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Mitigating the Impact of Swelling Clays on Wellbore Permeability in Geothermal Wells: A Case Study of Olkaria Geothermal Field, Kenya

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Abstract
Permeability of a geothermal field is an important parameter in the sustainable utilization of the geothermal fluids. However, one of the major problems experienced at Olkaria is by the presence of swelling clays (smectites), which affect permeability by reducing fluid flow into the wellbore. Olkaria geothermal field is characterized by high quantities of swelling/ smectite clays found in faults that laterally seal potential storage reservoirs. This study aimed at mitigating the overall impact of swelling clays on the well bore permeability in geothermal wells. A quantitative research method was adopted together with an experimental research design. Analysis of data entailed computing both descriptive and inferential statistics. Data on the intensity of swelling clays and well bore permeability was sourced from the lithology information and results of vertical interference testing of existing wells, respectively, as provided by KenGen. On the other hand, data on morphology of the smectite clays was sourced from an investigation of the gathered clays from the sampled wells in the laboratory. Similarly, data on the behavioural trends and effectiveness of the various chemicals was gathered from the results of laboratory tests on the clays gathered from the selected wells. Analysis of the data involved descriptive methods, and ANOVA. The results indicated that different clay types to have different characteristics and morphology. The study revealed a negative association between swelling clays and wellbore permeability. The study, through the ANOVA results concluded that the studied swelling mitigation strategies, namely lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride were significant. However, the study identified lime as the most effective mitigations strategies for improving the wellbore permeability since its effect were significant even in less porous clays.

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I. Introduction

1.1 Background Information

Geothermal resources are distributed within the Earth's crust with energy concentrations that are associated with systems of hydrothermal operations in volcanic areas at crustal plate boundaries (Axelsson, 2013). Olkaria geothermal field is a high-enthalpy geothermal field with temperatures greater than 2000C at depths of around 1000m. The field is associated with a region of quaternary volcanism in the Kenyan Rift valley System as shown in the fig 1.1 below.

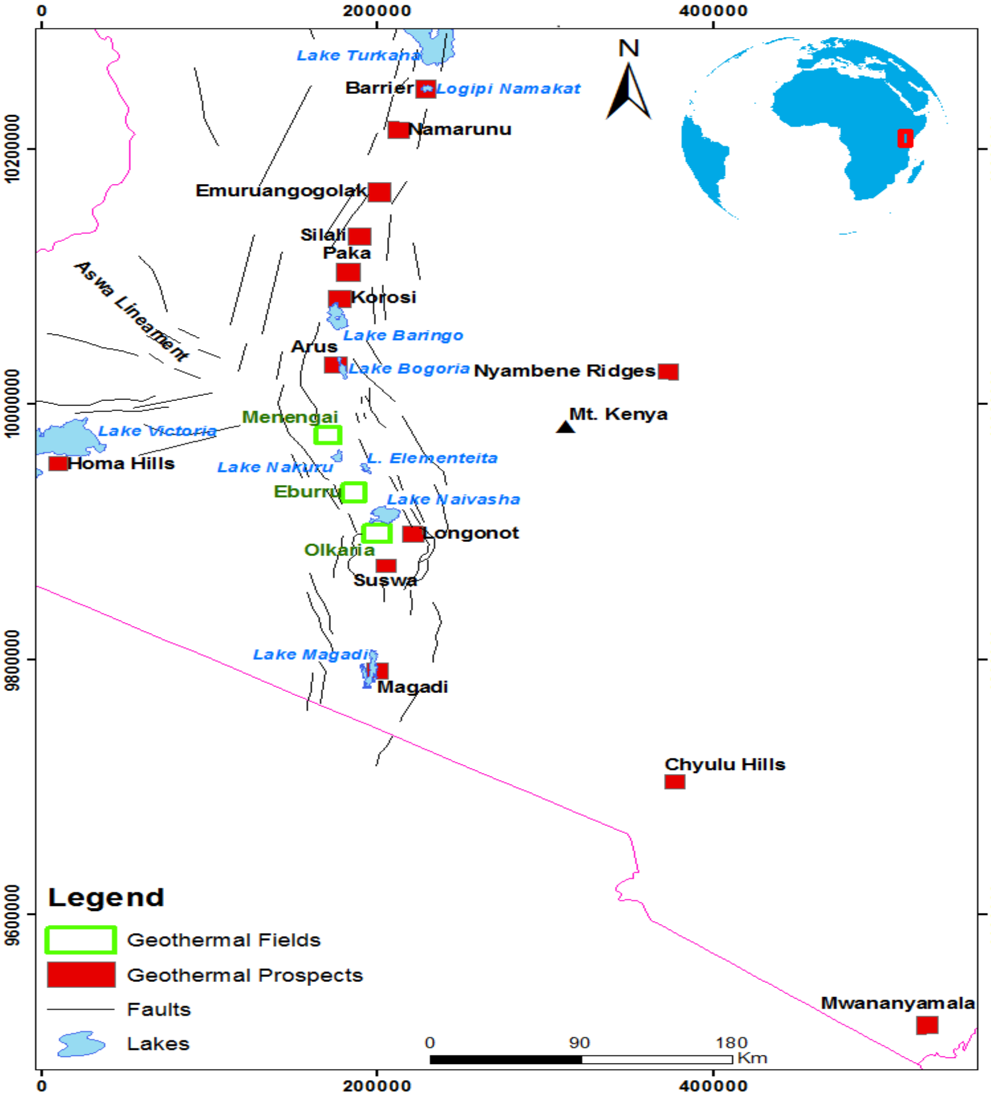

Fig 1.1. Map showing the location of Olkaria volcanic complex and other surroundings volcanic centres in the Kenyas Rift valley System. Source: (Otieno, 2016)

The geothermal resources are found in different countries and occur either as deep circulation systems in crystalline rocks or warm groundwater in sedimentary formations (Lund, & Boyd, 2016). Exploitable geothermal resources at Olkaria began in the early 1980s and continues to date with the number of drilled wells exceeding 200. The drilled wells at Olkaria have depths ranging between 950 and 3200m. The high depth makes the issue of permeability an important topic for geologists in relation to the exploitation of geothermal resources. Over the years, researchers have made numerous attempts to come up with better ways of targeting permeability for geothermal resource utilization. According to Axelsson (2016), the key to the successful utilization of any geothermal resource is correctly siting and designing the wells with a clear understanding and definition of the target attributes. Hence, wells and boreholes are critical components in geothermal research and utilization, because they play a significant role in providing sites for both energy extraction and data gathering.

Geothermal power has been viewed as a cost-effective resource in the Great Rift Valley of Kenya. Kenya was the first country in Africa to build geothermal energy sources. Currently, the country has over 865 MWe of installed geothermal capacity (Omenda & Simiyu, 2015), contributing about 40% to the country’s energy mix. It is important to note that geothermal resource utilization has a prominent place in Kenya’s overarching development plans (Bertani, 2016). Kenya’s plans necessitate the development of the energy generating sector in line with the Kenya Vision 2030 policy. The vision provides an ambitious development programme, which establishes several economic, social and political objectives with the aim of transforming Kenya into a newly industrializing, middle-income country that can provide high quality of life to all its citizens by 2030 in a clean and secure environment (Shortall et al, 2015). Energy generation has a critical role in supporting the development programme. As a result, a major target is for the Kenyan government to ensure there a deliberate switch to clean and sustainable sources of power, and to produce the energy internally without using suppliers from other countries. It is evident that geothermal power has the ability to contribute significantly to meet Kenya's future energy needs.

1.2 Problem Statement

Wellbore instability is a major problem hampering the drilling speed in many geothermal fields (Kahutu, 2016). Complex accidents such as wellbore collapse, sticking, well kick, and lost circulation happen frequently. Tests and theoretical analysis by Ng'ang'a, (2018), reveal that the wellbore instability in the Olkaria geothermal field is influenced by multiple interactive mechanisms dominated by the instability of the bedding shale. Another significant parameter that influences the wellbore stability is the wellbore permeability, which is the average permeability of the entire barrier over a vertical section of the well that is meant to isolate two permeable formations (Atwa, 2018). Generally, as pointed out by Macharia et al (2017), permeability is a broad area of study, particularly in geothermal geology. However, since it is a key parameter of investigation when siting geothermal wells, it is critical to focus on its associated factors to solve the general problem. One of the major permeability problems experienced at Olkaria is usually occasioned by the presence of swelling clays (smectites), which often compromise permeability of wellbore structure (Mwania, 2017). Comprehensive analysis of geological and engineering data in this area indicates that the Olkaria geothermal field is characterized by high quantities of swelling/ smectite clays found in faults that laterally seal potential storage reservoirs. Often, the swelling clays are encountered at shallow depths of less than 700m below the surface (Atwa, 2018). Nonetheless, some unique cases do exist where the swelling clays are encountered at a depth of more than 700m below the surface, like that of well OW-922 located east of Olkaria domes field where such clays were found at a depth of 1200m below the surface (Mwania, 2017). Whenever the swelling/smectite clays are encountered, drilling becomes a challenging exercise, and sometimes the drillers end up experiencing differential sticking. The proposed study will focus on enhancing wellbore stability during drilling, especially in water-sensitive shale and clay formations.

1.3 Research objective

The study aims at mitigating the impact of swelling clays on the well bore permeability in geothermal wells through use of effective mitigation strategies.

1.4 Specific Research Objectives

1. To determine how clays' swelling affects the drilling rate
2. To assess the behavioural trends of swelling clays particularly under wetting conditions
3. To compare the effectiveness of various clay swelling mitigation strategies

1.5 Research Justification

The available literature has inadequate research on how to mitigate the impact of swelling/ smectite clays on the wellbore permeability. Therefore, the findings of the proposed study will be important in attempting to reduce the problems encountered during drilling of geothermal wells in relation to wellbore permeability. It is hoped that the study will help drillers to understand the morphology and behavioural trends of smectite clays particularly under wetting conditions, hence making informed decisions on the drilling techniques, tools to use, and mitigation approaches to adopt. Further, the finding of the study may act as background information for future research works in similar or related topics.

1.6 Study Limitations

The study investigated four geothermal wells in Olkaria, which were selected based on convenience and availability of data. A possible limitation was as a result of possible sampling bias and high possibility of a sampling error (Yin, 2017). Also, the study was limited to the number of chemical additives that were investigated. As stated in the methodology section, the clay stabilizers to be investigated including lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride were significant.

1.7 Study area and research scope

The study was conducted in the Olkaria geothermal area, which is in close proximity to Lake Naivasha. Efforts were made to sample wells which served as good representatives of the various sectors of the Olkaria field. Data from drilling logs of the selected wells were assessed to identify the areas with swelling clays, from which samples of these clays gathered and taken to the laboratory for testing. The permeability of the wells was assessed using the distribution of the feed zones.

II. Literature Review

2.1 The General Geology of the study area

The evolution of the Kenya Rift System (KRS), a complex graben with 40-65 km wide bounded by major rift faults which appear in an echelon arrangement, dates back to the East African orogeny. The rift valley bisects the Kenya's domal uplift, which is superimposed on the eastern margin of the East African plateau. The Kenya Rift System (KRS) extends towards the boundary of Tanzanian Craton and the Pan-African Mozambique shear belt. According to Opondo, (2015) volcanism associated with the Kenyan Rift System started during the Miocene epoch, leading to a widespread basaltic eruption in the Turkana topographic depression, which was described as a failed Mesozoic rift system.

The surface geology of the Olkaria Volcanic Complex is dominated by comenditic lavas, pumice fall, and pyroclastic (Kibet *et al.*, 2019). Significant proportions of the pumice fall and pyroclastic deposits are hypothesized to have originated from Longonot and Suswa volcanoes, which lay approximately 20km east and 40km south of Olkaria Volcanic Complex. On the other hand, the geology of rocks encountered in Olkaria Volcanic Complex, consists of soda rhyolite, grains of quartz and alkali feldspars in the groundmass. Other formations of the rocks consist of pyroclastic, observed as pumiceous tuffs which contain a mixture of rock fragments riebeckite rhyolite, commonly known as trachyte, riebeckite trachyte, intercalations of tuffs/rhryolite, and basalts (Opondo, 2015).

Olkaria is a high-temperature geothermal system found in the central region of the Kenya's Rift Valley which is associated with an area of late Quaternary Rhyolitic volcanism. With the divide through the Olkaria hill, the study area can be separated into two sections namely the East and West stratigraphic zones. Structural, hydrothermal, and geochemical alterations have indicated that the west field is at the margin of the larger Olkaria system. According to Omenda (1998), the anomalous bicarbonate enrichment in the west sector is due to additional absorbed carbon dioxide from the mantle.

In a report by Otieno (2016), a possible reason for the development of obstruction between about 1200-1360m RKB was thought to be the presence of swelling clays. This triggered further research on the geology of the Olkaria area to investigate whether swelling clays were present. As a result, the XRD analysis confirmed the occurrence of swelling clays at zones around the depth of 1300m (Otieno, 2016).

2.2 Properties and behaviours of clay minerals

Clay minerals are small particles belonging to the group of hydrous aluminium silicates with maximum particle dimension of less than 0.005mm. The three main groups of clay minerals are Smectite, kaolinite, and illite. In clay cemented sandstones, montmorillonite which belongs to the smectite group represents 25% of all clays and is important in sandstones due to the reservoir quality issue. Previous research works have considered various clay minerals with different structures. For example, Doi et al (2019), investigated montmorillonite (of the smectite group), and kaolinite (of the kaolinite group), and observed varying behaviours and characteristics. In their report, Doi et al (2019) noted that kaolinite has a 1:1 layer structure, and a small Base Exchange capacity of 3.3 meq/100g. The authors claimed that kaolinite was a non-swelling clay but with the ability to disperse and migrate (Doi et al, 2019). On the contrary, montmorillonite was found to have a 2:1 layer structure, with a large Base Exchange capacity of between 90 and 150 meq/100g. This clay type was found to have the ability to absorb Na+ and other cations, all leading to a high degree of swelling and dispersion. Interlayer cations are variably hydrated, leading to swelling characteristics of smectite clay minerals.

Clays that exhibit changes in volume at varying moisture content are called expansive clays or swelling clays. The capacity of clay to shrink and swell is related to the minerals present, particularly montmorillonite, which swells up to fifteen times its dry volume and generates pressures in excess of 30,000 pounds per square foot. A major factor to consider in drilling wells is the depth of seasonal change of soil moisture and conditions such as porosity of soils that can significantly affect moisture absorption leading to an increase in swelling behaviour of expansive clays.

2.3 Permeability-porosity relationship Models

Previous research work has shown that there exists a relationship between characteristics of the sediment, such as shape, grain, roundness, size, and mineralogy, and permeability. Estimation models that assess the effects of porosity and other rock properties on the permeability have been classified into three groups based on the grain type, surface area, and pore dimensions (Schulz *et al*, 2019).

As stated by Sabet *et al*, (2019), researchers Kozeny and Garman derived the first porosity-permeability relationship. The model included hydraulic tubes and was derived based on the analogy between the flow of fluids through the preferential flow paths in porous media, and the parallel flow through a bundle of tortuous capillary tubes. Equation 2.1 expresses the relationship.

Equation 2.1: The first porosity-permeability relationship

$$\sqrt{\frac{k}{\emptyset}} = \frac{1}{\sqrt{2\tau}\sum g}\frac{\emptyset}{(1-\emptyset)}$$

Where k was the absolute permeability, τ the tortuosity, $\sum g$ the specific grain surface, and $\emptyset$ the porosity. Huang et al., (2019) noted that Krumbein and Monk later made some development of the analytical relationship between permeability and the grain size as well as the shape of the unconsolidated sand. A majority of the empirical studies on the relationship between porosity and permeability using the models revealed that the relationship was linear. For example, Wong *et al* (2017) performed flooding experiments with unconsolidated sand packs where an observation was made that the average permeability values decreased with a decrease in the grain size and poorer sorting in a linear trend. In another study, El Husseiny, and Vanorio, (2016), observed that more spherical grains occupied less pore space and that an increase in the grain angularity led to an increase in porosity.

In numerous publications, the decrease in permeability was associated with the presence of clay. However, the relationship between porosity and permeability for mixed materials, such as clay and sand, are significantly less developed than those for pure sands and clays. In some other findings based on empirical formulas, permeability evolution was shown with the porosity presented in semi-logarithm or power form. However, a majority of such formulas were obtained for samples with very high clay contents of more than 40%, even though a linear relationship was found for lower kaolinite content. Leary et al, (2019), observed that there was a significant power-law correlation of permeability and porosity with the formula shown in the equation 2.2, and suggested n=3 for high porosity samples.

Equation 2.1: Power-law correlation of permeability and porosity

$$k = \sim\emptyset^n$$

On the other hand, Zhao et al, (2018), suggested the empirical formula for assessing the relationship between porosity and permeability within clay samples, which took into account mineral composition of sandstone. The formula is as presented in the equation 2.3.

Equation 2.2: the empirical formula for assessing the relationship between porosity and permeability within clay samples

$$log_{10}k = A_f + 3log_{10}\emptyset - 2log_{10}(1-\emptyset) + \sum B_i M_i$$

Where; M_i was the weight fraction of each mineral component, B_i the constant for each mineral, and A_f the function of feldspar content. The analysis based on this model revealed that clay rich samples produced linear relationships between porosity and permeability only for samples with high porosity of more than 15%. To the contrary non-linear relationship existed between porosity and permeability for samples with low levels of porosity (Zhao et al., 2018).

In conclusion, the review of the permeability-porosity relationship models revealed that many equations were derived empirically, but all of them were very sample-specific. Also, it was revealed that no universal theoretical porosity-permeability relationship existed as a function of clay content.

2.4 Detection methods of clay swelling

Traditionally, quantification of clay swelling was done using the bulk volume method where increment in volume upon aqueous hydration of a small quantity of clay powder was measured, x-ray diffraction (XRD), scanning electron microscopy (SEM), dye staining, and differential thermal analysis (Aksu et al, 2015). As observed in the literature, XRD diffraction was the most common approach for the quantitative analysis of clay minerals in sandstones. The monitoring of the amount of swelling was done using the changes of interlayer spacing of the silicate layers in clay minerals at increasing relative humidity as well as electrolyte concentration.

However, in the recent past, the wet-cell technique has been adopted increasingly in monitoring in situ smectite hydration by XRD (Yanke et al., 2017). Also, there has been significant use of the Fourier Transform Infrared (FTIR) spectroscopy as well as small-angle neutron scattering (SANS) in the measuring of the degree of swelling at molecular levels. On the other hand, a significant majority of scientists have preferred scanning electron microscopy (SEM) method due to its ability to visualize the clay swelling. Nonetheless, the X-Ray micro-computed tomography (μ-CT) has been the method of choice for many scientists in the monitoring of clay swelling in porous media. In the petroleum industry, for example, μ-CT has been accepted as a routine core analysis tool for single and multi-phase flow from macro-scale (between 0.25 and 0.30 mm) to micro-scale (between 5 and 10 μ-m).

In a research by Fontenelle and Hoeman (2017), a highlight of the importance of the distribution of the porosity and permeability along the core samples was made. The authors used μ-CT data to control simulation results that were developed for the water-based drilling fluid injection.

2.5 Summary

The review of the articles on swelling of clay minerals in unconsolidated porous media and its impacts on permeability revealed that the effect of swelling clays on permeability reduction was dependent on the matrix grain size. In a majority of the articles, clay swelling was quantified using X-ray micro-computed tomography. Modelling was done using the swelling coefficient, which was then linked to the permeability reduction in natural samples.

2.6 Research Gap

The previous authors were able to quantify the clay swelling using X-ray micro-computed tomography and use various models to assess the effect of swelling clays on permeability reduction. However, none of them revealed the linear association between swelling clays and wellbore permeability. Hence, the literature lacks a description of the magnitude and direction of the impact of swelling clays on the wellbore permeability. In particular, none of the observed research works focused on the swelling challenges in the geothermal wells. Also, no clear investigations have been done on the morphology of smectite clays as well as the behavioural trends that these clays portray, particularly under wetting conditions. Above all, the existing literature has very little recommendations on how the problem of swelling clays can be mitigated. For example, in a study by Otieno (2016), the drillers through trial and error mitigated the problem by pumping a mixture of 1.75 tonnes of sodium hexametaphosphate [(NaPO3)6] (a dispersant) and 10m^3 of water into the wellbore to help break the clay bonds. While this proved successful, there is no documented evidence in the literature on the effectiveness of the dispersant in mitigating the problem of swelling clays. In particular, there is no information on the most effective chemical additives that can be used to mitigate the impact of swelling clays on the wellbore permeability.

III. Research Methodology

3.1 Research Method

The study adopted a quantitative research method, which entailed the collection of numerical data from the sample wells and from the clays gathered from these wells. The research used standard steps in allowing possibilities for replication and comparison. In addition, the approach allowed for a broader study that involve a greater number of subjects while enhancing the generalization of the results. Further, as put across by Bethea, (2018), quantitative approach allowed for a greater objectivity and accuracy of results in addition to avoiding researcher bias since the investigator is kept at a distance from the reacting systems and processes.

3.2 Target Population

The study targeted a population of all the wells in Olkaria geothermal field in Kenya. Currently Olkaria geothermal field has hundreds of wells distributed across the Olkaria I, II, III, IV and V power stations as described in Figure 3.1.

3.3 Samples and sampling method

The sampling process involved a selection of 4 wells in the Olkaria Geothermal area. The researcher employed a convenient sampling approach based on the availability of data. The wells included OW-45V, OW-737, OW-724B, and OW-205.The method of well selection was a non-probability sampling approach involving the drawing of a sample from the part of the population that is close to hand. The sampling approach was advantageous as it avoided cases of missing data in addition to saving precious time. The study area where the four wells were selected from is described in the Figure 3.1.

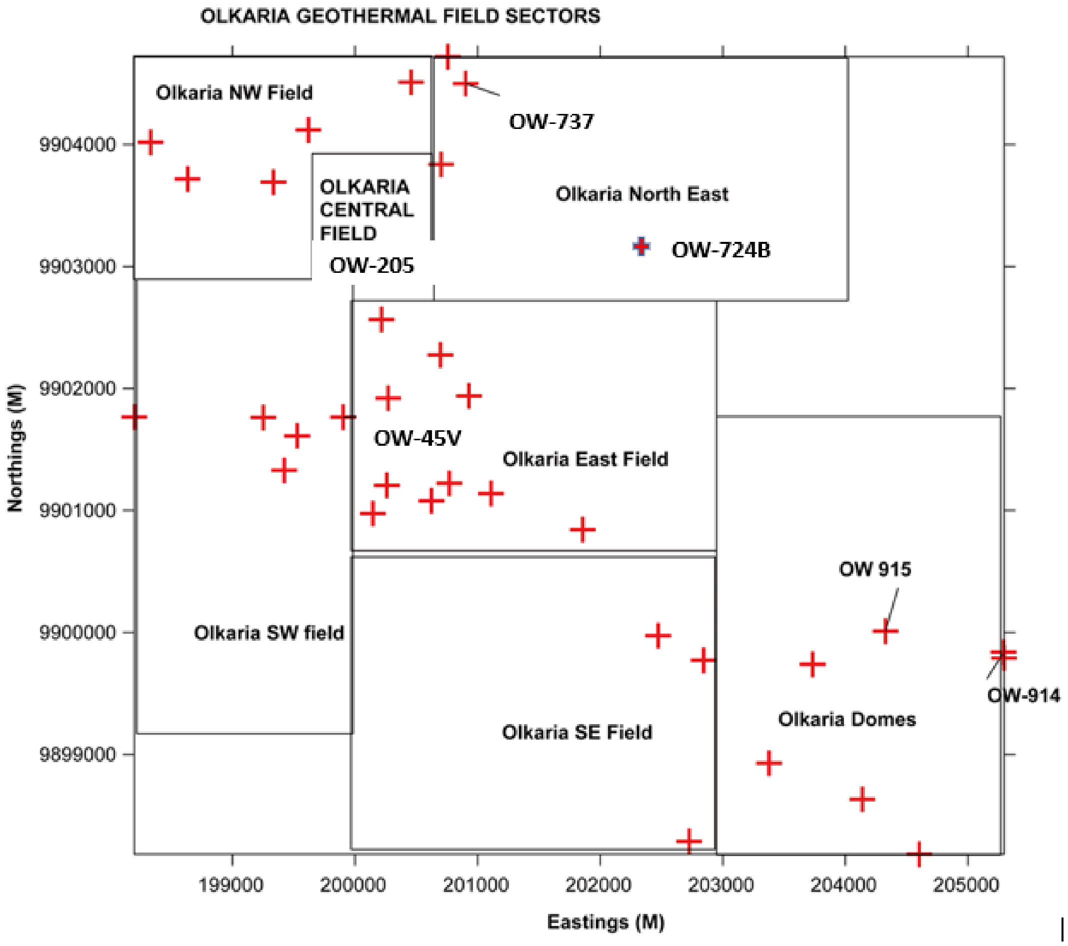

Fig. 3.1: The map of Olkaria Geothermal filed areas showing wells drilled in various fields. Source: (Simiyu & Keller, 2000).

3.4 Design of Experiments

The research design adopted was experimental. This means that the smectite clays gathered from the sampled wells were taken to the laboratory where experiment procedures were undertaken. To begin with, the study designed experiments to assess the behaviour trends of smectite clays under different conditions including wetting conditions (Moore& Lockner, 2007).

3.5 Research Procedures

The research procedure was guided by the three specific objectives. Each objective was achieved through a separate procedure which ensured that the researcher was able to answer the research question.

3.5.1 Specific Objective 1: To determine how clays' swelling affects the drilling rate

The data was gathered from secondary sources. The secondary sources of data included documentations and reports prepared by KenGen. The intensity of swelling clays in geothermal areas was obtained from the lithology data provided by KenGen for various wells in Olkaria geothermal field. Data for well bore permeability was gathered from the drilling report by drillers at KenGen Geothermal offices. Hence, two variables were used for this objective, namely, the intensity of swelling clays (the independent variable), and the drilling rate (the dependent variable.

Analysis to investigate the morphology of smectite clays in various stages of alteration was done using descriptive analysis techniques where comparative analysis was performed. Frequency distribution of the various characteristics of smectite clays was produced for different stages of alteration. Secondly, the researcher run a linear regression model of drilling rate on intensity of the swelling clays to investigate the impact of swelling clays on drilling rate. The regression model fitted to the was of the form;

Equation 3.1: Regression model for investigating the effect of swelling clays on drilling rate

$$y = \beta_0 + \beta_1 x + \varepsilon$$

Where y was the wellbore permeability as measured using the daily drilling rate and x the intensity of swelling clays. The betas represented the model parameters while the epsilon represented the error term in the model.

The justification for the choice of the linear regression model was that the approach was able to reveal the cause-and-effect relationship and the variations in the drilling rate that were explained by the intensity of swelling clays. The technique is most appropriate method of assessing the association between the two variables because it provided both the magnitude and direction of the effect of swelling clays on wellbore permeability.

3.5.2 Specific Objective 2: To assess the behavioural trends of swelling clays particularly under wetting conditions

The data for study's objective number two was gathered from primary sources. The source included KenGen Laboratories where experiments were conducted, Analysis to assess the behavioural trends of smectite clays particularly under wetting conditions was done using experimental research design. The experiments were designed to reveal the behaviour trends after a given period when the clays were subjected to wetting conditions. The researcher conducted several experiments to achieve this objective. The experiments were conducted at the Olkaria Laboratories. The following equipment were used to investigate the specific gravity of swelling clays.

i. Volumetric flask
ii. Digital Balance
iii. Distilled water
iv. Spatula
v. Vacuum pump
vi. Funnel
vii. Drying oven

Experimental procedure for deriving the specific gravity of the swelling clays was as follows.

i. Weight of the volumetric flask (W1)
ii. Fill the flask with water
iii. Weight of the volumetric flask filled with water (W2)
iv. Empty the flask
v. Weigh about 50 g of swelling clay
vi. Carefully put the swelling clay particles into the flask and find its weight (W3)
vii. Fill two thirds of the volumetric flask with water
viii. Apply vacuum and remove the air entrapped.
ix. Remove the vacuum, and add water to fill the flask and find its weight (W4)

The specific gravity was computed by finding the ratio of the weight in air of a given volume of soil particles at a certain temperature to the weight in air of an equal volume of water at the same temperature.

The density of the swelling clays was calculated as;

Equation 3.2: Equation of the density of the swelling clays

$$\rho_s = \frac{(W_3 - W_1) * \rho_w}{(W_2 - W_1) - (W_4 - W_3)}$$

Hence, the study computed the specific gravity for the swelling clays as

Equation 3.3: Equation of the specific gravity for the swelling clays

$$G_s = \frac{\rho_s}{\rho_w}$$

However, a correction was utilized to adjust the results at a reference temperature to enable comparison of the results with those from other studies done in the past and other regions of the world.

Equation 3.4: Equation of the corrected specific gravity for the swelling clays

$$G_{s,K} = G_s * K$$

Where K was the temperature correction factor.

The procedure to investigate the liquid limits and behaviour trends of the swelling clays was as follows.

i. Put solid pastes in cups
ii. Cut grooves at the centre of the soil pastes
iii. Lift the cups and drop them from a height of 10 mm. Observe the water content required to close the distance of 12.7 mm along the bottom of the groove and record the number of blows
iv. Repeat the experiment three times for the same clay samples at different moisture contents

The analysis entailed plotting the moisture content of the clays, in percent, and the associated blows on semi-logarithmic graph. The researcher then drew the line of best-fit to reveal the nature of association. The moisture level that corresponded to N 25, was observed to give the liquid limit of the swelling clays.

The plastic limit test was investigated by repeated rolling of ellipsoidal-sized clay mass by hand on a non-porous surface. The researcher then recorded the water content at which the thread of the clays just crumbled when it was carefully rolled out to a diameter of 3mm(1/8^n). breaking of the threads at diameters greater than 3mm indicated that the clay was drier than the plastic limit.

The study, also performed an experiment to investigate the Shrinkage limit (SL) of the swelling clays. The apparatus used in the experiment included evaporating dish, spatula and straight edge, balance-sensitive to 0.01g minimum, shrinkage dish, glass cup, glass plate, thermostatically controlled oven, wash bottle, graduated glass with a capacity of 25 ml, and mercury.

The experimental procedure included the following steps.

1. For the preparation of clay paste, the researcher took about 100 gm of clay sample from a thoroughly mixed portion of clay material passed through 425-micromilimeter I.S sieve. 30 gm of the clay was placed in the evaporating dish and thoroughly mixed with water to make a creamy paste.
2. The inside of the shrinkage dish was then coated with a thin layer of Vaseline to prevent the soil from sticking to the dish.
3. The dish was filled in three layers by placing approximately a third of the amount of wet clay using spatula for the first layer and the procedure repeated for the second and third layer. This helped in ensuring than the solid clay was filled uniformly with no air bubbles trapped inside.
4. The content was weighed and recorded as weight 1
5. The solid cake was then air dried for 6-8 hours until the pat turned from dark to light, before oven drying the cake at 105-110 degrees Celsius for about 12 hours.
6. The dried disk was removed from the oven and cooled in a desiccator, and then weighed and recorded as weight 2
7. The weight of empty dish was also determined and recorded as weight 3. These weights enabled the researcher to get the weight of the clay samples by subtraction.
8. The volume of dry soil pat was measured by removing it from the shrinkage dish and immersing it in the glass cup full of mercury and measuring the volume of the mercury that spills over.

The shrinkage limit was obtained as

Equation 3.5: Equation of the shrinkage limit

$$Shrinkage\ limit = W \times V \times \frac{\gamma_w}{W_0} \times 100$$

Where; W was the moisture content, V the volume of the clay, γ_w the weight of displaced mercury, and W_0 the weight of oven dry soil pat.

Conversely, the clay swelling pressures were measured using oedometer at Olkaria's Geothermal laboratories. The oedometer tests were performed by applying loads to the clay samples and measuring the deformation response. The results were critical in revealing how the clays in the field would deform in response to a change in effective stress.

3.5.3 Specific Objective 3: To compare the effect of various clay swelling mitigation strategies

Analysis to determine the characteristics of several chemicals for possible applications during drilling was done using ANOVA technique. ANOVA was the most appropriate way to compare the mean effectiveness among more than two chemicals together with the control. In this experiment, clay swelling was quantified by X-ray micro-computed tomography (Aksu, Bazilevskaya, & Karpyn, 2015). The soil mitigation strategies studied in this study were lime, chlorine chloride, tetramethylammonium chloride, and Potassium Chlorides. Experiment to achieve this objective involved compacting soil lime blends, moulded with three district amounts of lime (2%, 4%, and 6%), compacted to three different dry unit weights (14, 15, and 16 KN/cubic meters), and left for 3 hours. The three different dry unit weights (14, 15, and 16 KN/cubic meters) acted as blocking factor, implying that the experiment adopted a complete randomized block design. Also, the researcher moulded other soil balls which did not contain any chemical additives to act as control. The clay swelling was quantified by X-ray micro-computed tomography. A full factorial ANOVA model was fitted to the data with swelling as the dependent variable and lime, chlorine chloride, tetramethylammonium chloride, and Potassium Chlorides as the independent variable. The ANOVA helped in revealing both the treatment effects, the blocking effect and the interaction effects of the two on swelling of clays.

IV. Results And Discussions

4.0 Introduction

In this chapter, the results from the analysis of the collected data are presented and discussed in relation to the study objectives taking into account what is already known from literature. Hence, the chapter provides an important link between the study goals and the conclusions. The chapter is organized into four sub-chapters namely the descriptive statistics, the overall impact of swelling clays on the wellbore permeability, the behavioural trends of swelling clays particularly under wetting conditions, and the effect of various clay swelling mitigation strategies.

4.1 Descriptive statistics

Table 4.1 shows the descriptive statistics results for the drilling rate. The descriptive statistics revealed that the four wells under investigated, namely OW-45V, OW-724B, OW-737, and OW-205, were drilled to a depth of 2951m, 2936m, 2990m, and 2708m, respectively. All these wells were drilled to a depth of less than 3000 meters, which is the expected depth for geothermal wells, implying that there are challenges hindering the drilling process to the expected depth. Also, the drilling duration, for the wells was 76, 116, 117, 76, for the wells OW-45V, OW-724B, OW-737, and OW-205, respectively. All the wells were drilled for a period greater than 50 days, which the planned time for drilling a well at Olkaria. This was an indication that drillers met significant challenges when drilling all the four sampled wells. The overall average drilling depth per day for the four wells was 30.091 meters, which was significantly lower than the planned average depth of 60 meters. The individual wells had mean drilling rates equal to 38.829, 25.310, 25.556, and 35.632 for the wells OW-45V, OW-724B, OW-737, and OW-205, respectively.

Table 4.1: Descriptive statistics

Drilling Rate (depth (m) drilled per day)

	Obs	Means	Std. Deviations	Std. Errors	95% CI for Means		Sums
					L	U	
OW-45V	76	38.829	59.45965	6.82049	25.2418	52.4161	2951.00
OW-724B	116	25.310	34.69229	3.22110	18.9300	31.6907	2936.00
OW-737	117	25.556	38.04318	3.51709	18.5895	32.5216	2990.00
OW-205	76	35.632	56.08014	6.43283	22.8167	48.4464	2708.00
Total	385	30.091	46.22521	2.35586	25.4589	34.7229	11585.00

The significance of the observed difference in the mean drilling rates across the four wells was assessed using a one-way-ANOVA. The result of the ANOVA was presented in table 4.2. The table presents the sum of squares, degrees of freedom, mean sum of squares, and the F-statistic. The analysis produced a computed test statistic equal to F (3,381) =2.075 with a probability value of 0.103. The p-value was greater than 0.05, indicating that the ANOVA test failed to reject the null hypothesis of non-significance. Hence, a conclusion was made that the four wells had equal drilling rates. The results implied that the drilling challenge was common and a major problem across different wells in Olkaria. The intensity of the problem was equal across wells.

Table 4.2: ANOVA table for the comparison of mean drilling rate

Drilling Rate (depth (m) drilled per day)

	Sum of Squares	df	Mean Square	F	Sig.
Between. Groups	13193.641	3	4397.880	2.075	.103
Within. Groups	807326.177	381	2118.966		
Totals	820519.818	384			

4.2 The overall impact of swelling clays on the wellbore permeability

The study first assessed the relationship between the drilling rate and the intensity of the swelling clays in different depth zones across the sampled wells. The results were presented using a scatterplot diagram. From the scatterplot diagram (Fig. 4.1), the points depicted a downward trend with a change in the intensity of swelling clays. The line of best fit had a negative gradient of -15.738 indicating that there was a negative association between drilling rate and the intensity of swelling clays. That is, zones with high intensity of swelling clays were associated with low drilling rates and vice versa.

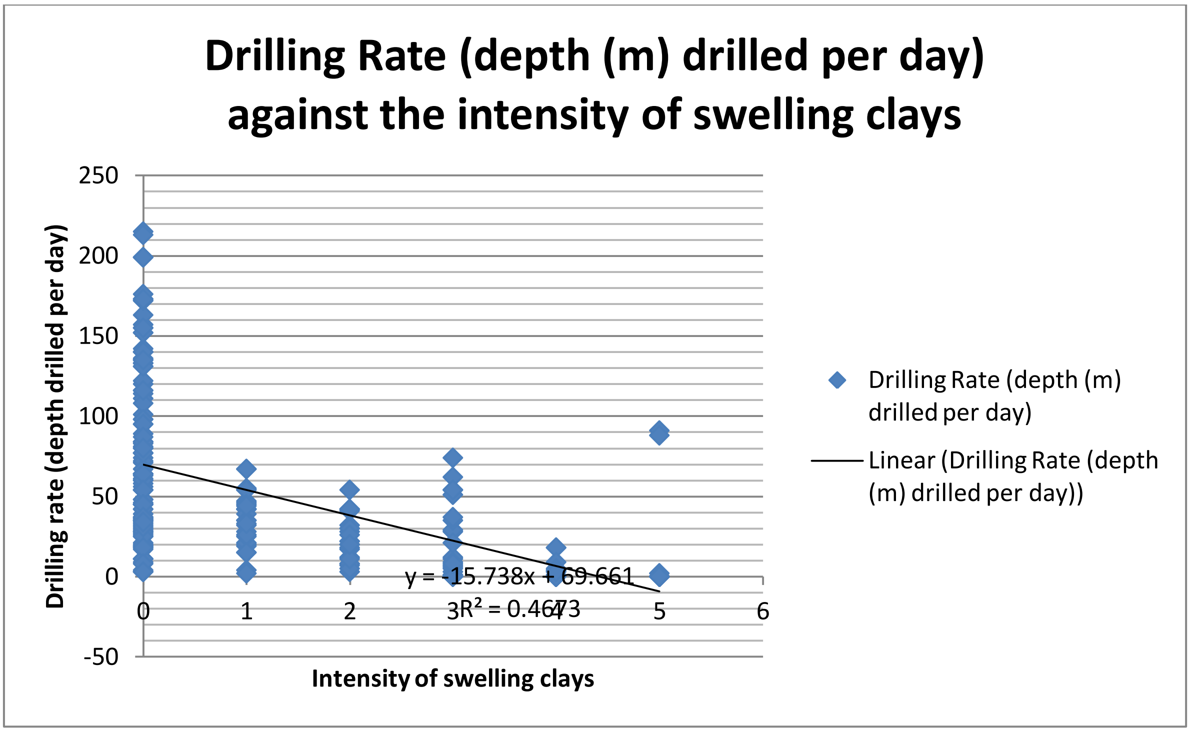

Fig 4.1: A scatterplot diagram for the relationship between swelling clays and wellbore permeability

The study assessed the overall impact of swelling clays on the wellbore permeability through a regression analysis technique where the drilling rate was regressed on intensity of swelling clays. Table 4.3 presented the results of the model summary with major statistics being R and R-squared. The model's summary statistics were equal to 0.684 and 0.467 for the R (coefficient of correlation), and R-square (coefficient of determination). The R-value revealed a moderate correlation (r=0.684) between swelling clays and wellbore permeability as measured using drilling rate. On the other hand, the r-squared value revealed that swelling clays explained 46.7% of the variations in the wellbore permeability.

Table 4.3: Model Summary

Models	R-value	R Square	Adjusted R Square	Std. Error of the Estimate
1	.684	.467	.466	33.78110

a. Predictors: (Constant), Intensity of Swelling Clays

The significance of the fitted model was tested using ANOVA. Table 4.4 shows the results of the ANOVA for the regression model of the drilling rate against intensity of swelling clays. The analysis produced a test statistic equal to F (1, 383) =336.021 with a probability value of p<0.01. The probability value was less than 0.05, implying that the ANOVA test rejected the null hypothesis of non-fitness of the model. Hence, a conclusion was made that the model fit was good, and that intensity of swelling clays could be used to estimate the wellbore permeability.

Table 4.4: Regression Model's ANOVA

Model		Sum of Squares	df	Mean Square	F	P-value
1	Regression	383454.451	1	383454.451	336.021	.000
	Residual	437065.367	383	1141.163		
	Total	820519.818	384			

a. Dependent Variable: Drilling Rate (depth (m) drilled per day)

b. Predictors: (Constant), Intensity of Swelling Clays

The results of the model coefficients produced values equal to 69.661 and -15.738 for the constant and coefficient of the intensity of swelling clays, respectively. Table 4.5 show the results of the model coefficients for the regression of drilling rate against intensity of swelling clays. The coefficients implied that the equation for the regression model was;

Equation 4.1: Regression equation for investigating the effect of swelling clays on drilling rate

$$y = 69.661 - 15.738x$$

Where y was the wellbore permeability as measured using the daily drilling rate and x the intensity of swelling clays. The regression equation suggested that the wellbore permeability is expected to decrease by 15.738 units for a unit change in the intensity of swelling clays. The constant value of 69.661 implied that the average daily drilling rate is expected to be 69.661 meters if the effect of swelling clays was eliminated. The significance of the effect of swelling clays on wellbore permeability was assessed using t-test technique. The analysis obtained a t-statistic equal to -18.331 with a probability value of $p<0.001$. The p-value was less than 0.05, implying that t-test rejected the null hypothesis of non-significance. Hence, the study concluded that the impact of swelling clays on well bore permeability is statistically significant.

Table 4.5: Model's Coefficients analysis results

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Errors	Betas		
1	(Constant)	69.661	2.761		25.229	.000
	Intensity of Swelling Clays	-15.738	.859	-.684	-18.331	.000

a. Dependent Variable: Drilling Rate (depth (m) drilled per day)

4.3 The behavioural trends of swelling clays particularly under wetting conditions

This section presents results of experimental process where the researcher subjected remoulded clay samples, from the selected wells, to full swelling and then allowed them to dry to their initial water content. The procedure was repeated severally to investigate the deformations after each cycle. The results of the physical and mechanical properties of the swelling clays were as presented in the table 4.6.

Table 4.6: The results of the physical and mechanical properties of the swelling clays

Soil Properties	Values
Specific gravity	2.74
Consistency limits	
Liquid limit level (LL)	70.2%
Plastic limit level (PL)	23.3%
Plastic Index value (PI)	46.9%
Shrinkage limit level (SL)	13.4%
Swelling Pressure	121 kPa
Compaction Study	
Optimum Water content	17%
Maximum dry density	1.7 Mg/m^3

The analysis revealed that the swelling clays have a specific gravity of 2.74. This value represented the ratio of the density of the clays to the density of water. According to the available literature, the average specific gravity of soil particles may vary from 2.0 to 3.3 with a mean of around 2.65. Hence, the analysis of the data revealed that the swelling clays have a higher specific gravity than other common soils.

Consistency limits averaged at 70.2%,23.3%, 46.9%, and 13.4% for the liquid limit (LL), plastic limit (PL), plastic index (PI), and shrinkage limit (SL), respectively. The analysis entailed plotting the moisture content of the clays, in percent, and the corresponding number of blows on semi-logarithmic graph. The researcher then drew the best-fit straight line through the plotted points. The moisture content corresponding to N 25, was determined from the curve to give the liquid limit of the swelling clays. The value of the water content corresponding to N 25 was equal to 70.2%, implying that the liquid limit of the swelling clays was 70.2%. The plastic limit of 23.3% revealed the proportion of water content at which the clays changed from the plastic state to a semisolid state. The figure 4.2 shows a scatterplot showing the association between water content and number of blows. The association between water content and number of blows was negative with a gradient of -1.0433.

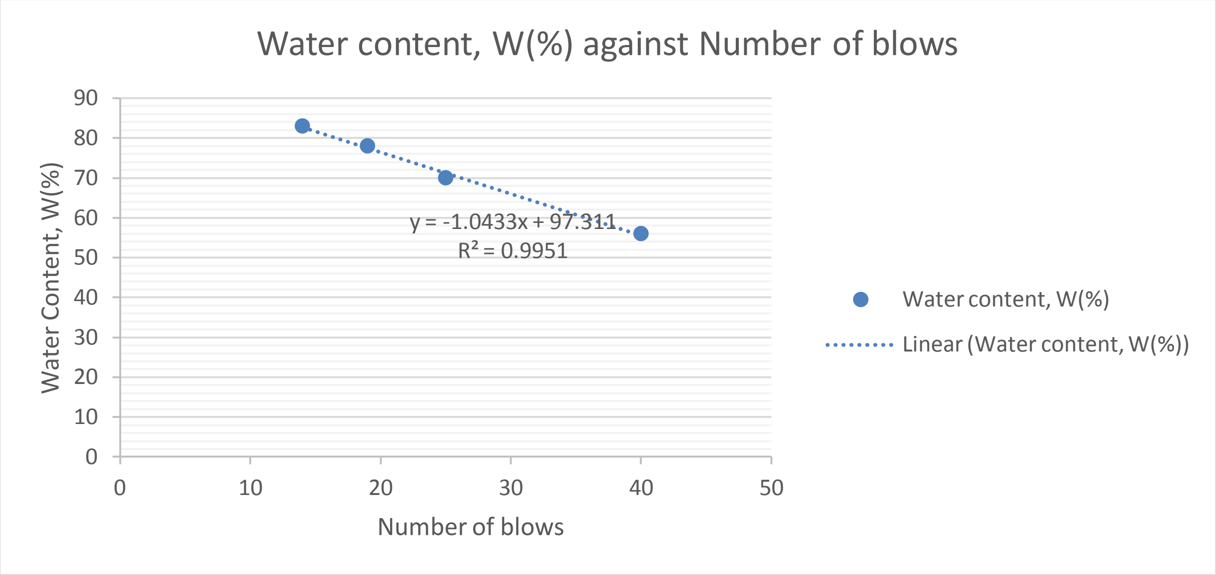

Fig 4.2: Scatterplot showing the association between water content and number of blows

The study revealed a swelling pressure of 120kPa. The swelling pressure was moderate, implying that the clays would swell at different rates if subjected to swelling factors. Other important characteristics assessed in the study included optimum water and dry mass density which had values equal to 18% and 1.6 Mg/m^3.

4.4 The effect of various clay swelling mitigation strategies

4.4.1 ANOVA Results

The study investigated the effect of swelling mitigation strategies across different levels of clay porosity using two-way analysis of variance technique. Table 4.7 shows the result of ANOVA comparing the effects of various mitigation strategies. The ANOVA produced test statistics equal to F (2,45) =177.096 (p-value=<0.001), F (4,45) =45.044 (p-value <0.001), and F (8,45) =2.43 (p-value=0.029) for the treatment effect (swelling mitigation strategies), blocking factor (, and interaction effects, respectively. The p-values for the treatment and blocking factor were less than 0.05. hence, the ANOVA test rejected the null hypothesis on similarity of the mitigation strategies (p<0.05), and similarity of the blocks (p<0.05), leading to a conclusion that mitigation strategies had significantly different effects on swelling index. On the contrary, the ANOVA test failed to reject the null hypothesis for the interaction effect between mitigation strategies (treatments) and porosity (blocks). Hence, a conclusion was made that the interaction effect between mitigation strategies (treatments) and porosity (blocks) was not significant.

Table 4.7: ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatments	985.8333	2	492.9167	177.0958	4.68E-22	3.204317
Blocks (porosity)	501.5	4	125.375	45.04491	3.5E-15	2.578739
Interaction	54	8	6.75	2.42515	0.028527	2.152133
Within	125.25	45	2.783333			
Total	1666.583	59				

4.4.2 Comparison of the clay swelling across different mitigation strategies

Figure 4.3 compared the clay swelling across different mitigation strategies. The descriptive analysis of the clay swelling across different mitigation strategies revealed mean values equal to 6.167 (SD=4.68), 7.58 (SD=4.94), 9.916 (SD=4.58), 7.417 (SD=5.35), and 14.33 (SD=3.14), for the lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride and control respectively. The findings revealed that the most significant mitigation strategies for clay swelling included lime, chlorine chloride, and Potassium Chloride. While tetramethylammonium chloride made noticeable reduction in the swelling nature of the clays, as compared to the control, its effectiveness was less than other three mitigation strategies.

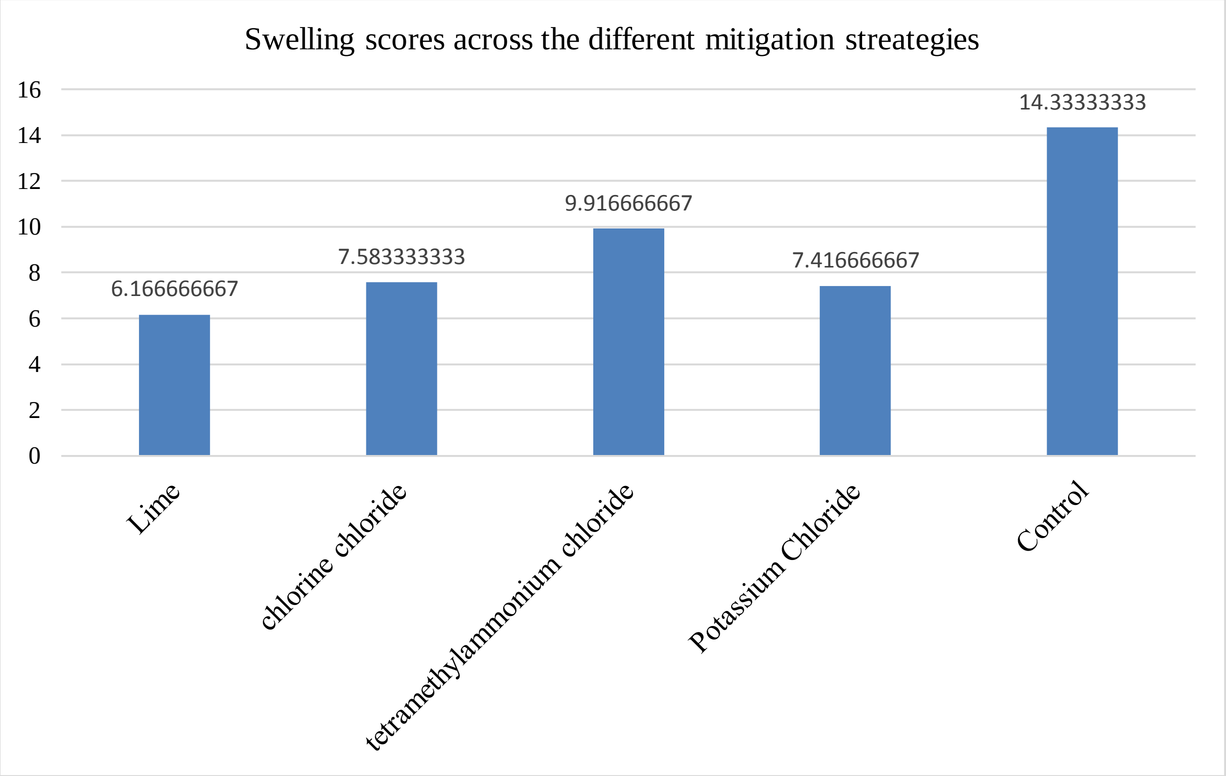

Fig 4.3: Clay swelling levels for different mitigation strategies

4.4.3 Descriptive Analysis of the treatments against the Blocking Factor (Soil Porosity)

The analysis of the different mitigation strategies (treatments) on clays with low levels of porosity (compacted to 16 KN/cubic meters), produced mean swelling levels of 12.25, 13.75, 15, 14, and 17.5 for the lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride and control respectively. The findings revealed that for less porous clays the mitigation strategies were not effective in controlling swelling. The means for the four mitigation strategies were almost equal to that of the control group. It can be argued that when the clays are less porous, the penetration of the chemicals is low hindering the ability by chemical additives to yield significant results.

Conversely, the analysis of the different mitigation strategies (treatments) on clays with moderate levels of porosity (compacted to 15 KN/cubic meters), produced mean swelling levels of 4.25, 6.25, 9.75, 5.25, and 14.5 for the lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride and control respectively. The findings revealed that for clays with moderate porosity, the mitigation strategies had almost equal effectiveness in controlling swelling although lime had significantly higher effect. Explanation to this was that lime increased the calcium and magnesium ions which substituted for sodium and potassium ions in the clay. Since the later have little dependence on water, they improved clay properties, decreasing swelling. On the other hand, porosity allows more water to be absorbed withing the clay particles, increasing the chances for swelling. It was argued that porosity increased the water proportions leading to an influence in the diffusion of cations, anions, and neutral molecules which led to increased swelling. However, the means for the four mitigation strategies were significantly lower than the mean of the control group. The results implied that there was still sufficient penetration of the chemicals for moderately porous clays. The second most effect chemical in mitigating the effect of swelling clays was Potassium chloride. The liquid potassium chloride was easy to apply and cheap and has widely been used in the drilling of oil wells. However, research show that potassium chloride, and other simple organic compounds such as $CaCl2$ are weak and temporary. Hence, they cannot be applied with steam either, or cannot perform best when mitigating areas with high temperatures like in the drilling of geothermal wells.

Table 4.8 shows the results of the swelling levels of clays subjected to different mitigation strategies under different porosity levels.

The analysis of the different mitigation strategies (treatments) on clays with high levels of porosity (compacted to 14 KN/cubic meters), produced mean swelling levels of 2, 2.75, 5, 3, and 11 for the lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride and control respectively. The findings revealed that for porous clays' the mitigation strategies had very significant effectiveness levels in controlling swelling. The means for the four mitigation strategies were significantly lower than the mean of the control group. It can be argued that when the clays are porous, the penetration of the chemicals is high enabling all the chemical additives to yield significant results.

Table 4.8: The swelling levels of clays subjected to different mitigation strategies under different porosity level

SUMMARY	Lime	chlorine chloride	tetramethylammonium chloride	Potassium Chloride (KCl)	Control	Total
16 KN/cubic meters (low porosity)						
Count	4	4	4	4	4	20
Sum	49	55	60	56	70	290
Average	12.25	13.75	15	14	17.5	14.5
Variance	0.916667	0.25	0.666667	3.333333	1.666667	4.263158
15 KN/cubic meters *(moderate porosity)*						
Count	4	4	4	4	4	20
Sum	17	25	39	21	58	160
Average	4.25	6.25	9.75	5.25	14.5	8
Variance	1.583333	4.916667	2.916667	10.25	1.666667	18.10526
14 KN/cubic meters *(High porosity)*						
Count	4	4	4	4	4	20
Sum	8	11	20	12	44	95
Average	2	2.75	5	3	11	4.75
Variance	0.666667	0.25	6.666667	1.333333	4.666667	13.46053

V. Conclusions and Recommendation

5.1 Conclusions

The study concludes that, indeed, there was a significant drilling challenge when drilling Olkaria wells. All the well were drilled to depth less than 3000 meters, the expected depth for geothermal wells, implying that there are challenges hindering the drilling process to the expected depth. Also, all the wells were drilled for a period greater than 50 days, the planned time for drilling a well at Olkaria. This was an indication that drillers met significant challenges when drilling all the four sampled wells leading to prolonged drilling time. Above all, the overall average drilling depth per day for the four wells was 30.091 meters, which was significantly lower than the planned average depth of 60 meters. The ANOVA results revealed that there was no difference in the mean drilling rates across the four wells. The results led to a conclusion that the drilling challenge was common and a major problem across different wells in Olkaria. The intensity of the problem was equal across wells. Since the wells were sampled randomly across the entire Okaria Area, it can be argued that the entire Olkaria field has soil characteristics that pose challenges to drillers.

The study concluded that there was a significant and negative impact of swelling clays on the wellbore permeability. From the scatter plot diagram, the line of best fit had a negative gradient of -15.738 indicating that there was a negative association between drilling rate and the intensity of swelling clays. That is, zones with high intensity of swelling clays were associated with low drilling rates and vice versa. The study, through the regression analysis of drilling rate against the intensity of swelling clays, revealed a moderate correlation ($r=0.684$) between swelling clays and wellbore permeability as measured using drilling rate. On the other hand, the r-squared value revealed that swelling clays explained 46.7% of the variations in the wellbore permeability. The regression ANOVA yielded significant results, leading to a conclusion that the model fit was good, and that intensity of swelling clays could be used to estimate the wellbore permeability. According to the study, the wellbore permeability is expected to decrease by 15.738 units for a unit change in the intensity of swelling clays. The significance of the effect of swelling clays on wellbore permeability was assessed using t-test technique. The analysis obtained a t-statistic equal to -18.331 with a probability value of $p<0.001$. The p-value was less than 0.05, implying that t-test rejected the null hypothesis of non-significance. Hence, the study concluded that the impact of swelling clays on well bore permeability is statistically significant. Hence, the study revealed that fine-grained soils that expand when in contact with water can be a major issue in the geotechnical situations.

Regarding the behavioural trends of welling clays, the study concluded that the swelling clays have a swelling gravity of 2.74. This value represented the ratio of the density of the clays to the density of water. According to the available literature, the average specific gravity of soil particles may vary from 2.0 to 3.3 with a mean of around 2.65. Hence, the analysis of the data revealed that the swelling clays have a higher specific gravity than other common soils. Consistency limits averaged at 70.2%,23.3%, 46.9%, and 13.4% for the liquid limit (LL), plastic limit (PL), plastic index (PI), and shrinkage limit (SL), respectively. The liquid limit of the swelling clays was equal to 70.2%. The plastic limit of 23.3% revealed the proportion of water content at which the clays changed from the plastic state to a semisolid state. The association between water content and number of blows was negative with a gradient of -1.0433.

The study, through the ANOVA results, concluds that the studied swelling mitigation strategies, namely lime, chlorine chloride, tetramethylammonium chloride, Potassium Chloride were significant in controlling swelling of clays. Also, the effect of these chemical additives varied significantly across clay porosity levels. On the contrary, the ANOVA test failed to reject the null hypothesis for the interaction effect between mitigation strategies (treatments) and porosity (blocks). Hence, a conclusion is made that the interaction effect between mitigation strategies (treatments) and porosity (blocks) was not significant. According to the study, the most significant mitigation strategies for clay swelling included lime, chlorine chloride, and Potassium Chloride. While tetramethylammonium chloride made noticeable reduction in the swelling nature of the clays, as compared to the control, its effectiveness was less than other three mitigation strategies.

The analysis of the different mitigation strategies (treatments) on clays with low levels of porosity (compacted to 16 KN/cubic meters), revealed that for less porous clays the mitigation strategies were not effective in controlling swelling. The means for the four mitigation strategies were almost equal to that of the control group. It can be argued that when the clays are less porous, the penetration of the chemicals is low hindering the ability by chemical additives to yield significant results. However, the analysis of the different mitigation strategies (treatments) on clays with moderate levels of porosity (compacted to 15 KN/cubic meters), revealed that for clays with moderate porosity, the mitigation strategies had almost equal effectiveness in controlling swelling although lime had significantly higher effect. Explanation to this was that lime increased the calcium and magnesium ions which substituted for sodium and potassium ions in the clay. Since the later have little dependence on water, they improved clay properties, decreasing swelling. Porosity allows more water to be absorbed withing the clay particles, increasing the chances for swelling. It was argued that porosity increased the water proportions leading to an influence in the diffusion of cations, anions, and neutral molecules which led to increased swelling. However, the means for the four mitigation strategies were significantly lower than the mean of the control group. The results implied that there was still sufficient penetration of the chemicals for moderately porous clays. The second most effect chemical in mitigating the effect of swelling clays was Potassium chloride. The liquid potassium chloride was easy to apply and cheap and has widely been used in the drilling of oil wells. However, research show that potassium chloride, and other simple organic compounds such as $CaCl2$ are weak and temporary. Hence, they cannot be applied with steam either, or cannot perform best when mitigating areas with high temperatures like in the drilling of geothermal wells.

Similarly, the study, through the analysis of the different mitigation strategies (treatments) on clays with high levels of porosity (compacted to 14 KN/cubic meters) revealed that for porous clays' the mitigation strategies had very significant effectiveness levels in controlling swelling. The means for the four mitigation strategies were significantly lower than the mean of the control group. It can be argued that when the clays are porous, the penetration of the chemicals is high enabling all the chemical additives to yield significant results. While chlorine chloride was considered effective at high concentrations, a bad odour of ammonia was noted during mixing of chlorine chloride with HCl acid, leading to the classification of the strategy as environmentally unfriendly.

5.2 Recommendation

The study recommends that drillers in Olkaria should be prepared to expect drilling challenges related to swelling clays whenever they venture new sites. Therefore, drillers should prepare the right tools for unsticking pipes due to swelling. Besides, the study revealed that application of lime was a significant mitigation strategy for the problem related to swelling clays. Hence, the drillers should use lime to lower the swelling intensity whenever they encounter swelling clays related challenges.

Further, future researchers should expand the research by investigating other potential mitigation strategies. Also, future research should adopt regression techniques to understand the individual and joint impact of the effects of various mitigation strategies on wellbore permeability.

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Appendix

Data on swelling clays intensity and Drilling rate

Well	**Intensity of Swelling Clays**	**Drilling Rate (depth (m) drilled per day)**	Well	**Intensity of Swelling Clays**	**Drilling Rate (depth (m) drilled per day)**
OW-45V	0	3	**OW-737**	0	58
OW-45V	0	45	**OW-737**	0	28
OW-45V	4	18	**OW-737**	5	0
OW-45V	5	0	**OW-737**	5	0
OW-45V	5	0	**OW-737**	2	22
OW-45V	5	0	**OW-737**	2	20
OW-45V	4	18	**OW-737**	1	32

OW-45V	5	0	**OW-737**	1	35
OW-45V	5	0	**OW-737**	1	47
OW-45V	5	0	**OW-737**	1	67
OW-45V	5	0	**OW-737**	0	120
OW-45V	5	0	**OW-737**	5	0
OW-45V	0	3	**OW-737**	5	0
OW-45V	0	25	**OW-737**	5	0
OW-45V	0	101	**OW-737**	5	0
OW-45V	0	48	**OW-737**	5	0
OW-45V	0	9	**OW-737**	2	22
OW-45V	0	21	**OW-737**	1	26
OW-45V	2	8	**OW-737**	1	55
OW-45V	4	0	**OW-737**	1	54
OW-45V	4	0	**OW-737**	4	0
OW-45V	4	0	**OW-737**	4	0
OW-45V	4	0	**OW-737**	4	0
OW-45V	4	0	**OW-737**	4	0
OW-45V	3	11	**OW-737**	4	0
OW-45V	2	30	**OW-737**	4	0
OW-45V	0	26	**OW-737**	4	0
OW-45V	0	20	**OW-737**	4	0
OW-45V	4	0	**OW-737**	4	0
OW-45V	0	77	**OW-737**	4	0
OW-45V	0	140	**OW-737**	4	0
OW-45V	0	157	**OW-737**	4	3
OW-45V	0	116	**OW-737**	4	4
OW-45V	0	77	**OW-737**	4	1
OW-45V	5	0	**OW-737**	5	91
OW-45V	5	0	**OW-737**	5	88
OW-45V	5	0	**OW-737**	3	28
OW-45V	5	0	**OW-737**	3	29
OW-45V	5	0	**OW-737**	3	7
OW-45V	5	0	**OW-737**	2	42
OW-45V	5	0	**OW-737**	1	33
OW-45V	5	0	**OW-737**	1	45
OW-45V	5	0	**OW-737**	5	0
OW-45V	5	0	**OW-737**	5	0
OW-45V	5	0	**OW-737**	5	0
OW-45V	5	0	**OW-737**	5	0
OW-45V	5	2	**OW-737**	5	0

OW-45V	0	155	**OW-737**	5	0
OW-45V	0	36	**OW-737**	5	0
OW-45V	0	98	**OW-737**	5	0
OW-45V	0	142	**OW-737**	5	0
OW-45V	0	95	**OW-737**	0	67
OW-45V	0	172	**OW-737**	0	133
OW-45V	0	215	**OW-737**	0	64
OW-45V	0	199	**OW-737**	0	60
OW-45V	0	173	**OW-737**	4	0
OW-45V	0	131	**OW-737**	4	0
OW-45V	0	176	**OW-737**	4	0
OW-45V	0	135	**OW-737**	0	28
OW-45V	0	80	**OW-737**	0	152
OW-45V	0	35	**OW-737**	0	4
OW-45V	3	0	**OW-737**	0	19
OW-45V	3	0	**OW-737**	0	45
OW-45V	2	3	**OW-737**	0	89
OW-45V	0	37	**OW-737**	0	111
OW-45V	0	3	**OW-737**	0	163
OW-45V	0	37	**OW-737**	0	35
OW-45V	0	74	**OW-737**	4	0
OW-45V	4	0	**OW-737**	4	0
OW-45V	4	0	**OW-737**	4	0
OW-45V	4	0	**OW-737**	2	42
OW-45V	4	0	**OW-737**	1	15
OW-45V	4	0	**OW-737**	0	122
OW-45V	4	0	**OW-737**	0	135
OW-45V	4	0	**OW-737**	0	42
OW-45V	4	0	**OW-737**	0	19
OW-724B	0	28	**OW-737**	4	0
OW-724B	0	17	**OW-737**	0	84
OW-724B	4	0	**OW-737**	0	25
OW-724B	4	0	**OW-737**	0	54
OW-724B	4	0	**OW-737**	0	64
OW-724B	0	27	**OW-737**	0	32
OW-724B	0	18	**OW-737**	3	0
OW-724B	0	11	**OW-737**	3	0
OW-724B	0	11	**OW-737**	3	0
OW-724B	0	30	**OW-737**	3	0
OW-724B	0	133	**OW-737**	3	0

OW-724B	0	199	**OW-737**	3	0
OW-724B	5	0	**OW-737**	3	0
OW-724B	5	0	**OW-737**	3	0
OW-724B	5	0	**OW-737**	3	74
OW-724B	5	0	**OW-737**	3	62
OW-724B	5	0	**OW-737**	3	54
OW-724B	3	51	**OW-737**	2	12
OW-724B	2	54	**OW-737**	2	42
OW-724B	3	0	**OW-737**	0	108
OW-724B	2	17	**OW-737**	0	54
OW-724B	4	0	**OW-737**	0	18
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	0	**OW-737**	5	0
OW-724B	4	4	**OW-737**	5	0
OW-724B	4	0	**OW-737**	4	5
OW-724B	4	9	**OW-737**	4	0
OW-724B	4	0	**OW-737**	4	0
OW-724B	1	28	**OW-737**	4	0
OW-724B	0	29	**OW-737**	4	0
OW-724B	2	7	**OW-737**	4	0
OW-724B	1	42	**OW-737**	4	0
OW-724B	0	33	**OW-737**	4	0
OW-724B	0	45	**OW-737**	4	0
OW-724B	0	11	**OW-205**	0	45
OW-724B	2	8	**OW-205**	0	31
OW-724B	1	20	**OW-205**	0	8
OW-724B	2	5	**OW-205**	4	0
OW-724B	1	46	**OW-205**	4	0
OW-724B	0	56	**OW-205**	4	0
OW-724B	4	0	**OW-205**	4	0
OW-724B	4	0	**OW-205**	4	0
OW-724B	4	0	**OW-205**	4	0
OW-724B	0	46	**OW-205**	4	0

OW-724B	0	114	**OW-205**	4	0
OW-724B	0	64	**OW-205**	4	0
OW-724B	0	60	**OW-205**	4	0
OW-724B	4	0	**OW-205**	3	12
OW-724B	4	0	**OW-205**	3	54
OW-724B	4	0	**OW-205**	3	35
OW-724B	2	28	**OW-205**	3	9
OW-724B	0	152	**OW-205**	3	21
OW-724B	1	4	**OW-205**	3	8
OW-724B	1	19	**OW-205**	5	0
OW-724B	0	45	**OW-205**	5	0
OW-724B	1	21	**OW-205**	5	0
OW-724B	0	71	**OW-205**	5	0
OW-724B	0	63	**OW-205**	5	0
OW-724B	0	35	**OW-205**	2	11
OW-724B	5	0	**OW-205**	2	30
OW-724B	5	0	**OW-205**	2	26
OW-724B	5	0	**OW-205**	2	20
OW-724B	0	39	**OW-205**	2	20
OW-724B	1	15	**OW-205**	1	44
OW-724B	3	1	**OW-205**	0	140
OW-724B	1	35	**OW-205**	0	136
OW-724B	0	42	**OW-205**	0	116
OW-724B	0	19	**OW-205**	0	77
OW-724B	5	0	**OW-205**	4	0
OW-724B	0	84	**OW-205**	4	0
OW-724B	1	25	**OW-205**	4	0
OW-724B	1	54	**OW-205**	4	0
OW-724B	0	64	**OW-205**	4	0
OW-724B	2	32	**OW-205**	4	0
OW-724B	4	0	**OW-205**	4	0
OW-724B	1	67	**OW-205**	4	0
OW-724B	0	84	**OW-205**	4	0
OW-724B	0	64	**OW-205**	4	0
OW-724B	0	54	**OW-205**	4	0
OW-724B	0	48	**OW-205**	4	0
OW-724B	5	0	**OW-205**	1	2
OW-724B	1	42	**OW-205**	0	155
OW-724B	0	61	**OW-205**	0	36
OW-724B	0	54	**OW-205**	0	98

OW-724B	4	0	**OW-205**	0	140
OW-724B	3	3	**OW-205**	0	95
OW-724B	1	42	**OW-205**	0	172
OW-724B	3	1	**OW-205**	0	213
OW-724B	3	6	**OW-205**	0	199
OW-724B	2	18	**OW-205**	0	173
OW-724B	5	0	**OW-205**	0	131
OW-724B	5	0	**OW-205**	0	87
OW-724B	5	0	**OW-205**	0	135
OW-724B	5	0	**OW-205**	0	80
OW-724B	2	41	**OW-205**	0	35
OW-724B	1	39	**OW-205**	4	0
OW-724B	0	83	**OW-205**	4	0
OW-724B	0	81	**OW-205**	4	3
OW-724B	0	72	**OW-205**	3	37
OW-724B	4	0	**OW-205**	0	3
OW-724B	3	5	**OW-205**	0	37
OW-724B	4	0	**OW-205**	0	34
OW-724B	4	0	**OW-205**	5	0
OW-724B	4	0	**OW-205**	5	0
OW-724B	4	0	**OW-205**	5	0
OW-724B	4	0	**OW-205**	5	0
OW-724B	4	0	**OW-205**	5	0
OW-724B	4	0	**OW-205**	5	0
OW-724B	4	0	**OW-205**	5	0
			OW-205	5	0

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