INTERNATIONAL BACCALAUREATE HL CHEMISTRY EXTENDED ESSAY

Investigation of The Effect of Concentration of *Lawsonia inermis* on the Adsorption of Activated Calcium Bentonite in aqueous solution

How does concentration of *Lawsonia inermis* (2.00%, 4.00%, 6.00%, 8.00%, 10.00%) affect the swelling of activated calcium bentonite in aqueous solution at 23.00°C under 100 kPa by measuring conductivity by conductivity probe(siemens/m)?

Word Count: 3997

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INTRODUCTION

Drilling mud, drilling fluid in other words, is defined to be the viscous fluid that eases the process of drilling a borehole into the earth. Four fundamental properties of drilling mud are high viscosity, high density, gel strength and filtration. The categorization of this substance is attributable to their fluid phase alkalinity, distribution, and the type of chemicals used in their formulation. Drilling mud is divided into two groups: Water Based Mud (WBM)'s and Oil Based Mud (OBM)'s. These two groups are differentiated according to their solvent. WBM's solvent is water whereas OBM's solvent is diesel. In addition, WBM is widely used worldwide, has lower cost and causes less pollution compared to WBM.

Unfortunately, there has been an increase in the costs of drilling operations due to wellbore instability which is defined to be the time lost due to complications in mud drilling. Wellbore instability is caused by changes in moisture content of shales. As a result of the effects it has on mud drilling operations, the issue has become a major concern for the petroleum industry. As a student living in a country which mainly uses petroleum as an energy source, I initiated this project to provide a solution to the increasing costs of mud drilling operations.

Once I had multiple interviews with various people from the petroleum industry, I noticed that the majority of them have mentioned that they were trying to find a solution to reduce the increased costs caused by wellbore instability. After doing research about the issue, I decided to do an adsorption test to observe the amount of water penetrating into the porous substance. I utilized *Lawsonia inermis* extract in the experiment as it is widely cultivated and harvested in my country and thus could potentially be a better solution for the issue of increasing costs of mud drilling operations as we could obtain *Lawsonia inermis* much more easily than any other plant.

Background Knowledge

To successfully carry out this experiment, it is essential to comprehend how drilling fluid interacts with shale formations and accurately explain pore pressure distribution, which has an impact on wellbore stability.

Pore pressure production is carried out in every basin where oil and gas exploration wells are drilled and sudden variations in pore pressure during wellbore drilling leads to serious issues. This risk can be decreased by improving wellbore stability, selecting the best casing seat, and developing mud programs with the aid of an accurate pore pressure prediction of the fluid.

The hydration of clay minerals is one of the significant interactions that occur between a rock matrix and pore fluid. It is best described by an adsorption isotherm that distinguish adsorption mechanisms based on the extended multilayer sorption phenomena and the porous surface structure. Reviewing the adsorption mechanism in clay minerals is useful in describing the adsorption process between aqueous fluids and shale rocks. A theoretical explanation for determining the adsorption isotherms in shale rocks can be developed with the aid of such background information.

The term adsorption can be defined as a (generally reversible) surface process that leads to transfer of a molecule from a fluid bulk to solid surface and it can be caused by physical forces or chemical bonds. Despite combining the operations of numerous different physical principles, the adsorption theory is the most widely recognized theory of adhesion. According to the theory, when two materials are in close contact, interatomic and intermolecular forces between the adhesive and substrate induce the materials to attach. In other words, a substance that has a porous structure with smaller magnitude of interatomic and intermolecular forces most likely has a smaller adsorption value. Thus, the moisture content of shale is correlated with water activity using a multilayer adsorption theory. In this case, when a shale has a higher water activity, it is seen that the porous structure decreases and thus the intermolecular and interatomic forces are strengthened and the amount of adsorption increases, which facilitates shale formation and reduces wellbore instability.

Conductivity is a term applied to physical phenomena and it has been used in many investigations to assess the removal rate of specified substances. In this investigation, this property of conductivity is used to determine a relation between conductivity and adsorption of solutions with different concentration values (using the equation stated in ‘Method’ section). Hence, change in conductivity values will be used to determine the adsorption value of each solution with varying concentration values (2.00%, 4.00%, 6.00%, 8.00%, 10.00%).

Lawsonia inermis

Lawsonia inermis is a medicinal plant that is also grown for its roots, bark, flowers, and seeds in addition to its leaves. Carbohydrates, proteins, lawsone, mannite, tannic acid, mucilage, gallic acid napthaquinone, and fatty acids are some of its constituents. Analgesic, hypoglycemic, anti-inflammatory, antibacterial, antiviral, antiparasitic, antitrypanosomal, antidermatophytic, antioxidant, antifertility, and anticancer characteristics have also been documented for the plant. The constituents of *Lawsonia inermis* can be determined by methods such as gas chromatography and mass spectrometry. It is today acknowledged as a valuable source of distinctive natural ingredients for the creation of industrial products as well as medications against various disorders.

Lawsonia inermis, a plant utilized in traditional customs of Anatolian countries and Egypt, is also known as henna in this area. It is used for painting processes and health in daily life. Consequently, the demand for henna dye is increasing and new introductions due to it are likely to occur.

Growing Conditions of *Lawsonia inermis*

Plant Type	*L. inermis* is a perennial, broadleaved and seed propagated plant.
Habitat	*L. inermis* is well adapted to various types of environmental conditions but it is best grown in dry and semi-arid habitats in coastal secondary scrubs.
Characteristics of *L. inermis*	Self-pollinated plant Requires high temperature (19-27°C) for germination and growth. Highest yield of *L. inermis* occurs at 4-8 years.
Rainfall	*L. inermis* can tolerate a rainfall range of 500 mm to 1500 mm.

Table 1: The growing conditions and characteristics of *L. inermis*

As seen in Table 1, it can be interpreted that the growing conditions of *Lawsonia inermis* are less delicate than most of the plants, the plants that grow in my country especially.

Activated Calcium Bentonite

Despite being utilized for thousands of years, most of its present applications were developed after 1900's. It is now an essential raw resource for the manufacture of steel and energy, as well as for many other everyday items and uses that are essential to the global economy. It also participates in agricultural applications in addition to these.

Bentonites are categorized as the smectite group of minerals that expand reversibly when it absorbs water (like montmorillonite). Between the silicate layers, exchangeable cations including sodium, calcium, and magnesium coexist with water molecules. Due to the exchangeability of certain elements, the exchange capacity is expressed in milliequivalents per 100 grams. It is classified into three: natural sodium bentonite, natural calcium bentonite and activated calcium bentonite.

Differences Between Natural Sodium Bentonite, Natural Calcium Bentonite and Activated Calcium Bentonite

Natural Sodium Bentonite	**Natural Calcium Bentonite**	**Activated Calcium Bentonite**
Has a basic pH (close to 9)	Has a neutral pH	Has a pH of between 9 and 10.
A mild swelling index.	Has a low swelling index.	High swelling index
Moderately equivalent quantities exchangeable sodium and calcium	Low proportion of exchangeable sodium & a high proportion of exchangeable calcium	High proportion of exchangeable sodium and calcium

Table 2: Natural Sodium bentonite, natural calcium bentonite and activated calcium bentonite are classified due to their different characteristics in the table above.

Wellbore instability is the term used to describe time lost because of complications with mud drilling brought on by variations in the moisture content of the shales. Pore pressure, or a substantial interaction between pore fluid and rock matrix brought on by the hydration of clay minerals, is used to explain this condition. By examining the hydration level of clay minerals such as activated calcium bentonite and subsequently the quantity of adsorption and moisture using the adsorption test, it is intended to decrease wellbore instability and lower expenses. A higher concentration of *Lawsonia inermis* in the mixture is projected to have a higher adsorption value based on earlier studies.

Many research have been done about converting bentonite into a fertilizer and it is stated that the use of sodium bentonite linked with agricultural wastes is a novel approach to boost bio-compounds with favorable effects on human health, to improve the medical and commercial value of crops, with significant implications for the bio and green economy.

In this research, the effect of *L. inermis* on the swelling of activated calcium bentonite is investigated in order to minimize the cost of activated calcium bentonite as a fertilizer by maximizing its mass. Activated calcium bentonite is used in the experimentation process as it has a higher swelling index with a higher portion of exchangeable sodium and calcium ions. Furthermore, the solution with the highest adsorption value will be predicted to have the greatest swelling value and thus the most productive solution to the issue of mud drilling.

Concentration

Concentration is defined to be the measure of the amount of substance in a defined volume. Various expressions of concentration are present such as molarity, mole fraction and percent composition. In this investigation, concentration will be expressed in terms of percent composition for categorization of the groups. In addition, concentration of each solution was determined systematically with an increasing mass of 10.00 (±0.01) g.

Concentration of each solution will be calculated by the equation below:

$$(m \div V) \times 100$$

m: mass of *Lawsonia inermis* (in terms of g)
V: volume of solution (in terms of mL)

Therefore, the concentrations of the solutions are 2.00%, 4.00%, 6.00%, 8.00% and 10.00% in an increasing order.

Research Question

How does concentration of *Lawsonia inermis* (2.00%, 4.00%, 6.00%, 8.00%, 10.00%) affect the swelling of activated calcium bentonite in aqueous solution at 23.00°C under 100 kPa by measuring conductivity by conductivity probe(siemens/meter)?

Hypothesis

Wellbore instability, defined as time lost due to complications in mud drilling which is caused by changes in the moisture content of the shales. This situation is explained as pore pressure, that is, a significant interaction between pore fluid and rock matrix due to the hydration of clay minerals. It is aimed to reduce wellbore instability and reduce costs by looking at the hydration amount of clay minerals and thus the amount of adsorption and moisture through the adsorption test. According to the previous researches, an increase in the concentration of *Lawsonia inermis* in the mixture is predicted to have higher adsorption value. Hence, wellbore instability decreases when *Lawsonia inermis* concentration increases.

Variables

Independent Variable	
Concentration of *Lawsonia inermis* in *Lawsonia inermis* extract	Different quantities of henna powder (10.00, 20.00, 30.00, 40.00, 50.00g with an uncertainty of 0.01) have been chosen for the experiment and measured up by an electronic scale reading up to 0.01g. 500mL of water was measured up by a graduated cylinder and added to each group to obtain 5 different concentrations (2.00%, 4.00%, 6.00%, 8.00%, 10.00%). Concentration values were given in terms of the mass of *Lawsonia inermis* in the solution.

Dependent Variable	
Adsorption of activated calcium bentonite	After the centrifuging process, the supernatant part(which is the solid residue obtained after the centrifuging process) of the solution will be measured by an electronic balance and the equation stated in ‘Materials and Method section will be utilized to calculate the adsorption value of the solutions. Adsorption of activated calcium bentonite is proportionate to the swelling of activated calcium bentonite.
c°- c value (S/m)	The conductivity values varied for each group and increased as a result of the increasing concentration of *Lawsonia inermis*. The values were measured by a conductivity probe. The values were required as the equation stated in the ‘Method’ section included the change in conductivity to obtain the adsorption value. In the investigation, the solution with higher values of (c°- c) was assumed to have higher adsorption value.

Controlled Variable	
Amount of activated calcium bentonite	2.50 (±0.01) g of activated calcium bentonite is added to each solution. Electronic balance was used in order to measure the mass of activated calcium bentonite.
Temperature	The temperature was kept constant at 23.00 (±0.05) °C during the experimentation process.
Pressure	The experiment was carried out in a laboratory throughout the experiment and the pressure value was constant at 200 kPa meanwhile.
Volume and mass of water in the solution	500.00 (±0.01) mL of water with a temperature of 23.00 (±0.05) °C was used for the solutions made during the experimentation process. The volume was measured up by a graduated cylinder whereas temperature was measured up by a temperature probe throughout the experiment.
Surface Area of the empty cup the solutions are stored in	As the evaporation rate depends on surface area, the variable was kept constant to minimize random error by using identical erlenmeyer flasks with same height, radius and volume values.

Uncontrolled Variable	
The amount of *Lawsonia inermis* precipitated.	While I was preparing the solutions, I observed *Lawsonia inermis* extract in some precipitates. To overcome this issue, I tried to stir the solutions continuously but could not completely prevent the loss in mass when I transferred the solutions from graduated cylinder to Erlenmeyer flask.
Time	During the heating up process of the experiment, the time required for the solution to reach 105.00 (±0.05) °C was not controlled.

Table 3: Independent, dependent, controlled, and uncontrolled variables of the experiment are shown in the table above.

SAFETY, ENVIRONMENT AND ETHICS

Safety

Lawsonia inermis to the keratin in people's skin. Even though it is permanent, it only penetrates the outermost layer of epidermis. As the cells that include the keratin that *Lawsonia inermis* binded to are replaced by newer cells, the color which *Lawsonia inermis* caused fade away. In addition, para-phenylenediamine is frequently present in *Lawsonia inermis* which result in a severe skin reaction with signs that resemble burns, such as redness, swelling, itching, and blistering, and in severe cases, lifelong scarring. Thus, glove usage was prioritized to avoid this circumstance.

The use of glass laboratory materials such as erlenmeyer flask poses a risk in terms of being sharp. In order to reduce the risks of such materials in terms of human health, glassware was kept in places where the risk of falling was the least and attention was paid to the use of aprons, gloves and goggles.

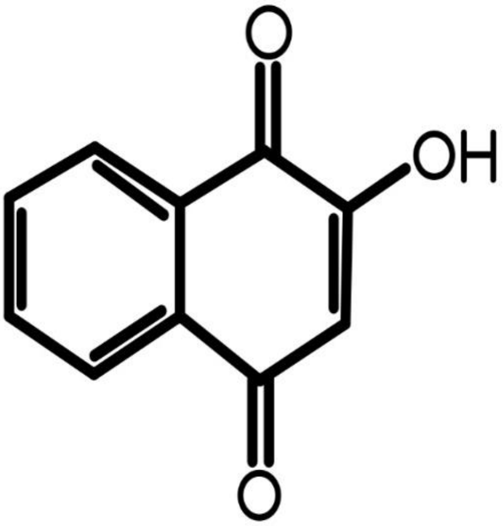

Figure 1: The figure illustrates chemical structure of *Lawsonia inermis*.

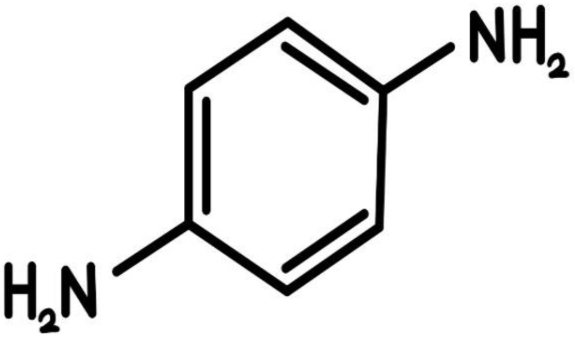

Figure 2: The figure illustrates chemical structure of para-phenylenediamine.

Environment

The wastes generated during the experiment were collected in a bottle and were not released directly into the environment. The wastes were collected in accordance with the laboratory usage rules. Therefore, the experiment did not cause any harm to the environment.

Ethics

The solutions that were prepared for the experiment cannot be reused for another purpose after the experimentation process. Using an excess amount of *Lawsonia inermis* and activated calcium bentonite results in an increase in non-recycable waste.

MATERIALS AND METHOD

Apparatus & Materials Required:

Apparatus/Materials Required	Quantity	Precision
Mortar	1	-
Centrifuge machine	1	-
Graduated Cylinder (50.0 mL)	5	± 0.5 mL
Erlenmeyer flask	5	±0.05 mL
Temperature probe	5	±0.05^{0}C
Glass rod	5	-
Empty cup	5	-
Magnetic Stirrer	5	-
Henna (*Lawsonia inermis*) extract	150.00 g	±0.01 g
Activated Calcium Bentonite	30.00 g	±0.01 g
Tapwater	2500.00 mL	±0.01 mL
Beaker	5	±0.05 mL
Thermometer (reading up to 0.1°C.)	5	±0.05 °C
Laboratory oven	1	±0.1°C
Electronic Balance	1	±0.01°C
Conductivity Probe	1	± 0.01 S/m

Table 4 : The equipment required for the experiment are shown in the table above with their quantity and precision.

Method:

Firstly, a *Lawsonia inermis* plant was used in the experiment and its leaves were dried in a laboratory oven at 25.0 (±0.1)°C. In a mortar, the dried leaves were converted to powder and preserved in a dry cup for 72 hours. An assembly (shown in Figure 1) was set up for each group with different concentration, and the *Lawsonia inermis* quantity measurements stated in the Procedure section were prepared. The assemblies each received 500.00 (±0.01) mL of water and had *Lawsonia inermis* applied to them. After the solutions were added to the assembly, their initial temperatures were recorded by using a thermometer. The initial temperature for each solution was 23.00°C (±0.05). Conductivity of each solution was measured by using conductivity probe. The mixture's temperature was allowed to rise to 105 °C. The heating process was carried out by measuring the change in heat by a temperature probe. When the mixtures reached the desired temperature, 2.5 g of bentonite was added, and each solution was then well stirred for 5 minutes. To homogenize the freshly formed solutions, 100.00 g of each solution were put on magnetic stirrers and swirled for 24 hours. After that, homogenized solutions were divided equally across test tubes and centrifuged for 30 minutes at 10,000 rpm. The swelling quantity of the bentonite was calculated using the following equation after measuring the mass and conductivity of the supernatant collected at the end of this operation. The equation used for the calculations is shown below.

$$q = [(c^{\circ} - c) \times m_{\text{Total Solution}} \times 0.001] \div m_{\text{Sample}}$$

q= Activated calcium bentonite adsorption
c°= *Lawsonia inermis* extract conductivity of the initial solution before the addition of activated calcium bentonite (S/m)
c= *Lawsonia inermis* extract conductivity of the solution after the addition of activated calcium bentonite (S/m)
$m_{\text{Total Solution}}$= Total mass of solution
m_{Sample}= Mass of the supernatant(solid residue after the centrifuging process)

Procedure:

PART A: Preparation of *Lawsonia inermis*

1. Cover the *Lawsonia inermis* leaves with aluminium foil and place it onto the tray and then dry the henna plant in a laboratory oven at 23.00 (±0.05) °C for 12 hours.

2. After drying the leaves in the laboratory oven, grind them in a mortar until it is completely powdered.

3. Preserve the leaves in a dry cup for 72 hours under the sun as well to ensure the leaves are completely dry.

- Henna extract can also be supplied from spice shops if there is limited time for the experimentation process, but I preferred to dry it myself in order to ensure that there are no additives involved in the powder.

PART B: Adsorption Test

A) Preparing different concentrations of *Lawsonia inermis* solutions

1. Weigh different amounts of *Lawsonia inermis* (10.00 (±0.01) g, 20.00 (± 0.01) g, 30.00 (± 0.01) g, 40.00 (± 0.01) g, 50.00 (± 0.01) g) by using electronic balance.
2. Measure 500.00 (±0.01) mL of water by a graduated cylinder and add the specified amount of water to each solution. Weigh each solution and record the initial values.
3. Create five assemblies of clamp, stand and an empty cup. The assembly is illustrated in Figure 3.
4. Pour the solutions into the empty cup. Light the spirit burners with a lighter, the distance between the bottom of the beaker and the tip of the wick must be equal for each assembly to carry out a more controlled experiment. Measure the conductivity of the solution by using conductivity probe.
5. Heat up the solutions to 105.00°C (±0.01), observe he change in temperature by using a temperature probe to have more accurate results.
6. Add 2.50 (±0.01) g of activated calcium bentonite to each of them.

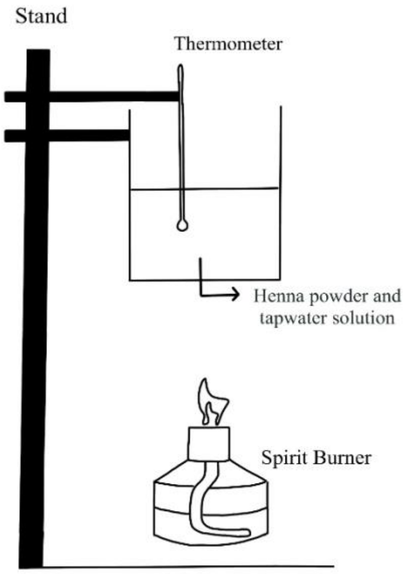

Figure 3: The assembly created for the experiment.

B) Magnetic Stirrer

1. Pour 100.00 (±0.01)g of the solutions into erlenmeyer flask and set the flasks into the magnetic stirrer.
2. Cover the top of the flask with aluminum foil to minimize mass loss.

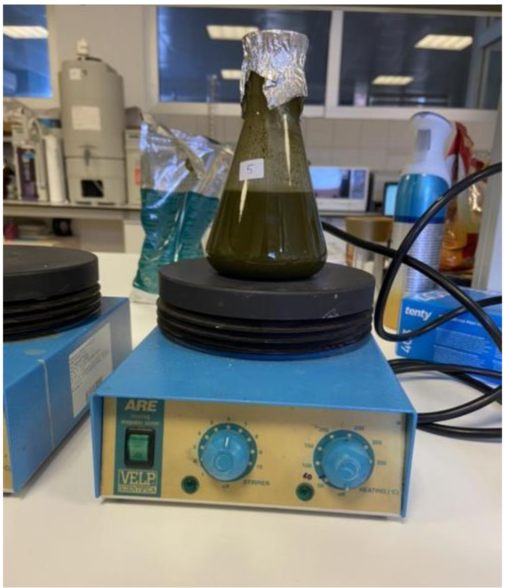

Figure 4: The model of the experiment at the magnetic stirrer step.

C) Centrifuging process

1. Centrifuge 75.00 (±0.01) mL of each solution for 30 minutes at 10,000 rpm.
2. Once the centrifuging process is finished, pour the upper part of the supernatant and dry the supernatant in the laboratory oven for 3 hours at 25.0 °C.
3. Measure the mass and conductivity of the supernatant by using conductivity meter.

DATA COLLECTION

Qualitative Observation

Before choosing the concentration values of the solutions, the observations I have obtained from my preliminary experiments have shown that a solution containing more than 50.00(±0.01) g of *Lawsonia inermis* formed a supersaturated solution and precipitated rapidly. In order to minimize the issue, the solutions were prepared by considering the data of the preliminary experiment. After the values were adjusted, I started with the solution that has the highest concentration of *Lawsonia inermis* (10%). In addition, a magnetic stirrer was used to homogenize each solution and ensure that the precipitation of solution is minimized. When the magnetic stirrer was utilized, it was difficult to find a value that could both stir the solution with the greatest concentration value (10%) and the solution with the least concentration value (2%) without breaking the glass. In addition, the solutions had a brownish color and many bubbles occurred on the surface when they reached 105.00 (±0.05°C).

Quantitative Data:

1. Raw Data

a) **Concentration of 2.00% (10.00 ±0.01 g):**

Mass of *Lawsonia inermis* in the solution (±0.01) g	**Conductivity of the solution before the addition of activated calcium bentonite (c°) (S/m) (±0.01)**	**Conductivity of the solution after the addition of activated calcium bentonite (c) (S/m) (±0.01)**
10.00	52.33	52.29
10.00	52.31	51.97
10.00	52.37	52.03
10.00	52.29	52.18
10.00	52.32	51.99

Table 5: The table above indicates the conductivity of the solution before and after the addition of activated calcium bentonite per trial (in two decimal places) when the mass of *Lawsonia inermis* was kept constant at 10.00 (±0.01) g.

b) **Concentration of 4.00% (20.00 ±0.01 g):**

Mass of *Lawsonia inermis* in the solution (±0.01) g	**Conductivity of the solution before the addition of activated calcium bentonite (c°) (S/m) (±0.01)**	**Conductivity of the solution after the addition of activated calcium bentonite (c) (S/m) (±0.01)**
20.00 (±0.01)	52.33	51.88
20.00 (±0.01)	52.29	52.13
20.00 (±0.01)	52.19	51.74

20.00 (±0.01)	52.27	51.79
20.00 (±0.01)	52.25	51.81

Table 6: The table above indicates the conductivity of the solution before and after the addition of activated calcium bentonite per trial (in two decimal places) when the mass of *Lawsonia inermis* was kept constant at 20.00 (±0.01) g.

c) Concentration of 6.00% (30.00 ±0.01 g):

Mass of *Lawsonia inermis* in the solution (±0.01) g	**Conductivity of the solution before the addition of activated calcium bentonite (c°)(S/m) (±0.01)**	**Conductivity of the solution after the addition of activated calcium bentonite (c) (S/m) (±0.01)**
30.00 (±0.01)	52.13	51.73
30.00 (±0.01)	52.21	51.76
30.00 (±0.01)	52.17	51.93
30.00 (±0.01)	52.15	51.72
30.00 (±0.01)	52.17	51.86

Table 7 : The table above indicates the conductivity of the solution before and after the addition of activated calcium bentonite per trial (in two decimal places) when the mass of *Lawsonia inermis* was kept constant at 30.00 (±0.01) g.

d) Concentration of 8.00% (40.00 ±0.01 g):

Mass of *Lawsonia inermis* in the solution (±0.01) g	**Conductivity of the solution before the addition of activated calcium bentonite (c°) (S/m) (±0.01)**	**Conductivity of the solution after the addition of activated calcium bentonite (c) (S/m) (±0.01)**
40.00 (±0.01)	52.15	51.72
40.00 (±0.01)	52.09	51.58
40.00 (±0.01)	52.10	51.67
40.00 (±0.01)	52.08	51.73
40.00 (±0.01)	52.09	51.60

Table 8 : The table above indicates the conductivity of the solution before and after the addition of activated calcium bentonite per trial (in two decimal places) when the mass of *Lawsonia inermis* was kept constant at 40.00 (±0.01) g.

e) Concentration of 10.00% (50.00 ±0.01 g):

Mass of *Lawsonia inermis* in the solution (±0.01) g	**Conductivity of the solution before the addition of activated calcium bentonite (c°) (S/m) (±0.01)**	**Conductivity of the solution after the addition of activated calcium bentonite (c) (S/m) (±0.01)**
50.00 (±0.01)	52.11	51.51
50.00 (±0.01)	52.07	51.60
50.00 (±0.01)	52.03	51.54
50.00 (±0.01)	52.02	51.55
50.00 (±0.01)	52.13	51.57

Table 9: The table above indicates the conductivity of the solution before and after the addition of activated calcium bentonite per trial (in two decimal places) when the mass of *Lawsonia inermis* was kept constant at 50.00 (±0.01) g.

2. Processed Data:

While measuring the mass of supernatant of each solution, the dried masses of supernatant were combined to get the average value of supernatant mass. Therefore, the average mass value of each solution is given in the table below.

Average Mass Value of the Supernatant Sample for Each Solution

Concentration of Solution (%)	**Average of “m_{Sample}” (±0.01)**
2.00 ±0.10%	2.45
4.00±0.06%	3.11
6.00±0.03%	3.78
8.00±0.03	3.44
10.00±0.03%	3.74

Table 10: The table above indicates the average mass of each solution when the mass of supernatant of the solution is measured.

The solution with a concentration of 2% will be used for the calculations.

Part A: Calculating “c°- c” (S/m)

To calculate the value, the initial conductivity should be subtracted from the final conductivity. In addition, uncertainty values must be added. A sample conclusion for the change in conductivity of the solution with a concentration value of 2% in first trial is calculated by;

Initial conductivity (in trial 1) - final conductivity (in trial 1)

52.33 (±0.01) - 52.29 (±0.01) = 0.04 (±0.02) S/m

The value of “c°- c” for each trial is shown in the table below.

Concentration of Solution - “ c°- c ”

Trials	“c°- c” value of the solution with a concentration of 2.00% S/m (±0.02)	“c°- c” value of the solution with a concentration of 4.00% S/m (±0.02)	“c°- c” value of the solution with a concentration of 6.00% S/m (±0.02)	“c°- c” value of the solution with a concentration of 8.00% S/m (±0.02)	“c°- c” value of the solution with a concentration of 10.00% S/m (±0.02)
I	0.04	0.45	0.40	0.43	0.60
II	0.34	0.16	0.45	0.51	0.47
III	0.34	0.45	0.24	0.43	0.49
IV	0.11	0.48	0.43	0.35	0.47
V	0.33	0.44	0.31	0.49	0.56

Table 11: The table above shows the “c°- c” value for each solution at each trial in two decimal places.

Part B: Finding the Outlier Data

The equations required for the calculation of outlier data are shown below:

Equation 1: Upper boundary (Q_3) + 1.5 × Interquartile Range (Q_3-Q_1) =

$$0.34 + 1.5 \times (0.34 - 0.08) = 0.73$$

Equation 2: Lower Boundary(Q_1) - 1.5 × Interquartile Range (Q_3-Q_1) =

$$0.08 - 1.5 \times (0.34 - 0.08) = -0.31$$

If the value is not between the values that are stated in these two equations, the value is considered to be an outlier data. Outlier data must be excluded from the average in order to increase accuracy and precision.

The value of Equation 1 is 0.73 and the value of Equation 2 is -0.31. The values of "c°- c" are between these values for each trial so there is no outlier data. There was no outlier data found for the other solutions.

Part C: Finding the average of "c°- c" value

The average value will be calculated by the following equation:

Total Value of "c°- c" ÷ Number of Trials

$$[0.04\ (\pm0.02) + 0.34\ (\pm0.02) + 0.34\ (\pm0.02) + 0.11\ (\pm0.02) + 0.33(\pm0.02)] \div 5$$
$$= 0.23\ (\pm0.02)$$

The average of each group is shown in table 12.**Concentration - Average of "c°- c" for each solution**

Concentration of Solution (%)	**Average of "c°- c" (±0.02) S/m**
2.00 ±0.10%	0.23
4.00±0.06%	0.40
6.00±0.03%	0.41
8.00±0.03	0.44
10.00±0.03%	0.51

Table 12: The table above shows the mean of "c°- c" value for each solution in two decimal places.

Part D: Calculating the amount of Activated Calcium Bentonite adsorption

As mentioned before, the equation which will be used for this calculation is:

$$q = [(c° - c) \times m_{\text{Total Solution}} \times 0.001] \div m_{\text{Sample}}$$

$$= [0.23 \times 510.00 \text{ g} \times 0.001] \div 2.450\text{g} = 0.048 \text{ s/m}$$

To find the uncertainty,

1- Percentage error of (c°- c) can be calculated by:

$$(0.02 \div 0.23) \times 100 = 8.7 \%$$

2- Percentage error of $m_{\text{Total Solution}}$ can be calculated by:

$$(0.02 \div 510.00) \times 100 = 0.004 \%$$

3- Percentage error of m_{Sample} can be calculated by:

$$(0.01 \div 2.45) \times 100 = 0.41\ \%$$

Thus, the percentage uncertainties must be summed to obtain an overall percentage error:

$$8.7 + 0.004 + 0.41 = 9.11\ \%$$

- Mass of water can be calculated by multiplying volume and density of water. It is assumed that the mass of water is 500.00 (±0.01)g 500.00 (±0.01) mL of water was used in the experiment and the density of water is 1.00 g/dm^3.

The data is shown in the 'Analysis' section.

CONCLUSION

In conclusion, the experiment and investigation have given an acceptance to the research question: How does concentration of *Lawsonia inermis* (2.00%, 4.00%, 6.00%, 8.00%, 10.00%) affect the swelling of activated calcium bentonite bentonite in aqueous solution at 23.00°C under 100 kPa by using conductivity measured by conductivity meter?

Like what I expected, the adsorption of activated calcium bentonite that is measure in relation with conductivity values, increased with an increase in the concentration of *Lawsonia inermis* in the solution. In addition, the investigation guides to a revolutionary invention in the petroleum industry as it proposes an alternative solution to the issue of increasing costs in mud drilling operations.

Analysis

Concentration - Adsorption

Concentration of Solution (%)	Adsorption related with q (S/m)
2.00 ±0.10%	0.048 ±9.11%
4.00±0.06%	0.067 ±4.02%
6.00±0.03%	0.057±7.53%
8.00±0.03	0.069±7.46%
10.00±0.03%	0.075±6.60%

Table 13: The table above shows the adsorption value for each solution. The data is given in four decimal places to show the significant difference between each group.

Concentration - Percentage Error - Percentage Uncertainty

Concentration of Solution (%)	Percentage Uncertainty (%)
2.00 ±0.10%	9.11
4.00±0.06%	4.02
6.00±0.03%	7.53
8.00±0.03	7.46
10.00±0.03%	6.60

Table 14: The table above shows the percentage percentage uncertainty of each solution with concentrations (2.00%, 4.00%, 6.00%, 8.00%, 10.00%).

As my main intention was to propose a solution to the issue of the increasing costs in petroleum industry due to wellbore instability, I prepared five different solutions and observed the relationship between the concentration of *Lawsonia inermis* extract and the adsorption of activated calcium bentonite.

Although the data may seem to have insignificant results, adsorption value of the same substance cannot usually vary in large amounts and even a slight change in adsorption value is significant. Therefore, the data ranked between the values of 0.048 to 0.075 and proved that the solution with the greatest concentration of *Lawsonia inermis* had the greatest adsorption value.

However, in contrast with the hypothesis, the solution with concentration value 6.0 % had a significant decrease in its adsorption value. This could be because of a random error caused by the precipitation of *Lawsonia inermis* or inaccuracies due to imprecise mass, volume and temperature measurements.

The percentage uncertainty varied between 4.02 and 9.11. These values are caused by random error made during the experiment. As the uncertainty values were non-consistent, it can be interpreted that random errors had a greater impact on the experiment than systematic errors. To obtain more accurate and consistent results, more repetitions could be made and more delicate measuring tools could be used. Moreover, to increase the overall accuracy, some changes could be made on the experiment which are:

- Using a magnetic stirrer in the heating process so that the temperature probe could obtain more accurate temperature data as it could measure the overall temperature of the solution.

- Covering the beaker while it is heated to minimize the systematic error caused by inaccuracies in mass and concentration values.
- Adjusting the temperature probe so that it will not get affected by the temperature of the cup in order to have more accurate, precise and consistent temperature values.

Factors that cause error in the experiment are also shown below.

Error Propagation

	Type of Error	Impact and Solution
Evaporation of Water	Systematic Error	As the water evaporated during the heating up process, the conductivity of the solution changed as the *Lawsonia inermis* concentration of the solution changed. The issue can be minimized by covering the top of the beakers.
Imprecise measurements of mass	Random Error	Imprecise measurements of mass may result in inaccuracies in calculations. To solve the issue, more delicate balance could be used.
Imprecise measurements of volume	Random Error	Imprecise measurements of volume may result in inaccuracies in calculations. To solve the issue, more delicate equipment could be used.
Mass loss due to the transfer of the solution from the cup to the erlenmeyer flask	Systematic Error	While transferring the solutions from the beaker to the erlenmeyer flask for the stirring process to homogenize the mixture, the *Lawsonia inermis* that precipitated during the heating process may have caused inaccuracy in each solution.
Imprecise measurements of temperature	Random Error	Imprecise measurements of temperature may result in inaccuracies in calculations. To solve the issue, more delicate temperature could be used. (A temperature reading up to 0.01°C instead of a temperature reading up to 0.1°C as an example.)

Table 15: The table above shows the types of error and its impact on the experiment. Solution to minimize the error is also given in Table 15.

Evaluation

For the experiment, Lawsonia *inermis* plant's leaves were first dried. The dried leaves were ground into powder and stored for 72 hours in a mortar. The *Lawsonia inermis* quantity measurements specified in the procedure section were prepared, and five identical assemblies were set up. After the conuctivity of each solution was measured, the solution was permitted to reach a temperature of 105°C while being monitored by thermometers in the assembly. Each solution was thoroughly agitated for 5 minutes after 2.5 g of bentonite was added once the solutions reached the proper temperature.

The freshly generated solutions were placed on magnetic stirrers and stirred for 24 hours to homogenize them. Following that, homogenized solutions were evenly divided between test tubes and spun at 10,000 rpm for 30 minutes. After determining the mass and conductivity of the supernatant that was collected at the conclusion of this procedure, the swelling quantity of the bentonite was estimated using the equation that is mentioned in the method.

The results have shown that the solution with highest *Lawsonia inermis* concentration had the greatest conductivity and adsorption. This might be because of porous nature of the absorbent. By adding more *Lawsonia inermis* extract into the solution, the pores in the water are filled and thus conductivity increases as the *Lawsonia inermis* extract in the solution removes hydrogen atoms from the chemical structure of the *Lawsonia inermis* extract constituents. As adsorption is correlated with conductivity, the adsorption level also increases.

As wellbore instability is caused by changes in moisture content of the shales that mud drilling operations take place in, it depends on the porous structure of the fluid and the interaction of it with the rock matrix. When the shale has a low adsorption value, the structure of the fluid becomes more porous and the intermolecular and interatomic interaction between the particles are weaker. Thus, there is more time lost due to complications in mud drilling and wellbore instability increases.

To overcome that problem, a clay mineral (activated calcium bentonite) is hydrated as it is best described as an adsorption isotherm. Furthermore, by observing the adsorption values of activated calcium bentonite in solutions with different concentrations, the data had proven that an increase in *Lawsonia inermis* concentration also increased the adsorption of activated calcium bentonite. Hence, the hypothesis is confirmed as the wellbore instability decreases when *Lawsonia inermis* concentratıın increases. Accordingly, the solution which had a higher adsorption value had stronger intermolecular and interatomic interactions and also had a less porous structure.

Strengths:

Strengths	**Reason**
Repetition and Preliminary Experiment	With the effect of repetition and preliminary experiment, the data that was derived from the Processed Data section of this Extended Essay was precise.
Equipments	The equipment used in the laboratory were advanced which led to less systematic error and thus increased the overall accuracy of the experiment.
Using a Magnetic Stirrer	Using a magnetic stirrer enabled the experiment to minimize the precipitation and have more accurate concentration and mass values.

Table 16: The table above shows the strengths of the experiment.

Weaknesses:

Weaknesses	**Reason**
Inaccurate measurements of mass	Concentration and amount of *Lawsonia inermis* varied and caused uncertainties as the experiment required multiple transfer processes between equipment.
Duration	Since the experimentation time was limited, the solutions were left at the magnetic stirrer assembly for only 24 hours. Increasing that time would increase homogeneity and thus the accuracy.
Evaporation of water	As the water evaporated during the heating up process, there has been inaccuracies in the concentration values and errors in the measurements. The issue can be solved by covering the top of the beaker or using a bomb calorimeter to prevent changes in concentration and volume of water while heating the solutions up.

Table 17: The table above shows the weaknesses of the experiment.

Further Investigation:

The procedure of this experiment could be applied to sodium bentonite and calcium bentonite to compare the amounts of adsorption that were derived from the data. In addition, hair dye could be used instead of *Lawsonia inermis* as they both bind to the outermost layer of our skin. As a result of using hair dye instead of *Lawsonia inermis*, the waste water caused by hair dying process can be used as a source for mud drilling operations. Thus, the hydrological ecosystem will be cleaner and aquatic creatures will not be harmed as a result of water pollution.

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