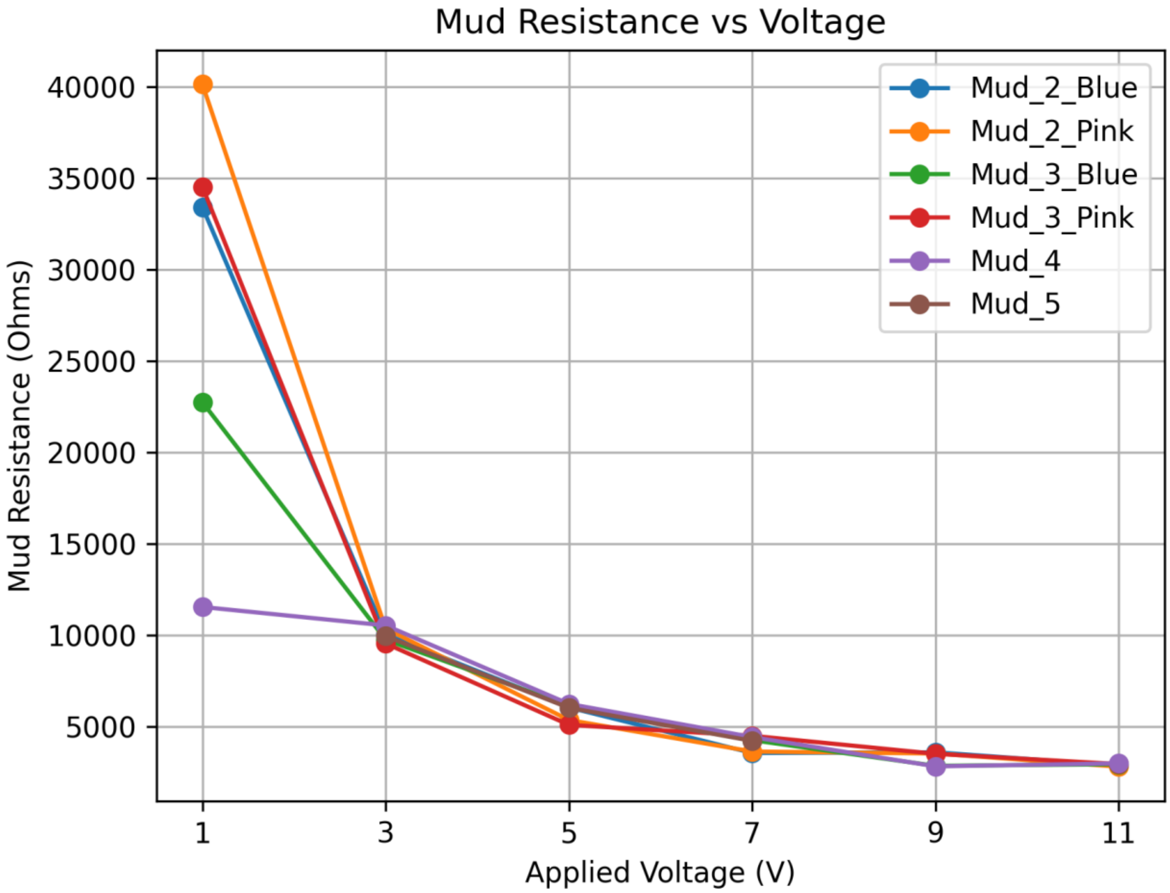

Fig 3. Calculated mud resistance vs. applied voltage

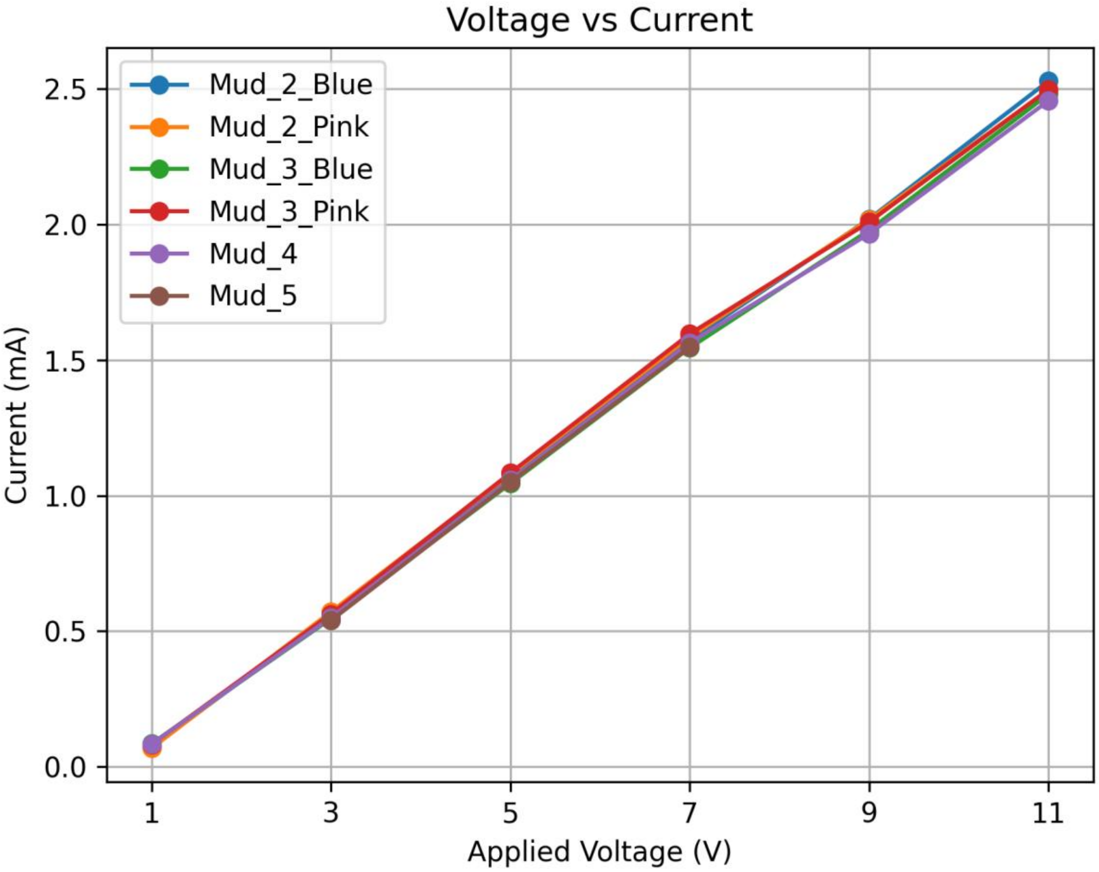

Fig 4. Calculated current across mud solution versus applied voltage.

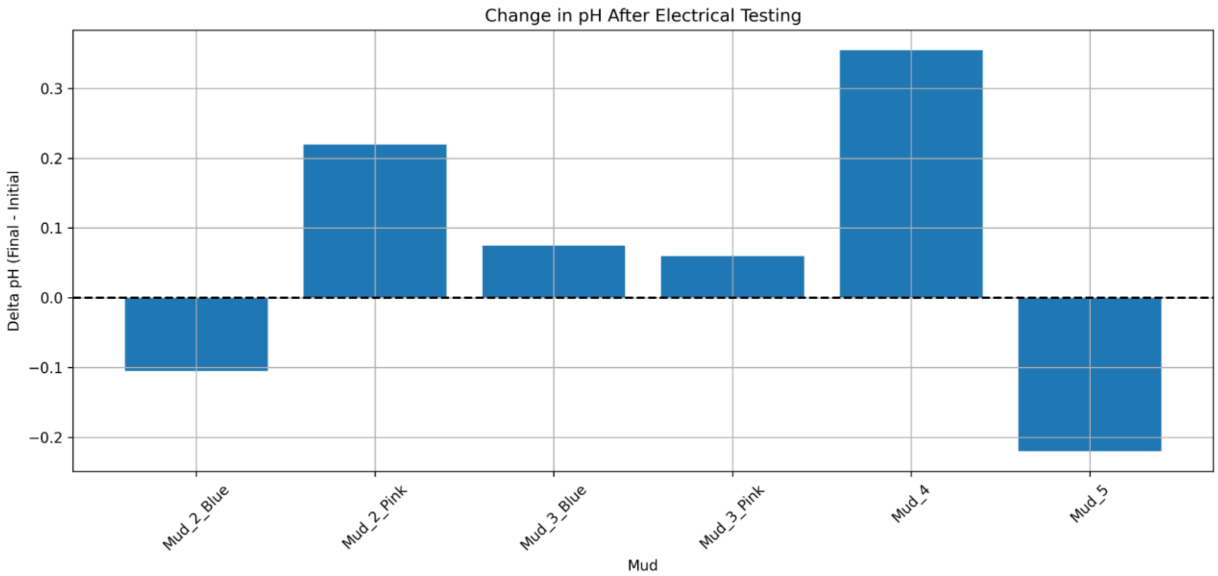

Fig 5. Change in pH before and after electrical testing