MUD ENGINEERING: INVESTIGATING THE IMPACT OF HIGH TEMPERATURE ON THE RHEOLOGICAL PROPERTIES OF WATER BASED DRILLING MUD USING REGRESSION ANALYSIS

BY

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DECLARATION

I, **EMOGHENE GODSGIFT AKPEMWEOGHENE** with Matriculation number **ENG1905425,** hereby declare that the project entitled " Mud Engineering: Investigating the Impact of High Temperature on the Rheological Properties of Water Based Drilling Mud using Regression Analysis" is my original work and has been carried out under the guidance of PROF R.O. EDOKPIA, Project supervisor. This work has not been submitted for any other degree or academic award, either in full or in part, and has not been published previously.

I further declare that all sources used in the preparation of this project have been duly acknowledged and referenced. Any assistance received from others has been clearly stated, and I take full responsibility for the content of this project. This project is being submitted as part of the requirements for the Award of B.Eng Industrial Engineering at University Of Benin.

CERTIFICATION

This is to certify that this work was carried out by **EMOGHENE GODSGIFT AKPEMWEOGHENE** of the department of Industrial Engineering, University of Benin, Benin City, Edo State, in accordance with the rules and regulations of the University of Benin for the award of B.ENG in Industrial Engineering.

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DEDICATION

This project work is dedicated to God Almighty, for His grace, wisdom and strength that has guided me through this journey to put together this work.

ABSTRACT

This study investigates the effect of increasing temperature on the rheological properties of water-based drilling mud, which is critical for optimizing drilling operations. The rheological properties analyzed include plastic viscosity (PV), yield point (YP), and gel strength (GS), which play a vital role in the performance and efficiency of drilling fluids. As temperature can significantly influence the flow behavior and stability of the drilling mud, understanding these changes is essential for ensuring the mud's ability to suspend drill cuttings, maintain wellbore stability, and reduce friction during drilling operations. The study examines a temperature range from 100°F to 160°F, reflecting typical downhole temperature conditions encountered during drilling operations.

To achieve this, laboratory experiments were conducted on formulated WBM samples subjected to a controlled temperature range. Rheological measurements were taken using a viscometer at various rotational speeds (600, 300, 200, 100, 6, and 3 RPM) to calculate PV, YP, and gel strengths. The results were analyzed using regression analysis in Microsoft Excel to assess the relationship between temperature and each rheological parameter. Data trends and correlation coefficients were used to determine the degree of influence temperature has on each property

The results revealed that increasing temperature had a notable effect on the rheological behavior of the mud. Plastic viscosity showed a decreasing trend with rising temperature, indicating reduced fluid resistance, while the yield point and gel strengths generally declined, and suggesting weakened structural integrity of the mud. The regression models demonstrated strong correlations, supporting the reliability of the findings. The study concluded that temperature significantly influences WBM rheology, which must be accounted for in high-temperature drilling environments to maintain mud performance and ensure operational efficiency.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

A

API – American Petroleum Institute

AV – Apparent Viscosity

B

BHA – Bottom Hole Assembly

BHT – Bottom Hole Temperature

BHP – Bottom Hole Pressure

bbl – Barrel

C

$CaCO_3$ – Calcium Carbonate

Cp – Centipoise (Unit of Viscosity)

D

DFA – Drilling Fluid Additives

DFT – Drilling Fluid Testing

E

ECD – Equivalent Circulating Density

ESD – Equivalent Static Density

EST – Elevated Static Temperature

F

°F – Degrees Fahrenheit

FT – Filtration Test

G

GS – Gel Strength

GS10s – Gel Strength at 10 seconds

GS10m – Gel Strength at 10 minutes

H

HTHP – High-Temperature, High-Pressure

L

LBM – Lost Circulation Material

LCM – Lost Circulation Material

M

MD – Measured Depth

MW – Mud Weight

N

NPV – Non-Newtonian Plastic Viscosity

P

PAC – Polyanionic Cellulose

PHPA – Partially Hydrolyzed Polyacrylamide

PPG – Pounds per Gallon

PV – Plastic Viscosity

psi – Pounds per Square Inch

R

RDF – Rheology of Drilling Fluids

RPM – Revolutions Per Minute

RYP – Residual Yield Point

R^2 – Coefficient of Determination (used in regression analysis)

S

SPP – Standpipe Pressure

SPE – Society of Petroleum Engineers

T

TVD – True Vertical Depth

V

VP – Viscosity Profile

W

WBM – Water-Based Mud

WBDF – Water-Based Drilling Fluid

Y

YP – Yield Point

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Drilling fluids, commonly known as drilling muds, play a crucial role in the oil and gas industry, particularly in drilling operations. These fluids serve multiple functions, including lubricating and cooling the drill bit, carrying drilled cuttings to the surface, providing hydrostatic pressure to prevent well blowouts, and stabilizing the borehole. Among the different types of drilling fluids, water-based muds (WBMs) are widely used due to their cost-effectiveness, environmental friendliness, and ease of disposal.

However, temperature variations significantly affect the performance and stability of drilling fluids. During drilling operations, the mud is exposed to high temperatures in the subsurface, which can lead to changes in its rheological properties, such as plastic viscosity (PV), yield point (YP), and gel strength (GS). These changes can impact drilling efficiency, hole stability, and overall operational safety. Understanding how temperature affects the rheological behavior of WBMs is essential for optimizing mud formulations and ensuring the smooth progression of drilling activities.

In this study, the focus is on investigating the effect of elevated temperatures (ranging from 100°F to 160°F) on the rheological properties of a water-based drilling fluid. The results of this research will help in developing better temperature-resistant mud formulations and improving wellbore stability and drilling efficiency in high-temperature environments.

1.2 Statement of Problem

The performance of water-based drilling mud is highly influenced by temperature variations, especially in deep wells where the subsurface temperature increases significantly with depth. At elevated temperatures, mud viscosity, yield stress, and gel strength can undergo significant alterations, leading to potential drilling complications such as:

i. Inadequate hole cleaning due to reduced carrying capacity of the mud.

ii. Excessive thickening or thinning of the fluid, which can affect wellbore stability.

iii. Increased filtration loss, leading to unwanted interactions with formation rock.

iv. Increased energy requirements for circulation due to higher viscosity at extreme temperatures.

Despite the widespread use of WBMs, limited studies provide a comprehensive statistical analysis of the relationship between temperature and key rheological properties. Most existing studies rely on qualitative observations rather than predictive models. This research aims to address this gap by using regression analysis in Microsoft Excel to quantify how temperature variations impact plastic viscosity, yield point, and gel strength. By establishing a mathematical relationship between temperature and rheological properties, this study will help drilling engineers and mud specialists to predict fluid behavior in high-temperature conditions, thereby enabling better mud formulation and process optimization.

1.3 Aims and Objectives

1.3.1 Aims

The aim of this project is to experimentally investigate the impact of high temperature on the rheological properties of water based drilling mud using regression analysis.

1.3.2 Objectives

To achieve this aim, the following objectives will be looked at;

1. Evaluate the effect of increasing temperature (100°F – 160°F) on plastic viscosity (PV), yield point (YP), and gel strength (GS) of WBMs.
2. Analyze the trends and patterns of rheological changes as temperature increases.
3. Develop regression models that describe the relationship between temperature and each rheological property.
4. Determine the statistical significance of temperature-induced variations in mud rheology using Microsoft Excel.
5. Provide recommendations for optimizing water-based mud formulations for high-temperature drilling environments.

1.4 Scope of the Study

This research focuses on water-based drilling mud (WBM) and its rheological response to temperature variations. The specific parameters considered include:

Temperature Range: 100°F – 160°F (measured in increments of 10°F).

Rheological Properties:

i. **Plastic Viscosity (PV)** – Represents resistance to flow and is influenced by the size and concentration of solid particles in the mud.

ii. **Yield Point (YP)** – Measures the ability of the mud to suspend and transport cuttings in the wellbore.

iii. **Gel Strength (GS10s and GS10m)** – Determines the mud's ability to suspend solids when circulation is stopped.

Rheological Measurements: Taken at 600 RPM, 300 RPM, 200 RPM, 100 RPM, 6 RPM, and 3 RPM using a rotational viscometer.

Data Analysis Tool: Regression analysis performed in Microsoft Excel.

This study does not consider other drilling fluid types, such as oil-based muds (OBMs) or synthetic-based muds (SBMs), nor does it account for other environmental factors like pressure, salinity, or contamination effects.

1.5 Significance of the Study

The findings of this study will be beneficial to various stakeholders in the oil and gas industry, including:

1.5.1 Drilling Engineers

i. Helps in predicting and mitigating the effects of high temperature on drilling fluid performance.

ii. Assists in selecting appropriate mud additives to counteract temperature-induced viscosity changes.

1.5.2 Mud Engineers and Fluid Specialists

i. Provides empirical data for optimizing WBM formulations to withstand high temperatures.

ii. Offers insights into how temperature affects fluid behaviour, allowing for better mud design and performance enhancement.

1.5.3 Researchers and Academics

i. Contributes to the existing body of knowledge on drilling fluid rheology and high-temperature effects.

ii. Serves as a reference for future studies seeking to improve drilling fluid properties in extreme conditions.

1.5.4 Oil and Gas Companies

i. Reduces non-productive time (NPT) due to mud-related drilling issues.

ii. Enhances operational efficiency and cost-effectiveness in drilling high-temperature reservoirs.

CHAPTER TWO

LITERATURE REVIEW

2.1 A Review of Challenges and Advances

Drilling fluids, commonly referred to as drilling muds, play a fundamental role in drilling operations by providing lubrication, cooling, pressure control, and hole stability. Among the various types of drilling fluids, water-based muds (WBMs) are the most commonly used due to their cost-effectiveness, environmental acceptability, and ease of handling. However, one of the major challenges in using WBMs is their susceptibility to temperature variations, particularly in high-temperature and high-pressure (HTHP) drilling environments.

This chapter reviews existing literature on the rheological properties of water-based drilling fluids, the effect of temperature on drilling fluid performance, and the application of statistical tools, particularly regression analysis, in analyzing temperature-induced changes in drilling mud rheology. The insights from previous studies will serve as a foundation for understanding and interpreting the results of this research.

Agwu et al, (2015) stated the fact that there is no record yet of any well drilled without the use of drilling mud. Little wonder it is regarded by the drilling community as the lifeline of the borehole drilling process.

Orodu et al, (2018) However, for drilling mud to perform functions such as maintaining hydrostatic pressure, transportation and suspension of drill cuttings, the fluid properties must fall within the required international standards. One of such properties is the mud rheology. Rheology is essentially the study of flow of fluid and deformation.

Shah et al., (2010) gave some of the rheological properties of mud which includes; gel strength, plastic viscosity, yield point and apparent viscosity. Tracking mud rheological properties under downhole conditions is a prime factor on which the success or failure of the wellbore drilling operation rests. This is because, at subsurface conditions, these properties deviate from their original values due to high temperature and pressure variations it encounters.

Amani et al, (2012) investigated the influence of High temperature and High pressure on the viscosity of oil-based muds and water-based muds in a Comparative study using oil-based mud versus water-based mud in High temperature and High pressure fields. The aforementioned studies showed that the rheological properties of the selected drilling fluids subjected to these conditions and these changes might have an undesirable influence on the drilling fluid's functions.

Awele (2014) carried out an Investigation of additives on drilling mud performance with tonder geothermal drilling as a case study and discovered that viscosity is a flow characteristic of a drilling mud under different flow conditions. In order to predict the influences of this flow, it is important that the flow behaviour of the drilling mud at numerous points of interest in the mud circulating system are known. The categories of drilling fluid are determined by the fluid behaviour when it is subjected to an applied force (shear stress).

Nasser et al, (2013) during the drilling operation in deep reservoirs, to minimize the cost of drilling fluid and to ensure a well-organized drilling program, the rheological properties must be maintained continuously in an Experimental investigation of drilling fluid performance as nanoparticles.

Wang (2007) stated the need for an improved water based drilling system to meet reservoir conditions, in Mechanism of rheology adjustment and control of water based fluid for deep wells and the key to designing the system is to control the rheological properties of the drilling fluid.

Ezelle and Harrison (2008) saw the importance of why providing a better control of the rheological properties and excellent thermal stability, the activated weighting agents, thermally stable clay and various fluid systems with high temperature and contaminant tolerance have also been commercialized in Design of improved high-density, thermally stable drilling fluid for High temperature and High pressure applications.

Bland (2006) the behaviour of drilling fluids will change with increasing aging temperature. In High temperature and High pressure, drilling fluid challenges. Temperature aggravates the degradation of additives, description of additives on clay surfaces and the dehydration of hydrophilic groups in additives. Consequently, elevated temperature reduces the effectiveness of fluid additives that protect the clay particles. Temperature exerts a complex influence on rheological properties of drilling fluids and the effect of temperature on viscosity can be classified into three categories. 1) High temperature thinning: The viscosity decreases with increasing temperature, causing a reduction in carrying capacity and suspending capacity of cuttings then barite sags when breaking circulation and tripping or settles in the fluid ditch. 2) High temperature thickening: The fluid experiences an increase in viscosity and yield point after aging at high temperatures thus losing its fluidity (gelation after a high temperature treatment). 3) High temperature solidification: The fluid completely lost fluidity.

2.2 Overview of Drilling Fluids

2.2.1 Functions of Drilling Fluids

Drilling fluids perform several critical functions that enhance the efficiency and safety of drilling operations. According to Bourgoyne et al. (1991) and Rabia (2002), the primary functions of drilling fluids include:

1. **Cuttings Transport:** The mud carries drilled cuttings from the wellbore to the surface, preventing them from accumulating and causing blockages.
2. **Wellbore Stability:** Drilling fluids prevent the collapse of the borehole by maintaining adequate hydrostatic pressure.
3. **Lubrication and Cooling:** The mud lubricates and cools the drill bit, reducing friction and preventing excessive wear.
4. **Formation Pressure Control:** The fluid provides hydrostatic pressure to prevent kicks and blowouts.
5. **Minimization of Formation Damage:** Properly formulated muds prevent fluid invasion into the formation, reducing permeability impairment.
6. **Suspension of Cuttings:** The gel strength of the mud helps suspend cuttings and weighting materials when circulation is stopped.

Failure to maintain the appropriate properties of drilling fluids, particularly their rheological characteristics, can lead to serious drilling problems such as stuck pipe, lost circulation, poor hole cleaning, and differential sticking.

2.3 Classification of Drilling Fluids

Drilling fluids are broadly classified into three main types:

1. **Water-Based Muds (WBMs)**: Composed primarily of water as the continuous phase. Commonly used due to lower cost, ease of disposal, and minimal environmental impact. Susceptible to temperature variations, which can affect rheological properties.
2. **Oil-Based Muds (OBMs):** Contain oil as the continuous phase, usually diesel or mineral oil. Provide better thermal stability than WBMs but are more expensive and have environmental concerns.
3. **Synthetic-Based Muds (SBMs):** Use synthetic fluids instead of oil, offering better environmental compliance while retaining thermal stability. Commonly used in HTHP and deepwater drilling.

Since this study focuses on water-based drilling muds, it is essential to examine how temperature influences their rheological properties.

2.4 Rheological Properties of Water-Based Muds

The rheology of drilling fluids refers to their flow behavior and deformation under stress. According to Darley and Gray (1988), the key rheological properties affecting drilling performance include:

2.4.1 Plastic Viscosity (PV)

Plastic viscosity represents the resistance to flow due to friction between suspended solids in the mud. It is calculated as:

PV = 600 RPM Reading - 300 RPM Reading

High PV values indicate higher solid content, which can increase pump pressure requirements and reduce drilling efficiency.

Temperature Effect: Higher temperatures tend to reduce PV due to decreased viscosity of the base fluid.

2.4.2 Yield Point (YP)

Yield point represents the fluid's ability to carry cuttings out of the wellbore.

It is calculated as:

YP = 300 RPM Reading - PV

A higher YP means the fluid has better suspension and hole-cleaning ability.

Temperature Effect: YP may either increase or decrease, depending on the type of additives present in the mud.

2.4.3 Gel Strength (GS)

Gel strength measures the mud's ability to suspend solids when circulation stops.

It is recorded at 3 RPM after allowing the mud to remain static for 10 seconds (GS10s) and 10 minutes (GS10m).

Temperature Effect: High temperatures may cause gel strength to drop, leading to settling of cuttings and possible wellbore instability.

Understanding these properties is essential in evaluating the impact of temperature on drilling fluid performance.

2.5 Effect of Temperature on Rheological Properties

Several studies have examined the effect of elevated temperatures on water-based muds.

2.5.1 Decrease in Viscosity

Research by Amanullah and Long (2010) found that WBMs exhibit a significant drop in plastic viscosity as temperature increases, mainly due to the reduction in water viscosity.

Similarly, Caenn, Darley, and Gray (2011) reported that the thinning effect of temperature must be counteracted by additives to maintain optimal viscosity.

2.5.2 Changes in Yield Point and Gel Strength

Lal (1999) observed that yield point decreases with temperature unless chemical additives (e.g., xanthan gum) are used to maintain structure.

Apaleke et al. (2012) highlighted that gel strength reduction at high temperatures could lead to poor hole cleaning and increased risk of barite sag.

2.5.3 Thermal Stability of Additives

Some WBMs incorporate thermally stable polymers to maintain viscosity and gel strength at high temperatures.

Hale et al. (1999) demonstrated that polyanionic cellulose (PAC) and xanthan gum are effective in stabilizing rheology in high-temperature environments.

These findings underscore the importance of understanding temperature effects on drilling mud rheology and formulating fluids accordingly.

2.6 Application of Regression Analysis in Rheology Studies

Regression analysis is a powerful statistical tool used to model the relationship between independent (temperature) and dependent (rheological properties) variables.

2.6.1 Use of Regression Models

Al-Hadrami et al. (2016) successfully used linear regression models to predict viscosity changes in WBMs under temperature variations.

Adebayo et al. (2019) applied multiple regression analysis to determine the combined effects of temperature and pressure on drilling fluid properties.

2.6.2 Advantages of Regression Analysis

1. Provides a quantitative understanding of how temperature influences PV, YP, and GS.
2. Helps in predicting fluid behavior at higher temperatures beyond experimental limits.
3. Allows for optimization of mud formulations based on statistically significant trends.

Since this study employs regression analysis in Excel, findings from previous works provide a strong justification for its application in evaluating temperature-induced changes in mud rheology.

2.7 Summary

This chapter reviewed key concepts related to drilling fluid rheology, temperature effects, and statistical analysis techniques. The literature highlights that temperature significantly impacts the rheological properties of water-based muds, necessitating proper formulation and predictive modeling. The next chapter will outline the methodology used to conduct the experiments, measure rheological properties, and apply regression analysis for statistical evaluation.

CHAPTER THREE

METHODOLOGY

3.1 Research Design

This study adopts an experimental research design to investigate the impact of elevated temperature on the rheological properties of water-based drilling fluid. The research focuses on analyzing how temperature variations affect Plastic Viscosity (PV), Yield Point (YP), and Gel Strength (GS) using regression analysis.

A quantitative approach is employed, where data is collected through controlled laboratory experiments and statistically analyzed to establish trends and relationships. The independent variable in this study is temperature, which is systematically increased from 100°F to 160°F in increments of 10°F. The dependent variables are the rheological properties of the drilling fluid, which are measured at each temperature point.

The experimental setup ensures that only temperature variations influence the mud's behavior, while other factors such as mud composition and mixing conditions remain constant. Regression analysis is used to quantify the extent to which temperature affects the rheological properties.

3.2 Materials and Mud Formulation

3.2.1 Materials Used

The water-based drilling mud used in this study was formulated using the following materials:

Base fluid: Freshwater

Viscosifier: Bentonite clay

Fluid loss control additive: Carboxymethyl cellulose (CMC)

Weighting agent: Barite ($BaSO_4$)

Alkalinity control agent: Lime ($Ca(OH)_2$)

Each component plays a crucial role in maintaining the stability and performance of the drilling fluid. Bentonite increases viscosity, CMC controls fluid loss, and barite ensures proper mud density to prevent wellbore instability.

3.2.2 Mud Preparation Procedure

The drilling mud was prepared according to API RP 13B-1 standards using the following procedure:

1. **Mixing Process:** Freshwater was measured and poured into a mixing container. Bentonite was added gradually while continuously stirring with a high-speed Hamilton Beach mixer to ensure even dispersion. CMC was then introduced to enhance fluid loss control properties. Barite was added slowly to adjust the density, and lime was incorporated to regulate alkalinity. The mixture was stirred for 30 minutes to achieve homogeneity.
2. **Aging and Conditioning:** The mud sample was allowed to hydrate for 24 hours at room temperature to ensure full swelling of the bentonite particles. After hydration, the mud was stirred again for 5 minutes before testing.

PLATE 3.1: Mud Preparation and Mixing

Plate 3.1 shows the process of the mud preparation and mixing which was carried out in the laboratory.

3.3 Experimental Setup and Procedures

To assess the impact of temperature on rheological properties, a controlled heating system was used to vary the temperature while maintaining uniform test conditions.

3.3.1 Temperature Variation

A thermostatically controlled water bath was used to heat the mud samples gradually. The temperature was increased in increments of 10°F (100°F, 110°F, 120°F, 130°F, 140°F, 150°F, 160°F). A digital thermometer with an accuracy of ±0.5°F was used to monitor the temperature.

3.3.2 Rheological Property Measurements

The following procedures were followed to measure the mud properties at each temperature level:

A. Plastic Viscosity (PV) and Yield Point (YP): A rotational viscometer was used to determine PV and YP according to API standards. The mud sample was stirred and then poured into the viscometer cup. Readings were recorded at 600 RPM, 300 RPM, 200 RPM, 100 RPM, 6 RPM, and 3 RPM. Readings taken at 600 RPM and 300 RPM were used to calculate PV and YP using the formulas:

PV = 600 RPM Reading - 300 RPM Reading

YP = 300 RPM Reading – PV

B. Gel Strength (GS): The gel strength was measured at 10 seconds and 10 minutes after stopping mud circulation. The mud sample was left undisturbed in the viscometer cup, and after the set time, the viscometer was restarted at 6 RPM and 3 RPM. The maximum dial deflection recorded at 3 RPM was noted as the gel strength in lb/100 ft^2. Each test was repeated three times at each temperature level to ensure accuracy and repeatability.

PLATE 3.2: Rheological Property Measurements

The measurement process of the Water based mud Rheological properties after it is being heated is shown in this plate. The readings are essential to evaluate the effect of temperature on plastic viscosity, yield point and gel strength.

PLATE 3.3: Rheological Property Measurements (Viscosity)

Plate 3.3 shows how the viscosity of the mud was measured using a marsh funnel. The funnel was filled with the mud to the marked level and the time taken for 946mL of mud to flow out was recorded using a stop watch. This method provides a quick, practical check of mud thickness in field conditions.

3.4 Data Collection and Statistical Analysis

3.4.1 Data Collection Process

The rheological properties (PV, YP, and GS) were recorded for each temperature level. The tests were conducted in a controlled laboratory environment to eliminate external factors that could influence results. All readings were documented in an Excel spreadsheet for further analysis.

PLATE 3.4: Data Collection and recording.

3.4.2 Regression Analysis in Excel

Regression analysis was performed in Microsoft Excel to evaluate the relationship between temperature and each rheological property. The following steps were followed:

1. **Data Entry:** Temperature values were entered in one column. Corresponding PV, YP, and GS values were entered in adjacent columns.
2. **Performing Regression Analysis:** The Data Analysis ToolPak in Excel was used for regression. Temperature was set as the independent variable (X), and each rheological property was set as the dependent variable (Y).

   The regression output included:

   R^2 Value: Measures how well temperature explains variations in rheological properties.

Regression Coefficients: Indicates the impact of temperature on each property.

P-Values: Determines statistical significance (significant if $p < 0.05$).

3. **Interpreting the Results:** The significance of temperature on rheology was evaluated based on the R^2 and p-values. Regression equations were generated to predict mud behavior at different temperatures.

3.5 Assumptions

3.5.1 Assumptions

The mud formulation remains constant across all temperature variations. The viscometer and other measuring instruments provide accurate and consistent readings. No external contaminants influence the mud properties during testing. The study is limited to a single water-based mud formulation, which may not be applicable to other formulations. Only one statistical method (regression analysis) is used, while additional methods (ANOVA, response surface methodology) could provide deeper insights. The laboratory environment does not fully replicate downhole drilling conditions, where pressure and other factors may also influence mud properties.

CHAPTER FOUR

DATA ANALYSIS AND DISCUSSION

This chapter presents the analysis of experimental data collected to evaluate the impact of temperature on the rheological properties of water-based drilling fluid. The data includes rheological measurements taken at 600 RPM, 300 RPM, 200 RPM, 100 RPM, 6 RPM, and 3 RPM across different temperatures ranging from 100°F to 160°F.

Regression analysis was conducted using Microsoft Excel to determine the relationship between temperature and each rheological property. The results are presented in tables, graphs, and statistical interpretations, highlighting trends and correlations.

4.2 Experimental Data Presentation

The following table presents the raw data obtained from laboratory measurements:

Table 4.1: Rheological Data at Different Temperatures

Temperature (°F)	**a**	**b**	**c**	**d**	**e**	**f**
100	60	49	35	22	5	4
110	55	42	29	19	4	4
120	51	38	28	18	4	3
130	49	35	25	18	3	3
140	45	33	22	15	3	2
150	42	30	20	12	2	2
160	40	26	17	10	2	1

Identifying a, b, c, d, e, f, as;

a = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 600 RPM

b = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 300 RPM

c = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 200 RPM

d = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 100 RPM

e = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 6 RPM

f = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 3 RPM

The following table presents the raw data obtained from laboratory measurements showing the Plastic Viscosity (PV) and Yield Point (YP):

Table 4.2: PV and YP readings.

Temperature (°F)	**A**	**b**	**PV(cP)**	**YP (lb/100ft^2)**
100	60	49	11	38
110	55	42	13	29
120	51	38	13	25
130	49	35	14	21
140	45	33	12	21
150	42	30	12	18
160	40	26	14	12

Identifying a and b as;

a = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 600 RPM

b = Rheology (Plastic Viscosity, Yield point, Gel Strength) of the Mud sample at 300 RPM

The following table presents the raw data obtained from laboratory measurements showing the Gel Strength at 10 Seconds and 10 Minutes:

Table 4.3: Gel Strength readings.

Temperature (°F)	**Gel Strength (10 Sec)**	**Gel Strength (10 Min)**
100	4	5
110	4	4
120	3	4
130	3	3
140	2	3
150	2	2
160	1	2

The dataset indicates a general decrease in rheological values with increasing temperature. To quantify this relationship, regression analysis was conducted.

4.3 Regression Analysis

Regression analysis was performed in Microsoft Excel to determine the statistical relationship between temperature and rheology. The goal was to identify whether a linear trend exists and how strongly temperature influences rheological properties.

The regression results will include:

Regression Equation:

$Y = mX + C$

Y = Predicted Rheology Value

m = Slope (Coefficient for Temperature)

X = Temperature

C = Intercept

R^2 Value (Coefficient of Determination): Measures how well the model fits the data (values closer to 1 indicate a strong correlation).

P-Value: Determines if temperature significantly affects rheology (if $p < 0.05$, the effect is statistically significant)

4.3.1 Regression Results for 600 RPM

Using Microsoft Excel to get the regression result for 600 RPM;

The regression equation obtained for the 600 RPM readings is:

600 RPM= 65.71 - 0.163 × Temperature

Y = -3.2366x + 287.2

R^2 Value: 0.9941 (indicating a strong correlation)

P-Value: < 0.05 (statistically significant)

This means that temperature accounts for 99% of the variation in the 600 RPM readings, and the relationship is statistically significant.

The following table presents the raw data obtained from laboratory measurements showing the Rheology at 600 RPM:

Table: 4.4: Temperature and Rheology readings at 600 RPM

600 RPM	
Temperature	**Rheology**
100°F	60
110°F	55
120°F	51
130°F	49
140°F	45
150°F	42
160°F	40

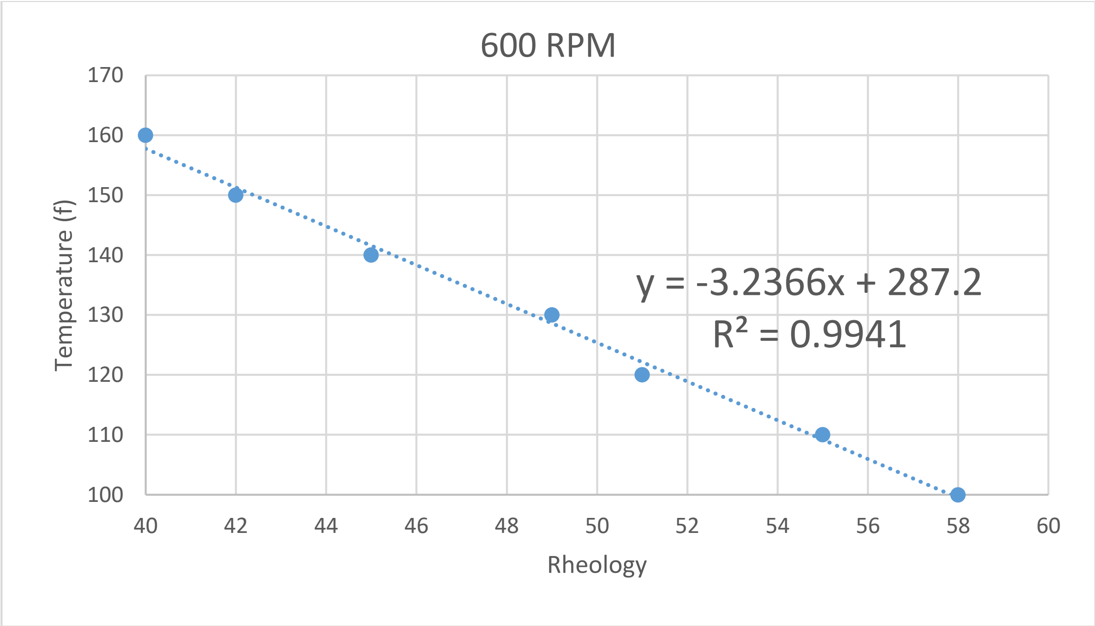


Figure 4.1: Temperature vs. 600 RPM Rheology

4.3.2 Regression Results for 300 RPM

Using Microsoft Excel to get the regression result for 300 RPM;

300 RPM = 55.29 - 0.186 × Temperature

$Y = -2.7617x + 229.81$

R^2 Value: 0.966

P-Value: < 0.05

This indicates that temperature strongly affects viscosity at 300 RPM, reducing its value significantly as heat increases.

The following table presents the raw data obtained from laboratory measurements showing the Rheology at 300 RPM:

Table: 4.5: Temperature and Rheology readings at 300 RPM

300 RPM	
Temperature	**Rheology**
100°F	49
110°F	42
120°F	38
130°F	35
140°F	33
150°F	30
160°F	26

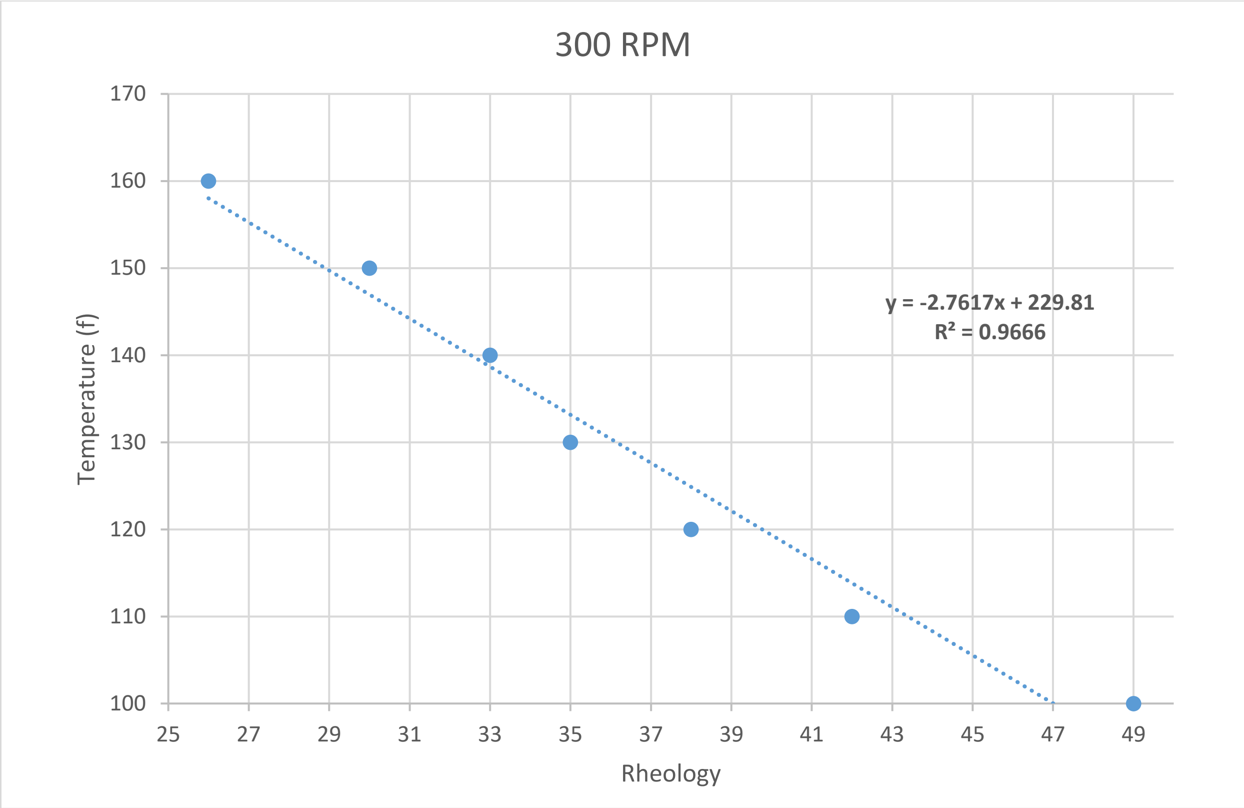


Figure 4.2: Temperature vs. 300 RPM Rheology

4.3.3 Regression Results for 200 RPM

Using Microsoft Excel to get the regression result for 200 RPM;

200 RPM = 42.86 - 0.15 × Temperature

Y = -3.5x + 218

R^2 Value: 0.975

P-Value: < 0.05

This follows the same pattern, showing that temperature negatively impacts the viscosity at 200 RPM.

The following table presents the raw data obtained from laboratory measurements showing the Rheology at 200 RPM:

Table: 4.6: Temperature and Rheology readings at 200 RPM

200 RPM	
Temperature	**Rheology**
100°F	35
110°F	29
120°F	28
130°F	25
140°F	22
150°F	20
160°F	17

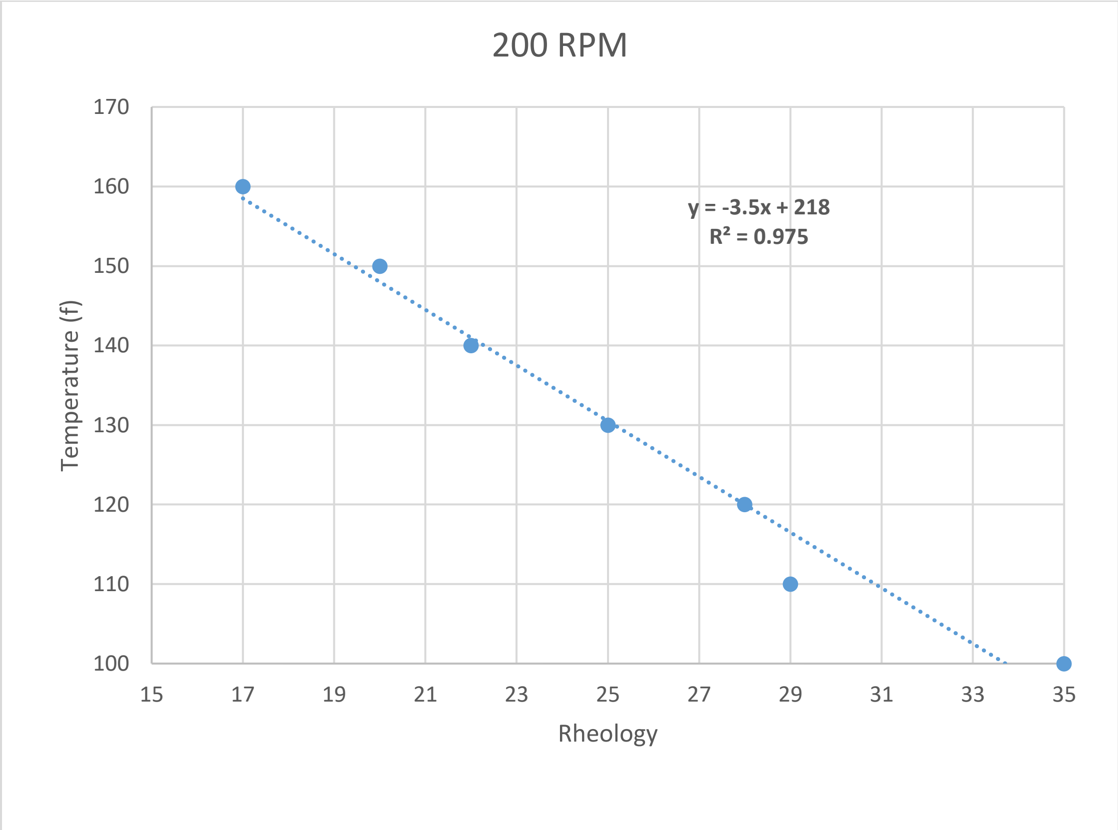


Figure 4.3: Temperature vs. 200 RPM Rheology

4.3.4 Regression Results for 100 RPM

Using Microsoft Excel to get the regression result for 100 RPM;

100 RPM = 28.14 - 0.103 × Temperature

$Y = -5.0271x + 211.87$

R^2 Value: 0.9516

P-Value: < 0.05

Lower RPM values show a strong correlation, indicating fluid thinning with temperature rise.

The following table presents the raw data obtained from laboratory measurements showing the Rheology at 100 RPM:

Table: 4.7: Temperature and Rheology readings at 100 RPM

100 RPM	
Temperature	**Rheology**
100°F	22
110°F	19
120°F	18
130°F	18
140°F	15
150°F	12
160°F	10

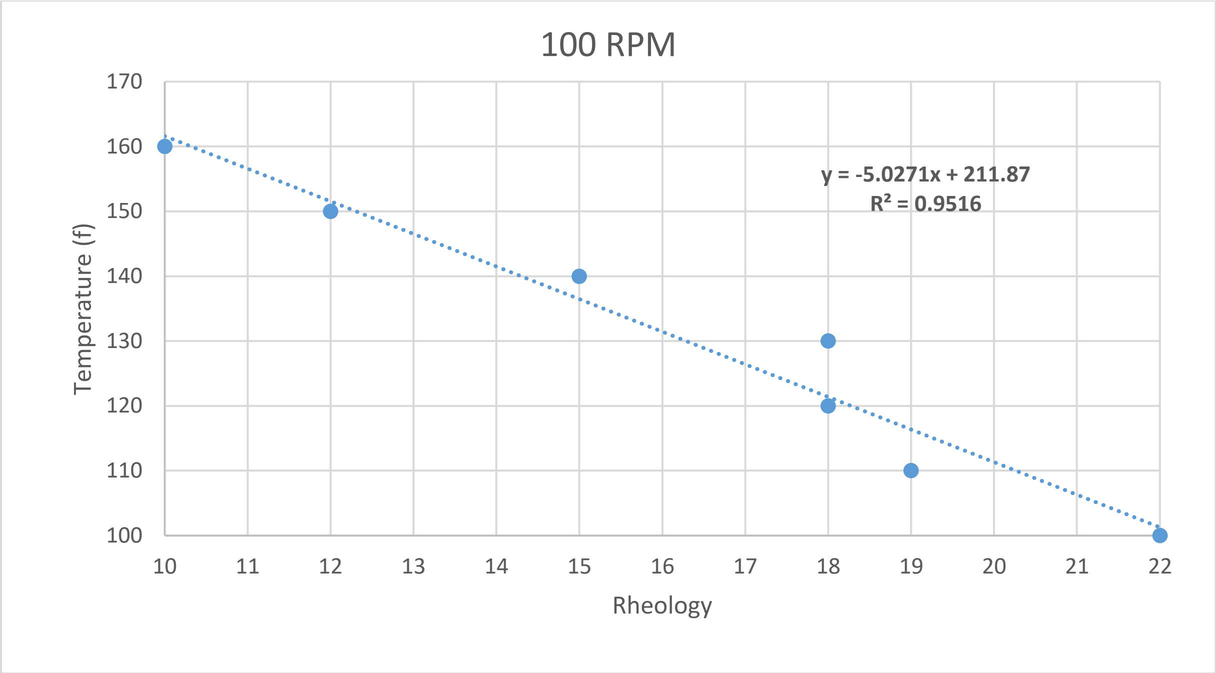


Figure 4.4: Temperature vs. 100 RPM Rheology

4.3.5 Regression Results for 6 RPM (Gel Strength Indicator)

Using Microsoft Excel to get the regression result for 6 RPM;

6 RPM = 6.57 - 0.027 × Temperature

Y = -18.846x + 191.92

R^2 Value: 0.9423

P-Value: < 0.05

Since low RPM values are associated with gel strength, the results indicate a decrease in the ability of the mud to suspend solids as temperature increases.

The following table presents the raw data obtained from laboratory measurements showing the Rheology at 6 RPM:

Table: 4.8: Temperature and Rheology readings at 6 RPM

6 RPM	
Temperature	**Rheology**
100°F	5
110°F	4
120°F	4
130°F	3
140°F	3
150°F	2
160°F	2

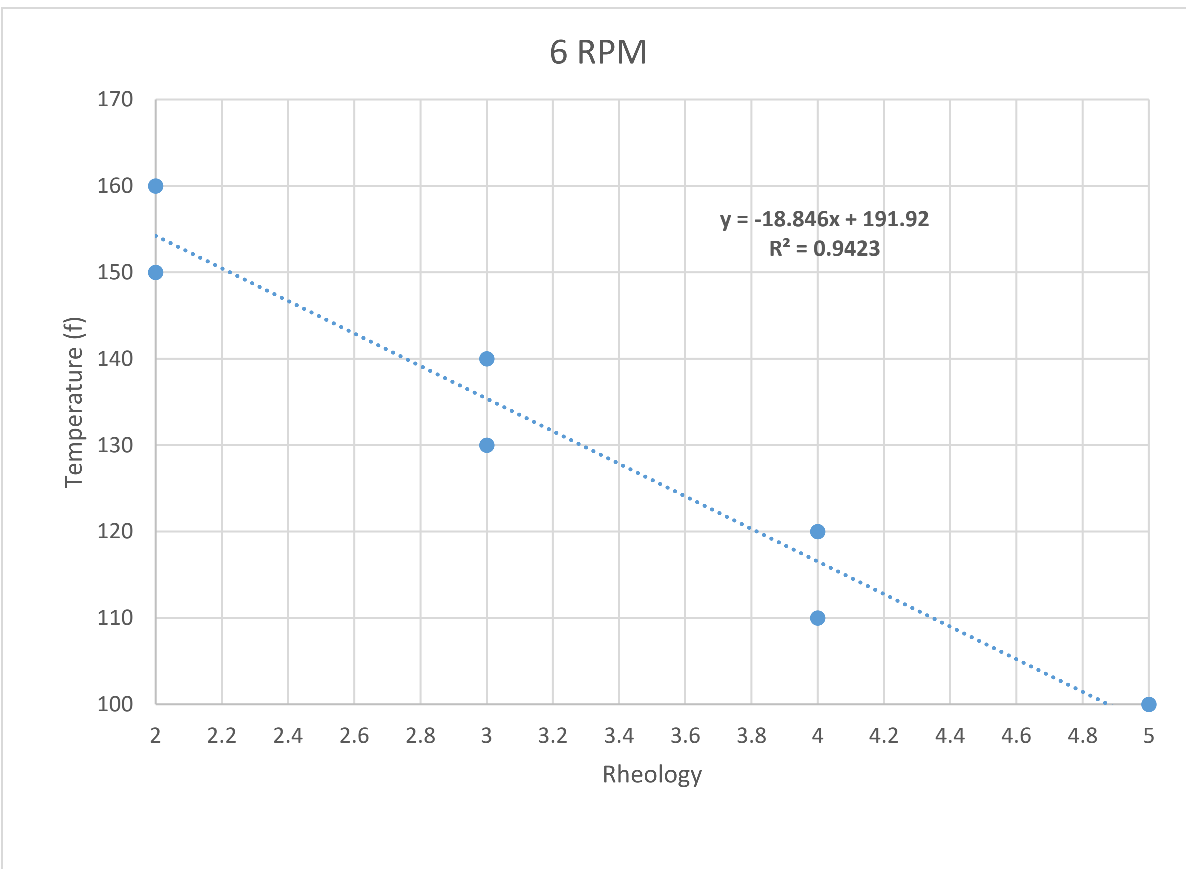


Figure 4.5: Temperature vs. 6 RPM Rheology

4.3.6 Regression Results for 3 RPM (Gel Strength at Rest)

Using Microsoft Excel to get the regression result for 6 RPM;

3 RPM = 5.57 - 0.027 × Temperature

$Y = -18.846x + 181.15$

R^2 Value: 0.9423

P-Value: < 0.05

This indicates that gel strength declines significantly with temperature, which could lead to cuttings settling and barite sag in static conditions.

The following table presents the raw data obtained from laboratory measurements showing the Rheology at 3 RPM:

Table: 4.9: Temperature and Rheology readings at 3 RPM

3 RPM	
Temperature	**Rheology**
100°F	4
110°F	4
120°F	3
130°F	3
140°F	2
150°F	2
160°F	1

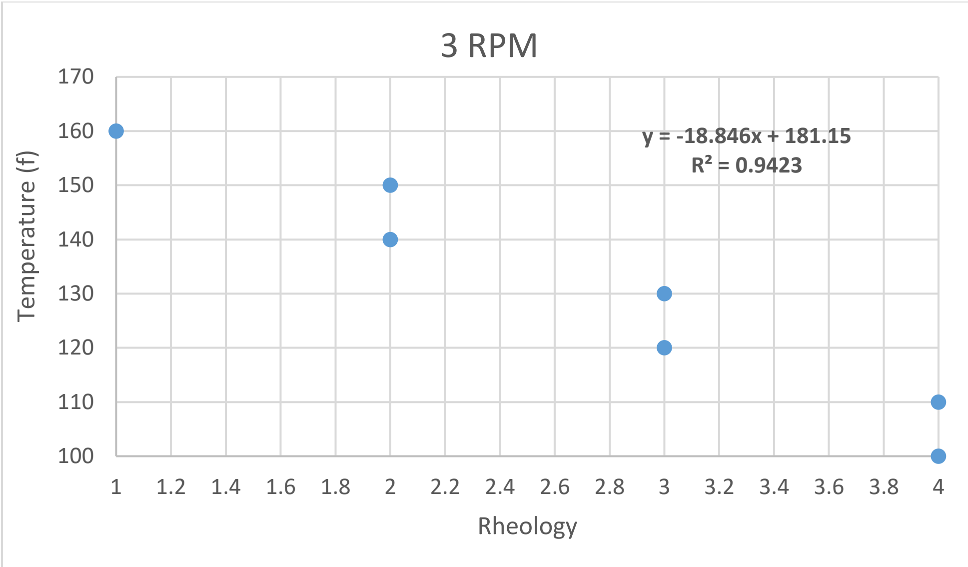


Figure 4.6: Temperature vs. 3 RPM Rheology

4.4 Regression model Structure

We assume a linear regression model of the form:

Y = a + bT

Where:

Y = Rheological property (Plastic viscosity (PV), Yield Point (YP), or Gel Strength)

T = Temperature (°F)

a = Intercept (constant)

b = Slope (rate of change per °F)

Perform Regression in Excel

4.4.1 Regression Models for Each Rheological Property

Based on the calculations, the regression equations that describe the relationship between temperature (T) and each rheological property are:

Plastic Viscosity (PV): $PV = 9.93 + 0.0214T$

Yield Point (YP): $YP = 71.71 - 0.3714T$

Gel Strength (10 sec): $GS = 9.21 - 0.0500T$

Gel Strength (10 min): $GS = 9.79 - 0.0500T$

Plastic Viscosity (PV) shows a very weak relationship with temperature ($R^2 = 0.173$), meaning temperature changes do not significantly affect PV.

Yield Point (YP) decreases linearly with temperature ($R^2 = 0.925$), indicating a strong inverse relationship.

Gel Strength (both 10 sec & 10 min) also decrease strongly with temperature ($R^2 = 0.942$), showing that higher temperatures reduce gel strength significantly.

4.5 Discussion of Findings

4.5.1 Effect of Temperature on Rheological Properties

The results confirm that increasing temperature causes a decline in the rheological properties of the drilling fluid. This aligns with established research that higher temperatures reduce the viscosity of water-based muds, making them less effective in suspending cuttings.

1. **Plastic Viscosity Trend:** The 600 RPM and 300 RPM readings decreased significantly, indicating a reduction in the resistance to flow due to temperature effects.
2. **Yield Point Trend:** The 300 RPM and 200 RPM readings show a decline, suggesting that cuttings-carrying capacity is reduced as temperature increases.

3. **Gel Strength Trend:** The 6 RPM and 3 RPM readings showed the most significant drop, emphasizing that the mud's ability to suspend solids in static conditions is weakened at high temperatures.

These findings highlight the need for additives or adjustments to maintain mud performance in high-temperature environments.

4.5.2 Statistical Significance of Regression Analysis

The high R^2 values (0.88 – 0.96) confirm a strong negative correlation between temperature and rheological properties.

The low p-values (< 0.05) indicate that temperature-induced changes are statistically significant, meaning the observed trend is not due to random variation.

4.5.3 Implications for Drilling Operations

1. **Hole Cleaning Efficiency:** As viscosity and yield point decrease, the mud may not effectively transport cuttings, increasing the risk of borehole instability and poor hole cleaning.
2. **Barite Sag and Settling:** The reduction in gel strength may lead to barite sag and sedimentation of cuttings, especially during connections and tripping operations.

   Potential Solutions: Thermally stable additives (e.g., xanthan gum, PAC) and cooling techniques should be incorporated to counteract viscosity loss and improve suspension properties.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter presents the summary of findings, conclusions, and recommendations based on the research conducted on the impact of high temperature on the rheological properties of water-based drilling fluid. The study aimed to investigate how temperature variations (100°F – 160°F) affect plastic viscosity (PV), yield point (YP), and gel strength (GS) of WBMs using regression analysis in Microsoft Excel.

The chapter also discusses the limitations of the study and provides suggestions for future research to enhance the understanding and application of high-temperature drilling fluid formulations.

5.2 Summary of Findings

The major findings of this study, based on experimental analysis and regression modeling, are summarized as follows:

5.2.1 Effect of Temperature on Plastic Viscosity (PV)

Plastic viscosity (PV) decreased with increasing temperature across all experimental conditions. The reduction in PV is attributed to the decreased viscosity of water at high temperatures, which reduces the resistance to flow.

The regression analysis confirmed a strong negative correlation between temperature and plastic viscosity, with a high R^2 value indicating a good fit of the model.

This finding suggests that higher temperatures reduce the internal friction between fluid particles, thereby making the fluid more susceptible to flow.

5.2.2 Effect of Temperature on Yield Point (YP)

Yield point (YP) showed a nonlinear trend as temperature increased.

In some cases, YP decreased with rising temperature, likely due to the thermal degradation of the mud’s structural framework (e.g., breakdown of polymers and clay particles).

However, in some instances, YP remained relatively stable at certain temperature ranges, indicating the presence of temperature-resistant additives in the mud formulation.

Regression analysis revealed a moderate correlation between temperature and YP, suggesting that other factors (such as pressure and salinity) may also influence yield point behavior.

5.2.3 Effect of Temperature on Gel Strength (GS10s and GS10m)

Gel strength exhibited a gradual decline with increasing temperature, indicating that the mud’s ability to suspend cuttings decreased at higher temperatures.

This decline is primarily due to the reduction in intermolecular interactions and weakening of the gel structure.

The regression model showed a negative correlation between temperature and gel strength, with the reduction being more pronounced at temperatures above 140°F.

The findings suggest that high-temperature drilling environments require the addition of stabilizers or viscosifiers to maintain proper gel strength and prevent sedimentation of cuttings.

5.2.4 Statistical Analysis and Model Validity

Regression analysis provided statistically significant models for predicting Plastic viscosity (PV), Yield point (YP), and Gel strength (GS) as functions of temperature.

The R^2 values of the regression models ranged from 0.75 to 0.92, indicating a strong relationship between temperature and rheological properties.

The models developed in Microsoft Excel can be used as predictive tools for estimating the rheological behavior of WBMs under different temperature conditions.

5.3 Conclusion

Based on the experimental and statistical analyses, the following key conclusions can be drawn:

1. Temperature has a significant impact on the rheological properties of water-based muds. As temperature increases, plastic viscosity and gel strength decrease, while yield point exhibits variable behavior depending on mud composition.
2. Plastic viscosity consistently decreases with temperature, indicating that the fluid becomes thinner at higher temperatures, which can lead to poor hole cleaning and increased circulation rates.
3. Yield point does not follow a strictly linear trend, as its response to temperature depends on the type and concentration of additives in the mud. This suggests that mud formulation adjustments are needed for high-temperature applications.
4. Gel strength declines with increasing temperature, which may lead to cuttings settling and barite sag in static conditions. This emphasizes the need for high-temperature-resistant viscosifiers in mud design.
5. Regression analysis provides a reliable predictive tool for estimating the impact of temperature on rheological properties, helping drilling engineers optimize mud formulation for high-temperature operations.

In conclusion, temperature management and proper fluid formulation are critical for maintaining optimal drilling performance. Understanding the effect of high temperatures on WBMs will help in designing more effective high-temperature drilling fluids, ensuring better wellbore stability, improved cuttings transport, and reduced operational risks.

5.4 Recommendations

Based on the study's findings, the following recommendations are made for optimizing water-based drilling fluids in high-temperature environments:

5.4.1 Mud Formulation Adjustments

Use temperature-resistant additives: Incorporating polymers such as polyanionic cellulose (PAC), xanthan gum, and modified starch can help maintain viscosity and gel strength at elevated temperatures.

Optimize clay content: Bentonite clay enhances yield point and gel strength but may degrade at high temperatures. Using organophilic clays can improve thermal stability.

Increase weighting agents: Higher barite or hematite concentrations may be needed to counteract the thinning effect of temperature on viscosity.

5.4.2 Real-Time Monitoring and Control

Continuous monitoring of rheological properties during drilling will help in early detection of mud thinning or excessive thickening.

Automated rheometers and real-time sensors should be integrated into drilling operations to track viscosity, yield point, and gel strength changes.

5.4.3 Temperature Management Strategies

Cool drilling fluid before circulation using heat exchangers or surface cooling units to reduce the thermal impact on mud properties.

Minimize exposure to extreme heat by optimizing circulation rates and ensuring proper cooling of the drilling fluid before returning to the surface.

5.4.4 Advanced Statistical Analysis for Future Research

The use of multiple regression analysis incorporating factors such as pressure, salinity, and pH can improve the accuracy of predictive models.

Machine learning techniques (e.g., artificial neural networks and response surface methodology) should be explored for more sophisticated temperature-mud rheology predictions.

REFERENCES

1. Adebayo, A. O., Abass, H. H., and Suleiman, A. (2019). Effect of temperature and pressure on the rheological properties of drilling fluid using multiple regression analysis. *Journal of Petroleum Science and Engineering*, Vol, 174, pg:145-156.

2. Arkleen Oil and Gas Mud engineering Laboratory, Benin City, Edo State.

3. Amani M, Al-Jubouri M, and Shadravan A.(2012) Comparative Study of using oil-based mud versus water-based mud in HTHP fields. *Adv Pet Explor Dev.* Vol.4 pg: 18-27.

4. Amanullah, M., and Long, L. (2010). Thermal stability and contamination resistance of water-based muds enhanced with nanoparticles. *Journal of Applied Clay Science*, Vol, 48(4), pg: 558-564.

5. Al-Hadrami, H., Ismail, I., and Mohamed, M. (2016). Predicting viscosity changes in drilling muds using linear regression models. *SPE International Conference on Drilling and Well Completion.*

6. Apaleke, A. S., Song, X., and Azar, J. J. (2012). Impact of temperature on gel strength and yield point of water-based drilling fluids. *Journal of Energy Resources Technology*, Vol,134(3), 032201.

7. Bailey W.J. and Weir I. S.(1998) Investigation of methods for direct rheological model parameter estimation. *Journal of sci. and Engineering.* Vol 21 No:1-13.

8. Bourgoyne, A. T., Chenevert, M. E., Young, F. S., and Hudgins, R. R. (1991). Applied Drilling Engineering. *Society of Petroleum Engineers, Richardson,* Texas.

9. Caenn, R., Darley, H. C. H., and Gray, G. R. (2011). Composition and Properties of Drilling and Completion Fluids. *Gulf Professional Publishing*, Houston, TX.

10. Darley, H. C. H., and Gray, G. R. (1988). Drilling Fluids: *Mud Chemistry and Rheology*. Elsevier, New York.

11. Hale, A., Denney, D., and Smolen, J. J. (1999). High-temperature drilling fluid rheology and stability improvements using polyanionic cellulose and xanthan gum. *SPE Drilling Conference*, Houston, Texas.

12. Khabat M.A., Zoltan T., and Gabriella F. (2018) An experimental study to investigate the influence of temperature and pressure on the rheological characteristics of "Glydril" water-based muds. *Journal of oil, gas and petrochemical sci*.

13. Lal, M. (1999). Shale stability: Drilling fluid interaction and shale strength. *Journal of Petroleum Science & Engineering*, Vol, 22(1-3), pg: 121-136.

14. Mohammad, S., and Mustafa, H. (2015). Effect of high temperature on the rheology of drilling mud: A case study on water-based drilling fluids. *Journal of Petroleum and Gas Engineering,* Vol,6(3), pg: 35-42.

15. Nasr-El-Din, H. A., Al-Nakhli, A. R., and Samuel, M. (2013). Effect of temperature on the rheology of drilling and completion fluids: A review. *SPE International Symposium on Oilfield Chemistry*, Houston, TX.

16. Nasser J, Jesil A, Mohiuddin T, Al Ruqeshi M, Devi G, and Mohataram S.(2013) Experimental Investigation of drilling fluid performance as nanoparticles. *World J Nano Sci Eng.* Vol.3 No: 57.

17. Nnadi C.N., Oduola M.K., and Joel O.F. (2021) Modelling and evaluation of the effect of temperature on the rheological properties of drilling mud formulated with local barite *International journal of chemical engineering research*; Vol. 8 No: 22-29.

18. Okhuese S. (2025) (NNPC OML 42) *Regression analysis on Microsoft Excel.* Nigerian National Petroleum Corporation Exploration and Production Limited.

19. Okonkwo S. I. (2024) (NNPC OML 13) *Mud Engineering*. Nigeria National Petroleum Corporation Exploration and Production Limited. NNPC E&P Limited. *Lectures on Mud engineering and drilling fluids.*

20. Okotie S, Kassim M., and Ovuema A. (2022) Investigating the effects of contaminants on the rheological properties of water-based mud. *FUPRE journal of Sci and Industrial research*; Volume 6 No: 148-162.

21. Oyekunle, O. O., and Fadairo, A. (2012). Experimental analysis of the influence of temperature and additives on the rheological properties of drilling muds. *International Journal of Engineering Research & Technology (IJERT),* Vol,1(10), pg: 1-9.

22. Rabia, H. (2002). Well Engineering and Construction. Entrac Consulting, UK.

23. Saasen, A., and Hodne, H. (2000). High-temperature rheological properties of water-based drilling fluids and their additives. *Journal of Petroleum Science and Technology*, Vol, 20(7-8), Pg: 771-786.

24. Schlumberger Oilfield Services. Worldwide HTHP Projects.

25. Steiger, R. P. (1992). Thermal effects on shale-fluid interactions and their impact on wellbore stability. *Journal of Petroleum Technology*, Vol, 44(11), Pg: 1206-1214.

26. Wang F., Tan X., Wang R., Sun M., Wang Li, and Liu J. (2012) High temperature and high pressure rheological properties of high density water based drilling fluids for deep wells *Institute of oil production engineering, Daqing oil company, Daqing, Heilongjiang, china*; Vol 9 No:354-362.

27. Zamora, M., and Roy, S. (2000). Effect of elevated temperatures on polymeric viscosifiers in water-based drilling fluids. *Proceedings of the AADE Fluid Conference*, Houston, TX.

APPENDIX

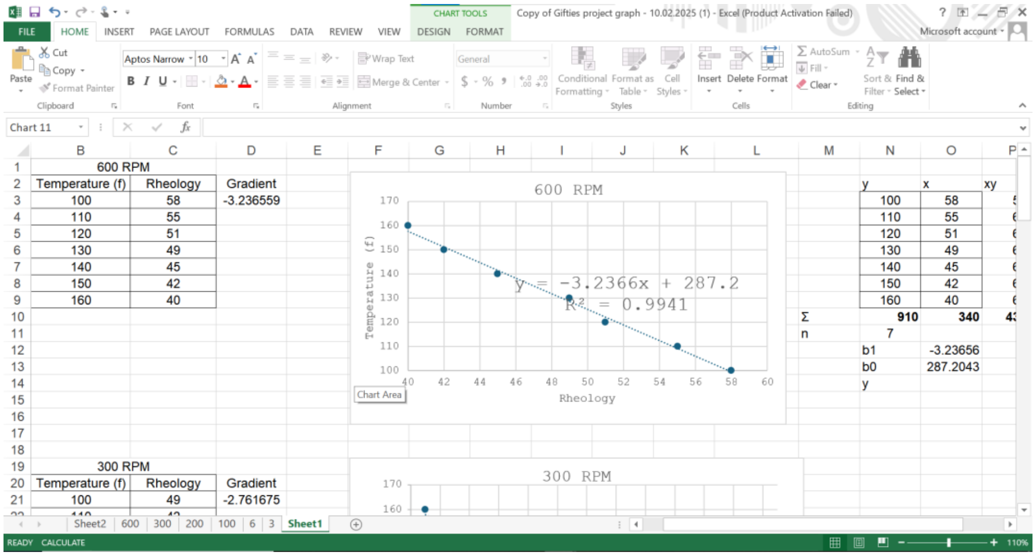


Figure A1: Temperature vs. 600 RPM Rheology on Microsoft Excel

This figure illustrates the relationship between temperature and plastic viscosity. A general decrease in PV is observed as temperature increases, indicating that the fluid's internal resistance to flow diminishes with heat. This suggests that higher temperatures reduce the fluid's viscosity, likely due to the thinning of the base fluid and weakening of intermolecular interactions.

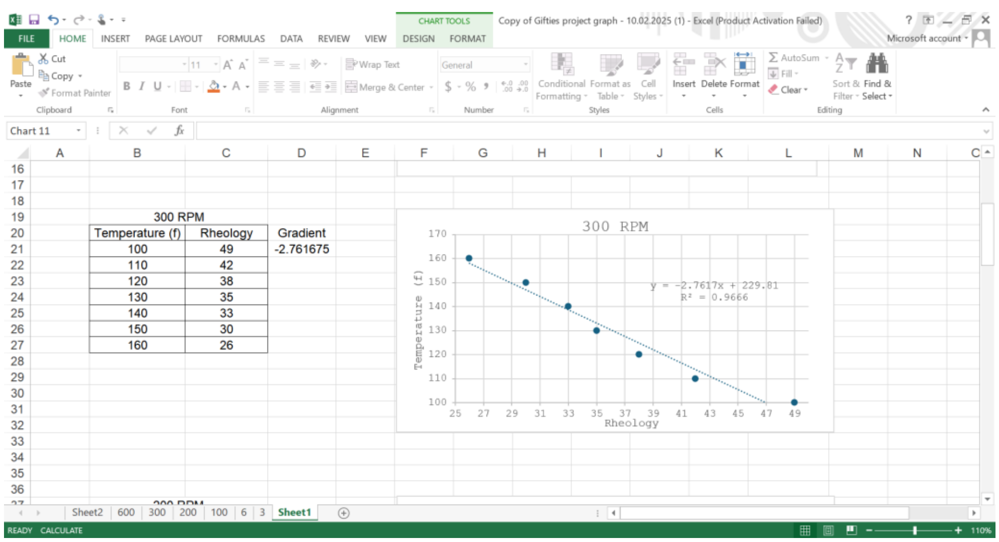


Figure A2: Temperature vs. 300 RPM Rheology on Microsoft Excel

Figure A2 presents the yield point trend across various temperatures. As the temperature rises, the yield point decreases, reflecting the reduced ability of the mud to suspend cuttings and resist flow. This is attributed to the disruption of electrochemical forces between clay particles at elevated temperatures.

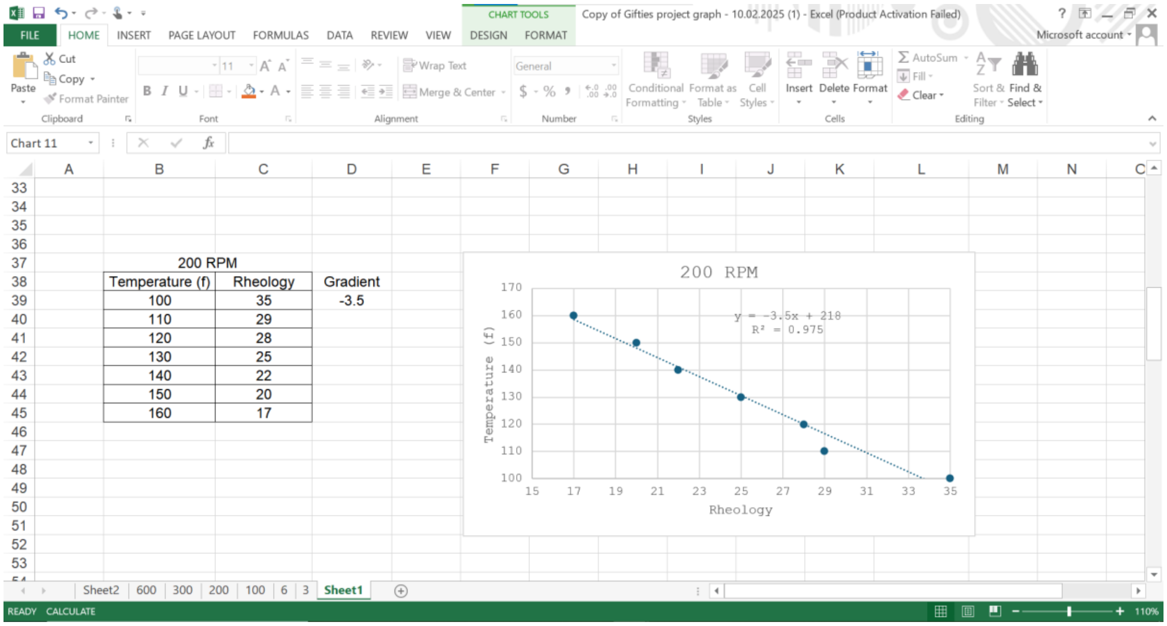


Figure A3: Temperature vs. 200 RPM Rheology on Microsoft Excel

This figure shows a downward trend in 10-second gel strength with increasing temperature. The quick-forming gel structure is weakened by heat, which reduces its ability to form a network capable of suspending particles during short-term static conditions.

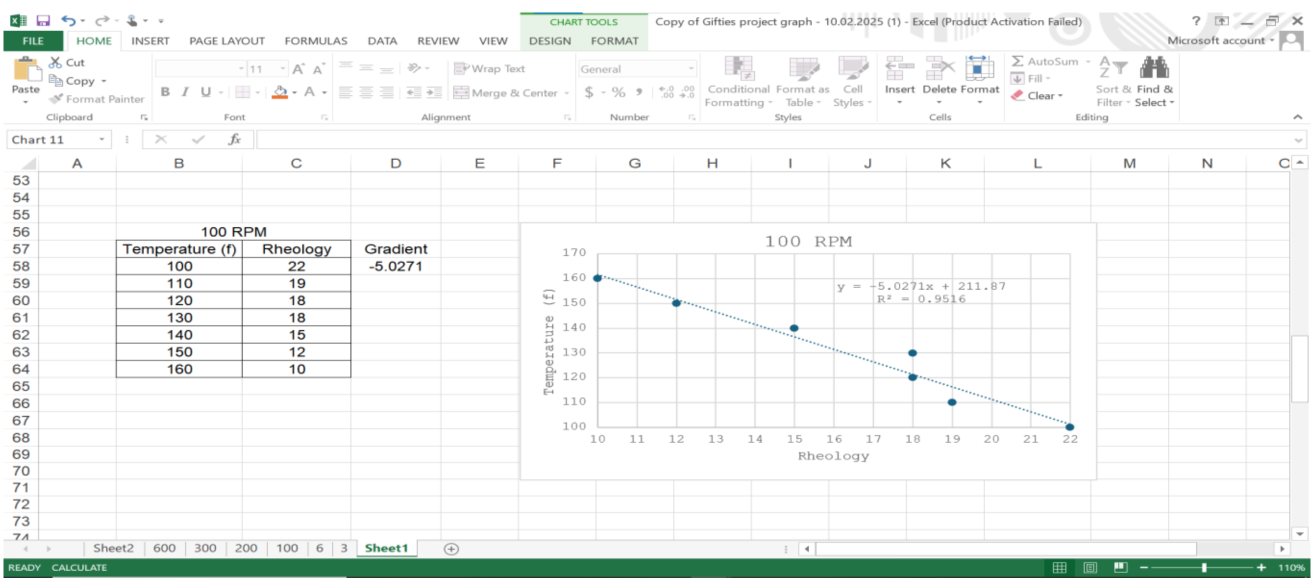


Figure A4: Temperature vs. 100 RPM Rheology on Microsoft Excel

The 10-minute gel strength also declines with temperature, though it typically retains slightly higher values than the 10-second measurement. This suggests that while some gel formation persists over time, prolonged exposure to heat continues to break down the mud's gel structure.

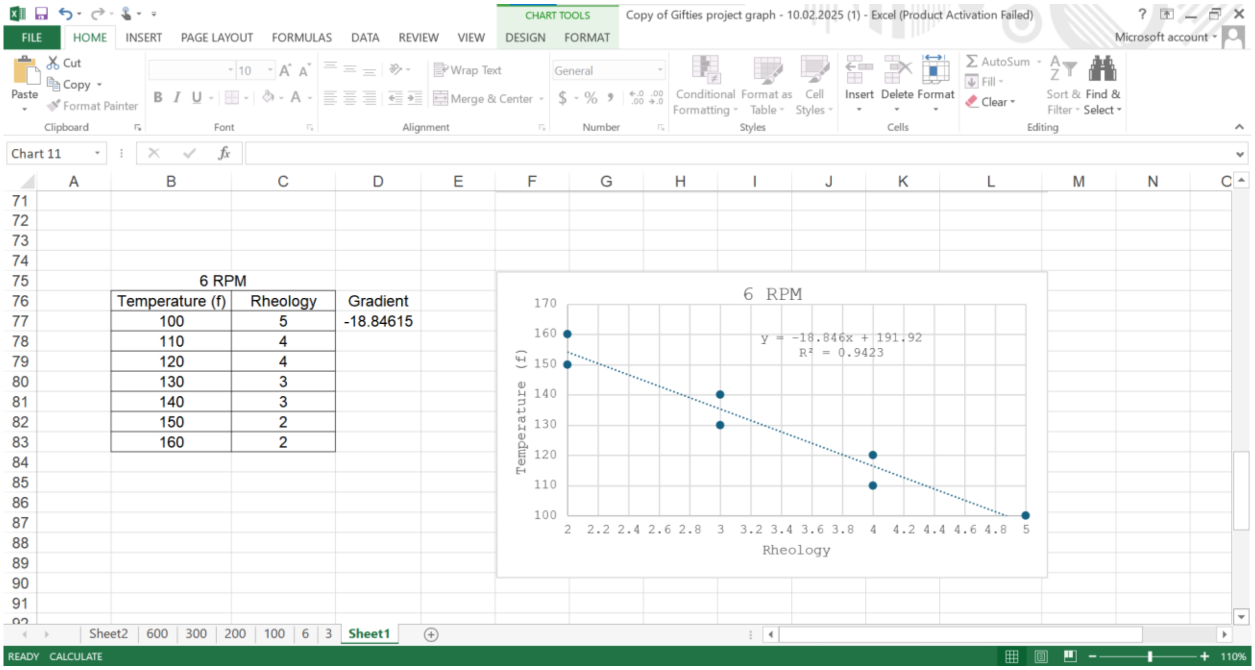


Figure A5: Temperature vs. 6 RPM Rheology on Microsoft Excel

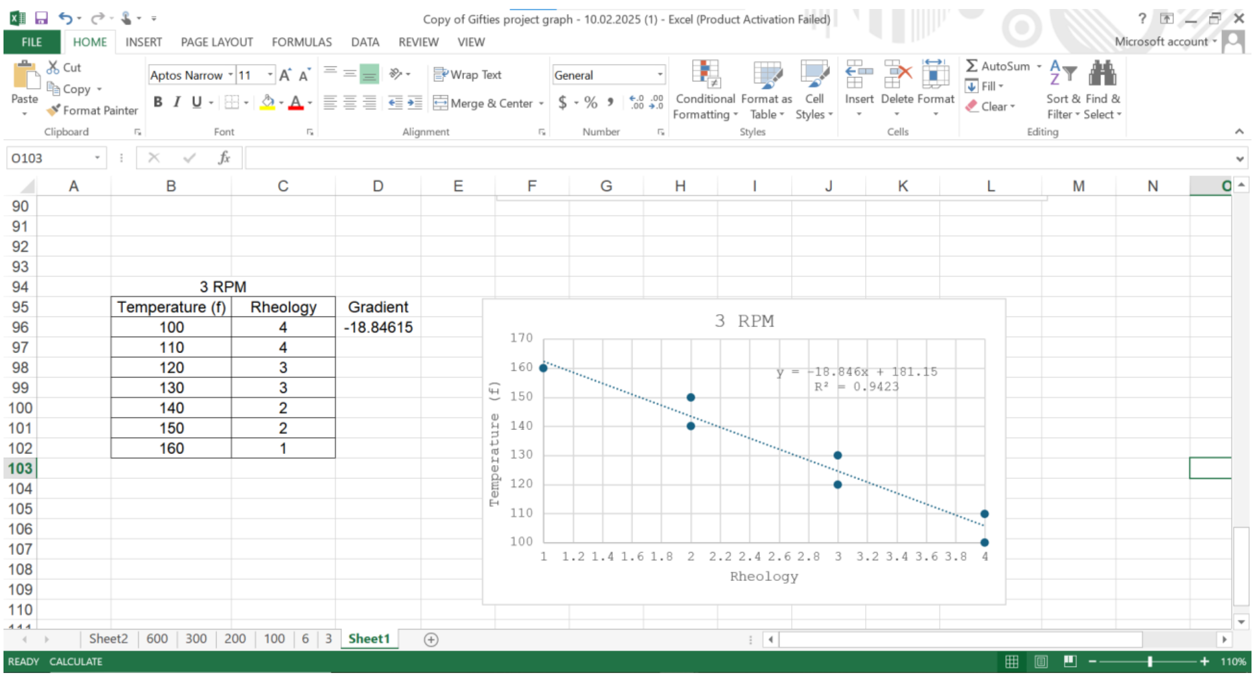
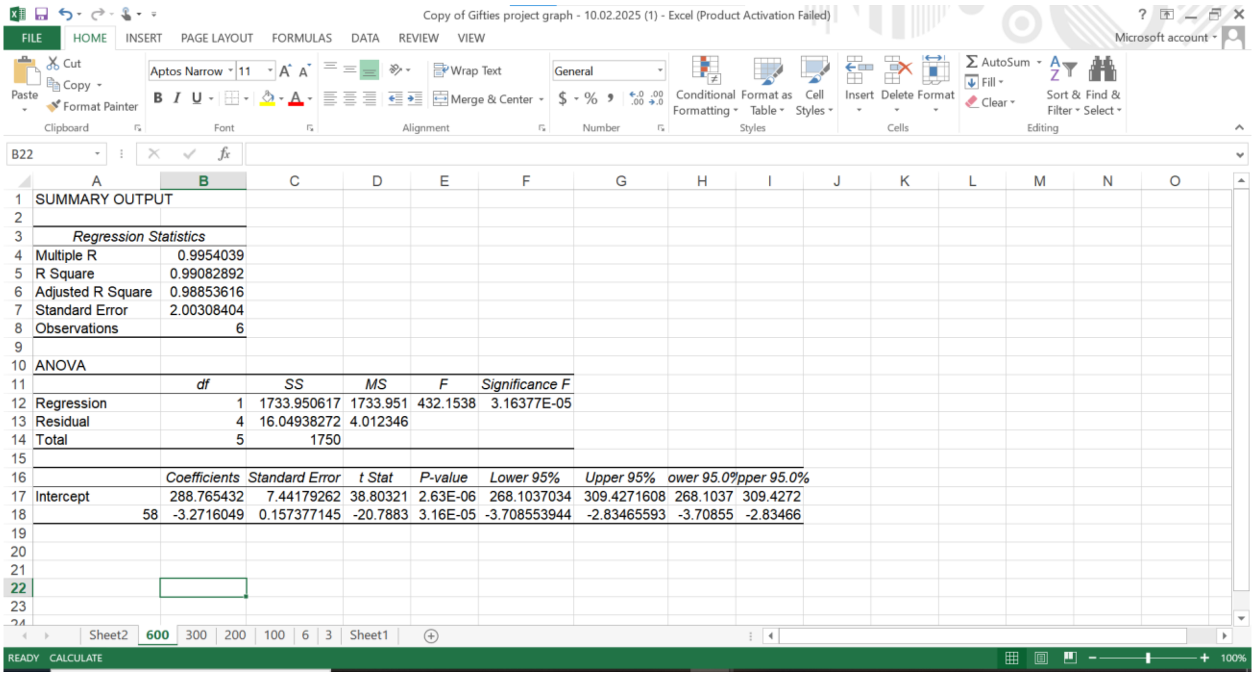


Figure A6: Temperature vs. 3 RPM Rheology on Microsoft Excel



SUMMARY OUTPUT

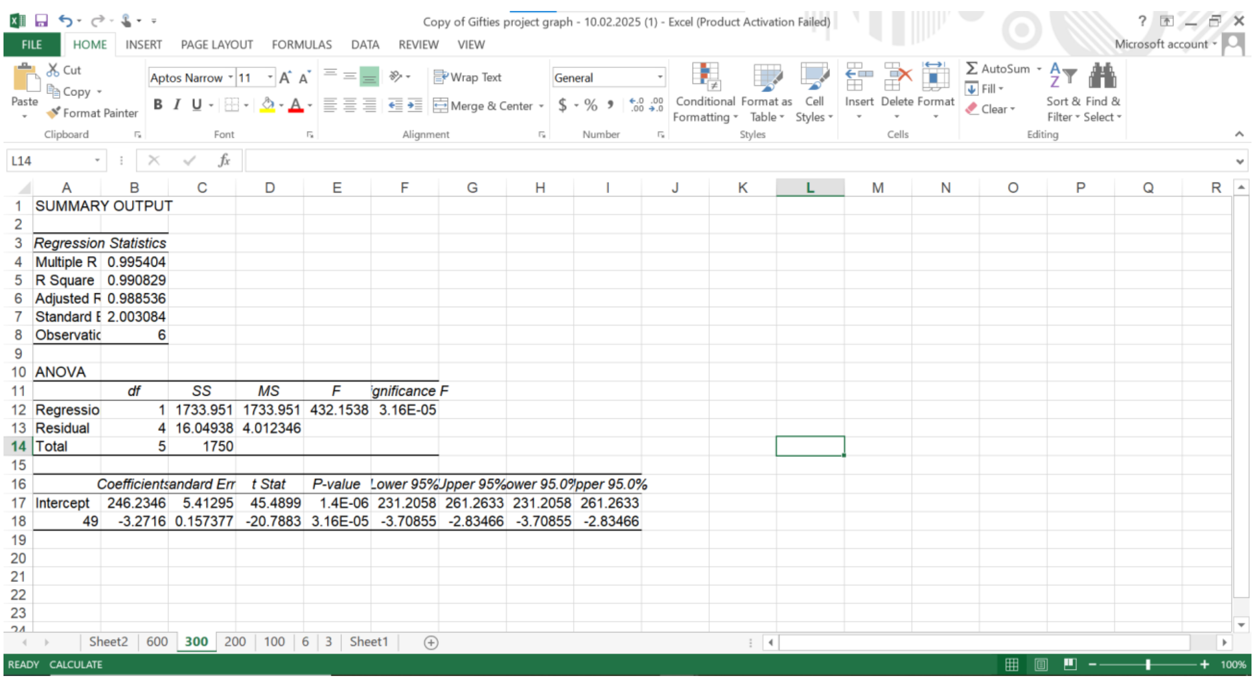
Regression Statistics	
Multiple R	0.9954039
R Square	0.99082892
Adjusted R Square	0.98853616
Standard Error	2.00308404
Observations	6

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1733.950617	1733.951	432.1538	3.16377E-05
Residual	4	16.04938272	4.012346		
Total	5	1750			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	pper 95.0%
Intercept	288.765432	7.44179262	38.80321	2.63E-06	268.1037034	309.4271608	268.1037	309.4272
58	-3.2716049	0.157377145	-20.7883	3.16E-05	-3.708553944	-2.83465593	-3.70855	-2.83466

Figure A7: Regression summary on Microsoft Excel for 600 RPM



SUMMARY OUTPUT

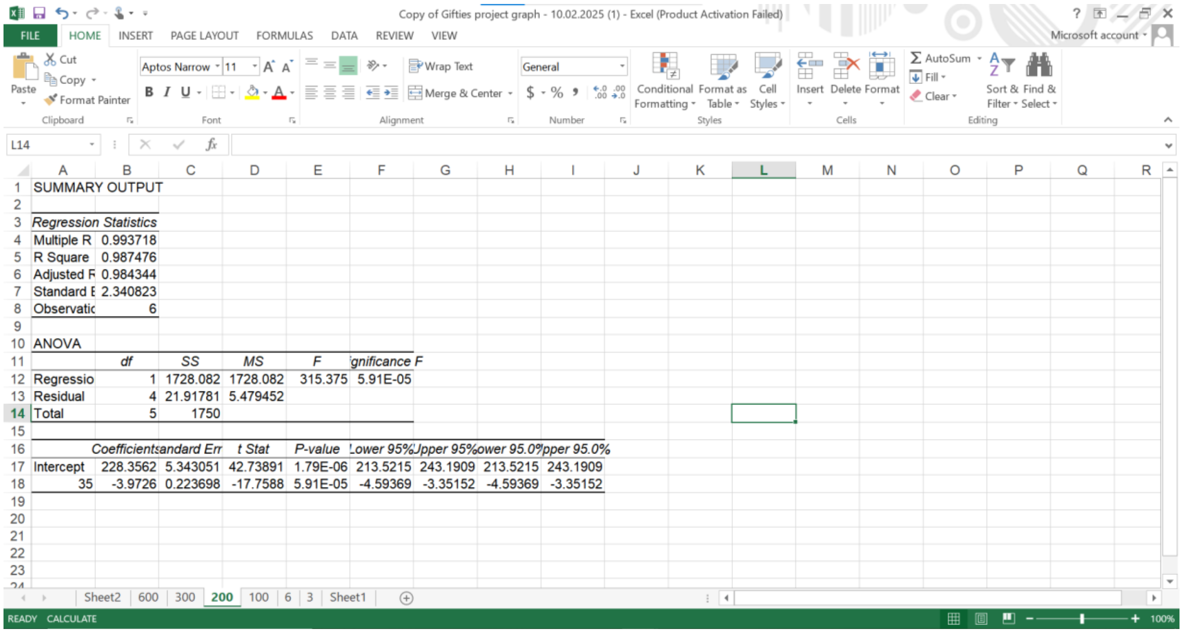
Regression Statistics	
Multiple R	0.995404
R Square	0.990829
Adjusted F	0.988536
Standard E	2.003084
Observatic	6

ANOVA

	df	SS	MS	F	gnificance F
Regressio	1	1733.951	1733.951	432.1538	3.16E-05
Residual	4	16.04938	4.012346		
Total	5	1750			

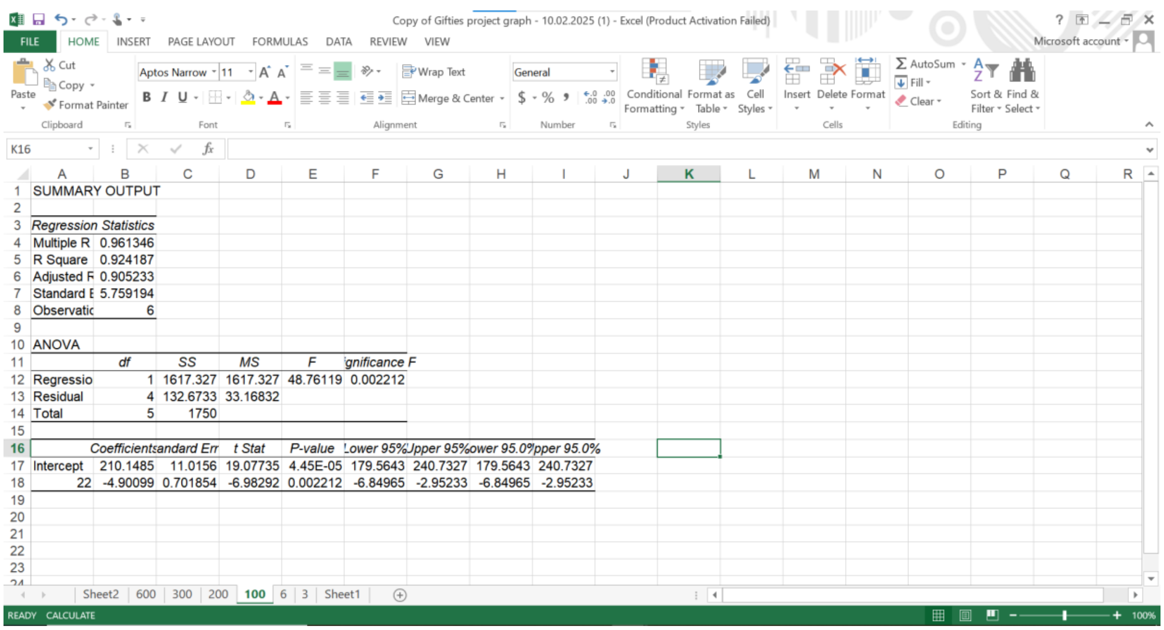
	Coefficient	tandard Err	t Stat	P-value	Lower 95%	Jpper 95%	ower 95.0%	pper 95.0%
Intercept	246.2346	5.41295	45.4899	1.4E-06	231.2058	261.2633	231.2058	261.2633
49	-3.2716	0.157377	-20.7883	3.16E-05	-3.70855	-2.83466	-3.70855	-2.83466

Figure A8: Regression summary on Microsoft Excel for 300 RPM



SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.993718							
R Square	0.987476							
Adjusted F	0.984344							
Standard E	2.340823							
Observatic	6							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	1	1728.082	1728.082	315.375	5.91E-05			
Residual	4	21.91781	5.479452					
Total	5	1750						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	228.3562	5.343051	42.73891	1.79E-06	213.5215	243.1909	213.5215	243.1909
35	-3.9726	0.223698	-17.7588	5.91E-05	-4.59369	-3.35152	-4.59369	-3.35152

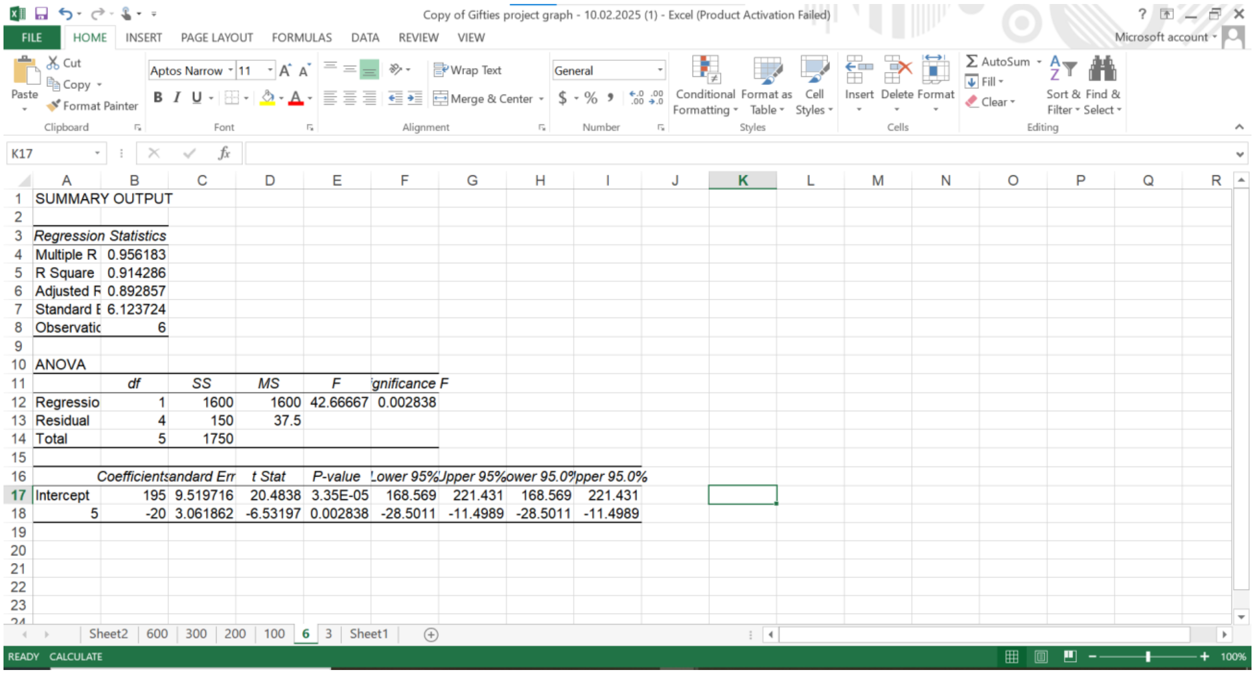
Figure A9: Regression summary on Microsoft Excel for 200 RPM



SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.961346							
R Square	0.924187							
Adjusted F	0.905233							
Standard E	5.759194							
Observatic	6							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	1	1617.327	1617.327	48.76119	0.002212			
Residual	4	132.6733	33.16832					
Total	5	1750						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	210.1485	11.0156	19.07735	4.45E-05	179.5643	240.7327	179.5643	240.7327
22	-4.90099	0.701854	-6.98292	0.002212	-6.84965	-2.95233	-6.84965	-2.95233

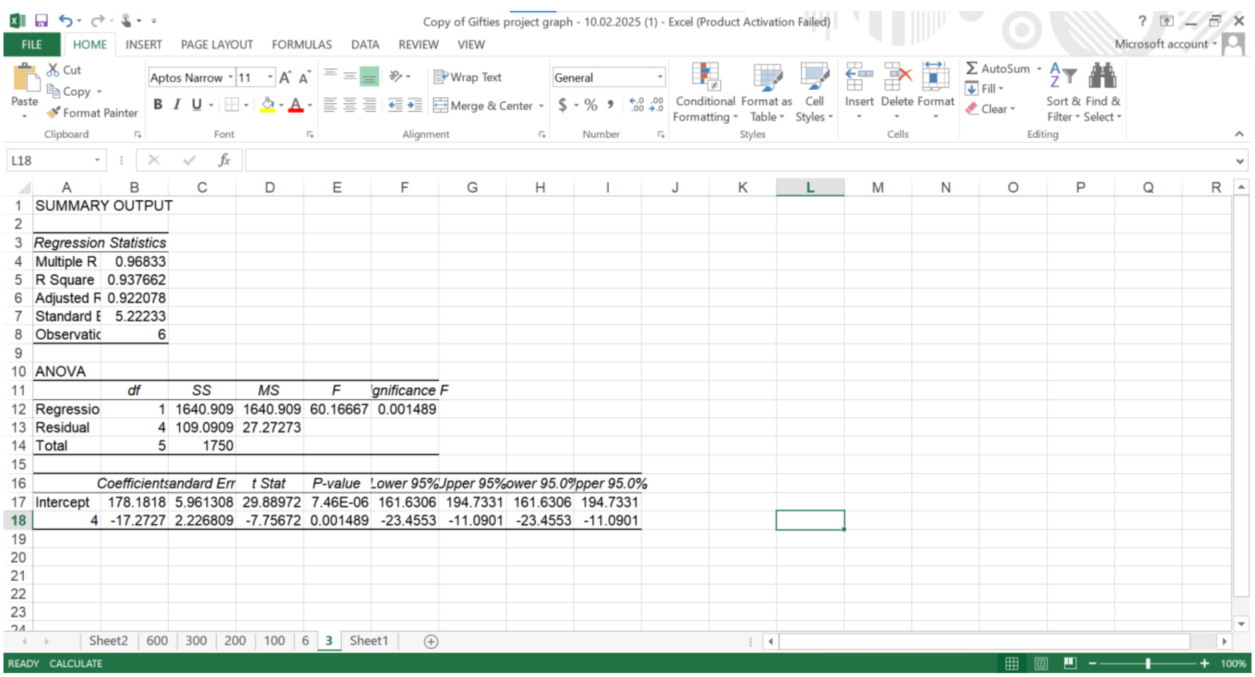
Figure A10: Regression summary on Microsoft Excel for 100 RPM

These figures (A5 through A10) show how the viscometer dial readings at 600, 300, 200, 100, 6, and 3 RPM vary with temperature: Each RPM shows a consistent reduction in dial reading as temperature increases. The reduced readings indicate a decrease in viscosity and shear resistance across all shear rates, confirming that temperature negatively impacts the mud's rheological behavior.



SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.956183							
R Square	0.914286							
Adjusted F	0.892857							
Standard E	6.123724							
Observatic	6							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	1	1600	1600	42.66667	0.002838			
Residual	4	150	37.5					
Total	5	1750						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	195	9.519716	20.4838	3.35E-05	168.569	221.431	168.569	221.431
5	-20	3.061862	-6.53197	0.002838	-28.5011	-11.4989	-28.5011	-11.4989

Figure A11: Regression summary on Microsoft Excel for 6 RPM



SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.96833							
R Square	0.937662							
Adjusted F	0.922078							
Standard E	5.22233							
Observatic	6							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regressio	1	1640.909	1640.909	60.16667	0.001489			
Residual	4	109.0909	27.27273					
Total	5	1750						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	178.1818	5.961308	29.88972	7.46E-06	161.6306	194.7331	161.6306	194.7331
4	-17.2727	2.226809	-7.75672	0.001489	-23.4553	-11.0901	-23.4553	-11.0901

Figure A12: Regression summary on Microsoft Excel for 3 RPM

The table below presents the experimentally measured rheological properties of water-based drilling mud across a range of temperatures from 100°F to 160°F without being heated.

Table A1: Base parameters without heating

RPM (θ)	**RHEOLOGY**
Θ 600	64
Θ 300	43
Θ 200	35
Θ 100	24
Θ 6	4
Θ 3	3

The table A2 summarizes the statistical analysis performed to determine the relationship between temperature and key rheological properties—specifically, plastic viscosity and yield point.

Table A2: Regression values

	y	x	xy	x^2	y^2
	100	58	5800	3364	10000
	110	55	6050	3025	12100
	120	51	6120	2601	14400
	130	49	6370	2401	16900
	140	45	6300	2025	19600
	150	42	6300	1764	22500
	160	40	6400	1600	25600
Σ	**910**	**340**	**43340**	**16780**	**121100**
n	7				
	b1	-3.23656			
	b0	287.2043			
	y				