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Scale Reduction In Oil Pipes Using Pineapple Peel Acetic Acid and Hcl: A Laboratory Study

Novrianti[1] , Arjun Anggara P[1] , Neneng Purnamawati[1], and M. Ridha Fikri[1,2]

[1] Department of Petroleum Engineering, School of Engineering,
Universitas Islam Riau 113 Kaharuddin Nst Street, Pekanbaru, Indonesia.

[2] Department of Petroleum Engineering, School of Mining and Petroleum Engineering,
Institut Teknologi Bandung 10 Ganesha Street, Lb, Siliwangi, Coblong District, Bandung City,
West Java, 40132, Indonesia.

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ABSTRACT

The reduction in oil production rates due to the formation of calcium carbonate ($CaCO_3$) scale deposits on production pipes is a common problem in upstream oil and gas operations. This study aims to evaluate the effectiveness of acetic acid produced from pineapple peel fermentation, alone and in combination with hydrochloric acid (HCl), as an organic-based scale-removal agent, with EDTA-2Na used as a comparison via chelation. The research methods included acetic acid extraction via two-stage fermentation, characterization of functional groups by infrared spectroscopy (FTIR), and analysis of mineral scale composition by X-ray fluorescence (XRF). Scale testing was carried out using the weight-loss method with immersion times of 30, 60, and 90 minutes. FTIR results showed the presence of characteristic organic acid functional groups, while XRF results confirmed that the scale was dominated by calcium as the main component of $CaCO_3$. The test results showed that the mixture of acetic acid and HCl provided the highest effectiveness with a mass loss of 0.43 grams at 90 minutes, followed by pure acetic acid at 0.36 grams, while EDTA-2Na produced a reduction of 0.08 grams. These results indicate that biomass-based acetic acid has the potential to be a more environmentally friendly alternative for scale removal in oil and gas production piping systems.

Corresponding author:
E-mail: (novrianti@eng.uir.ac.id) Novrianti

INTRODUCTION

One of the main problems in oil production operations is a decline in production rates due to the formation of scale deposits on production pipes. Scale is formed from certain ionic compounds, including cations (such as Na^+, Ca^{2+}, Mg^{2+}, Ba^{2+}, Sr^{2+}, Fe^{3+}) and anions (such as Cl^-, HCO_3^-, SO_4^{2-}, CO_3^{2-}) that are carried along with formation water during the production process. Increased water cut and changes in well pressure and temperature accelerate the scale formation process (Fadillah 2020). The presence of scale causes a narrowing of the pipe's inner diameter, thereby increasing fluid flow resistance and requiring greater pumping power to maintain the flow rate. In severe cases, scale can cause increased internal pressure, mechanical damage, and even pipe leaks (Musmuliadi 2020). Common types of scale found in the field include calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), barium sulfate ($BaSO_4$), as well as other types such as gypsum ($CaSO_4{\cdot}2H_2O$), strontium sulfate ($SrSO_4$), and ferrous carbonate ($FeCO_3$) (Jafar Mazumder 2020).

Various methods have been implemented to prevent or reduce scale formation and its effects, including lowering the pH through acid injection, polymer application, and the use of organic acids. Scale issues, particularly those involving calcium carbonate ($CaCO_3$), are known to be significantly influenced by operating conditions such as temperature, pH, and production fluid flow rate, which play a key role in accelerating the nucleation and growth of scale crystals. Recent studies indicate that the selection of a scale removal chemical system must consider not only dissolution effectiveness but also corrosion potential, material compatibility, and environmental impact. Experimental studies reported in Scientific Contributions on Oil and Gas (SCOG) indicate that the effectiveness of carbonate scale dissolution is significantly influenced by the type of acid, contact time, and the reaction mechanisms involved, whether through acid dissolution or metal ion complexation.

In addition to the use of conventional chemicals such as HCl and its combinations (Akhdan et al., 2022), research over the past decade has also reported the use of environmentally friendly and

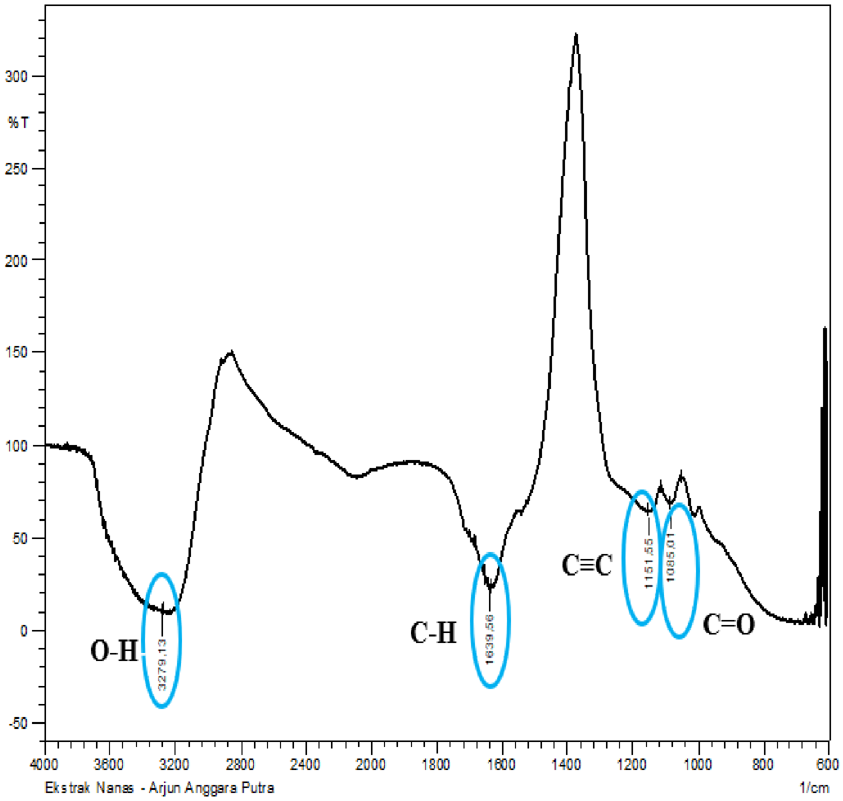

Figure 1. FTIR analysis results of pineapple extract

Tabel 2. FTIR Spectrum Interpretation of Pineapple Peel Extract

No.	Wave number ($cm^{-1)}$)	Types of vibration	Function all group	Interpretation
1	3272,19	Strain O–H (broad)	Hydroxyl (–OH)	Indicates the presence of alcohol or carboxylic acid
2	1639,95	Strain C–H sp²	Aliphatic (–CH=CH–)	Indicates the methyl/vinyl group of ethanol or a carboxylic acid compound
3	1450 indikatif	Strain C=C	Alkenes / aromatics	Possible unsaturated compounds derived from lignin or aromatic compounds
4	1151,85	Strain C–O	Secondary alcohol / eter	Hemicellulose or lignocellulose degradation products
5	1083,51	Strain C–O–C	Eter	Indicates complex polysaccharide compounds or lignocellulose residues
6	1700–1750 (tidak tampak)	Strain C=O	Carbonyl (–COOH)	Characteristic acetic acid group, possibly overlapping or of low intensity

biomass-based materials as scale removal or scale control agents. Several studies indicate that the use of waste-derived materials and biodegradable polymers has the potential to reduce corrosion risk and environmental impact compared to mineral acids; however, they still have limitations, such as relatively low concentrations of active compounds, slower reaction rates, and variations in chemical composition depending on the source and extraction process (Gamal et al., 2019; Popuri et al., 2014). Therefore, further evaluation is needed to assess the effectiveness and limitations of applying waste-based materials in oil and gas production systems.

In the context of sustainable development, the use of waste as a functional industrial material aligns with the sustainable development goals (SDGs), particularly Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action). This approach supports the concept of a circular economy by repurposing biomass waste into value-added products, while simultaneously reducing the environmental burden. In the oil and gas industry, this strategy is becoming increasingly relevant as demands grow for the adoption of more environmentally friendly and sustainable technologies without compromising operational reliability.

One waste-based alternative with development potential is the utilization of pineapple peel waste. National pineapple production during the 2000–2022 period showed a significant upward trend, with an average growth rate of 13.42% per year and an increase of up to 23.85% over the past five years (Dermawan 2023). Pineapple peel waste is known to contain organic compounds that can produce acetic acid through fermentation. Acetic acid is an organic acid with a carboxyl group that has the potential to dissolve carbonate scale through an acid dissolution mechanism, even though it is classified as a weak acid (Kohar et al., 2010). In this study, EDTA-2Na was used as a reference because it has been widely applied in the oil and gas industry as a chelating agent that acts through a mechanism of metal ion complexation, particularly Ca^{2+} ions, which are the components of carbonate scale. This mechanism differs from acid-based dissolution and generally has a slower reaction rate compared to mineral acids (Moghadasi et al., 2007). This comparison is important for evaluating the relative position of waste-based acetic acid as an alternative scale removal agent.

Based on this background, this study aims to evaluate the effectiveness of fermented pineapple peel extract as a scale removal agent against $CaCO_3$ scale using the weight loss method with soaking times of 30, 60, and 90 minutes, and to compare it with an EDTA-2Na-based chemical system and an acetic acid–HCl mixture. It is hoped that the results of this study can contribute to the development of more environmentally friendly and sustainable scale control technologies for application in oil and gas production systems.

METHODOLOGY

This study employed a laboratory experimental approach to produce acetic acid from pineapple peel waste and evaluate its effectiveness as a scale removal agent. Pineapple peel waste (Ananas comosus) was obtained from a traditional market in Pekanbaru. Other materials used included Saccharomyces cerevisiae yeast, a vinegar starter containing Acetobacter sp., granulated sugar, ammonium sulfate ($(NH_4)_2SO_4$), 0.1 N NaOH solution, phenolphthalein indicator, hydrochloric acid (37% HCl), and EDTA-2Na. Scale samples were obtained from the production flowline at Field X in the Sumatra oil and gas operational area during pipeline maintenance operations.

Acetic acid production is carried out through a two-stage fermentation process, which involves the conversion of sugars into ethanol by Saccharomyces cerevisiae, followed by the oxidation of ethanol into acetic acid by Acetobacter sp. (Fitria et al., 2021). A total of 0.5 kg of pineapple peel was boiled in 1 liter of water until it reached a boil, then filtered to obtain the filtrate. In the first stage, 500 mL of the filtrate is mixed with 15 g of sugar, 0.9 g of ammonium sulfate, and 3.75 g of yeast, then fermented anaerobically for 14 days at room temperature to produce ethanol. After alcohol formation, the second stage was carried out by adding 2.3 mL of vinegar starter, followed by aerobic fermentation for 24 days until acetic acid was formed. The chemical composition of pineapple peel, which serves as the fermentation substrate, is shown in Table 1, dominated by the lignocellulose fraction.

Tabel 1. Chemical composition of pineapple skin

Contents	Composition (weight %)
Cellulose	19
Hemi-cellulose	22
Lignin	5
Sucrose	5.2
Glucose	3.1
Fructose	3.4

The concentration of acetic acid produced by fermentation was determined using an acid–base titration method with 0.1 N NaOH solution as the titrant and phenolphthalein as the indicator. The titration was carried out until the endpoint was reached, indicated by a stable pink color change. Characterization of the acetic acid functional group was performed using FTIR with the attenuated total reflectance (ATR) method in the wavenumber range of 4000–400 cm^{-1} to identify the characteristic functional groups of organic acids.

The inorganic elemental composition of the scale samples was analyzed using X-ray fluorescence (XRF) to confirm the dominant type of scale, particularly the calcium content as the main component of $CaCO_3$ scale. The effectiveness of scale removal was tested using the weight loss method. Scale samples with an initial mass of ±5 g were soaked in a solution of fermented acetic acid, a mixture of acetic acid–HCl, and an EDTA-2Na solution as a control. The soaking process was conducted at room temperature with soaking times of 30 minutes, 60 minutes, and 90 minutes. After soaking, the samples were dried to a constant mass and reweighed to determine the mass loss as an indicator of scale removal effectiveness.

RESULT AND DISCUSSION

Characterization of acetic acid by FTIR spectroscopy

The addition of acetic acid to the fermented pineapple peel extract was not intended to produce new acetic acid, but rather to standardize the acidity level and ensure the dominance of acetic acid in the test solution. This approach aims to minimize variations in chemical composition caused by fermentation byproducts, such as ethanol, dissolved sugars, and lignocellulose derivatives, so that the observed scale removal performance can be directly attributed to the presence of acetic acid as the primary active component. Therefore, measurements using fourier-transform infrared spectroscopy (FTIR) were performed not to identify new compounds, but to confirm the presence of characteristic carboxylic acid functional groups and to evaluate the possible presence of other functional groups from biomass residues remaining after fermentation. Thus, FTIR serves as a qualitative chemical verification of the solution system used in the scale removal testing.

The results of the FTIR spectrum analysis revealed several major absorption bands indicating the presence of functional groups in the compounds derived from pineapple peel fermentation. A broad absorption band at a wavenumber of approximately 3272.19 cm^{-1} is associated with O–H stretching, which is characteristic of hydroxyl groups in alcohols and carboxylic acids. The presence of this group indicates the contribution of ethanol as a primary fermentation product and acetic acid as a secondary oxidation product (Nowack & Sigg 1997), while also confirming the acidic nature of the test solution. The absorption at 1639.95 cm^{-1} is interpreted as an aliphatic C–H vibration, specifically the sp^2 bond commonly found in the methyl group (–CH_3), which reinforces the indication of the presence of carboxylic acid compounds or ethanol residues in the fermentation solution. Additionally, two absorption bands at 1151.85 cm^{-1} and 1083.51 cm^{-1} are associated with the stretching of C–O and C–O–C groups, indicating the presence of ether and secondary alcohol bonds.

These groups generally originate from intermediate products resulting from the degradation of hemicellulose and lignin in lignocellulosic biomass such as pineapple peel (Socrates 2001), indicating that some fermentation precursor compounds have not been fully converted or that byproducts from biochemical reactions are still present during the process. The characteristic absorption band of the C=O carbonyl group, which typically appears in the 1700–1750 cm^{-1} range, was not clearly detected in the obtained spectrum. However, the absence of this band does not necessarily rule out the presence of the carbonyl group, as it may be due to spectral overlap with other groups or relatively low signal intensity resulting from the solution conditions.

Given that the fermentation and chemical oxidation of ethanol produce acetic acid, the presence of the carbonyl group remains highly likely even if it is not sharply observed in the FTIR spectrum (Urbaninggar & Fatimah 2021). Therefore, the FTIR results in this study were used as qualitative confirmation of the presence of the main functional group, not as a method for quantifying acetic acid content.

Analysis of inorganic components in production scale deposits

The chemical composition of the $CaCO_3$ scale, as determined by the researchers in the laboratory, was 34.06%. Based on the XRF analysis, there are 12 chemical components present in the scale; these 12 components are listed in Table 3.

Tabel 3. Scale compound components

Components	Results	Standard deviation	Unit
Ca	85.256	0.030	Mass%
Mn	2.563	0.024	Mass%
Fe	11.152	0.019	Mass%
Ni	0.189	0.004	Mass%
Cu	758	26	Mg/kg
Zn	610	14	Mg/kg
Sr	0.605	0.010	Mass%
Ba	896	55	Mass%

Laboratory analysis of scale samples from the production system showed that the most dominant element was calcium (Ca), followed by iron (Fe) and strontium (Sr). In addition, manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn), and barium (Ba) were also found in varying concentrations. Complete data are presented in Table 3.

The high calcium content, reaching 85.256 mass%, indicates that the formed scale is most likely calcium carbonate ($CaCO_3$) or calcium sulfate ($CaSO_4$). These types of scale are very common in oil and gas operations, particularly in systems experiencing supersaturation of Ca^{2+} ions and carbonate or sulfate anions, especially under high-pressure and high-temperature conditions (Jaberi et al., 2022).

Iron was also detected in significant amounts, specifically 11.152 mass%. The presence of this element is typically associated with internal corrosion in tubing or production pipes. In certain environments, iron can interact with carbonate or hydroxide ions to form ferrous carbonate ($FeCO_3$) or ferric hydroxide ($Fe(OH)_3$) scale. Additionally, the manganese content of 2.563 mass% contributes to the formation of deposits, due to its tendency to form insoluble compounds such as MnO_2 in alkaline environments.

Other notable metallic elements are strontium and barium, with concentrations of 0.605 mass% and 896 mg/kg, respectively. Both are known to form extremely hard scale in the form of $SrSO_4$ (celestite) and $BaSO_4$ (barite), which have very low solubility. This type of scale is difficult to treat with standard chemical methods and often requires specialized mechanical or chemical approaches (Moghadasi et al., 2007).

Copper and zinc, detected at 758 mg/kg and 610 mg/kg, respectively, generally do not form primary deposits; however, their presence can serve as an early indicator of corrosion in alloyed metal components, particularly fittings and tubing joints. Nickel was detected at a relatively low concentration (0.189 mass%) and likely originates from the degradation of corrosion-resistant metals or as a minor contaminant from formation water.

pH Value of pineapple peel acetic acid, a mixture of pineapple peel acetic acid and HCl, and EDTA-2Na

Scale testing was conducted using three types of acids: acetic acid (pineapple peel), a mixture of acetic acid (pineapple peel) and HCl, and EDTA-2Na (ethylenediaminetetraacetic acid). The pH values obtained using a pH meter for these three acids are shown in Table 4.

Table 4. pH Values

Type of reducing agent	pH
Acetic Acid (Pineapple Peel)	4.59
A mixture of acetic acid (pineapple peel) and HCl	5.42
EDTA-Na	5.34

pH measurements of several types of reducing agents revealed variations in acidity that reflect the relative strength of each compound in releasing H^+ ions into the solution. The pH measurement data are presented in Table 4. Acetic acid produced by pineapple peel fermentation has a pH value of 4.59, placing it in the weak acid category.

This acidity stems from the carboxyl group (–COOH), which undergoes partial dissociation in water (Khormali et al., 2018). Although it is classified as a weak organic acid, this pH value is sufficient to demonstrate acetic acid's potential as a natural reducing agent, particularly in mild applications such as the removal of light scale or initial reactions in carbonate systems.

A mixture of acetic acid from pineapple peel and hydrochloric acid (HCl) yields a pH value of 5.42, which is relatively higher than that of pure acetic acid. This increase in pH appears to be caused by a buffering effect or interactions between weak and strong acids in the mixture, in which the total acidity does not increase linearly. This phenomenon can occur if the amount of strong acid (HCl) added is not significant enough to lower the system's pH, or if partial neutralization occurs with other compounds in the mixture (Popuri et al., 2014).

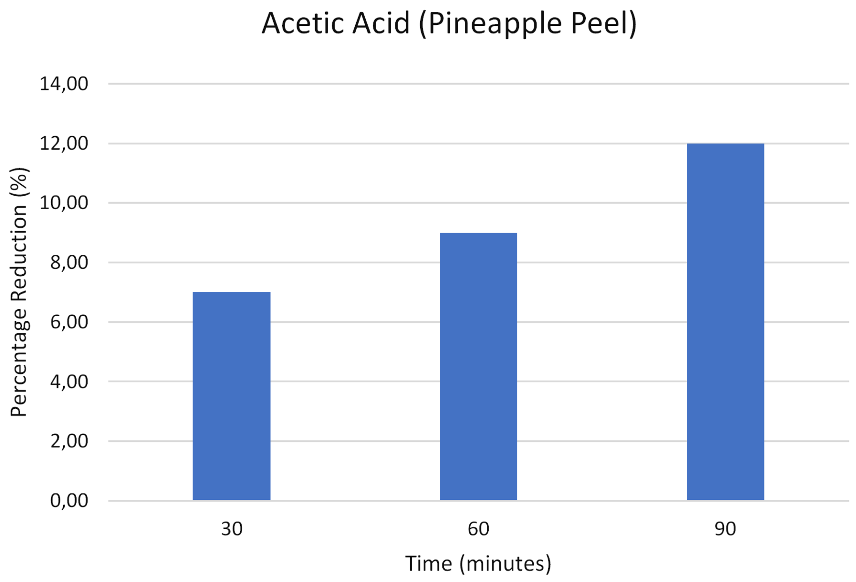

Figure 2. Effect of organic acids extracted from pineapple peel on scale reduction

EDTA-2Na (ethylenediaminetetraacetic acid), known as a chelating agent, has a pH of 5.34, which falls between that of acetic acid and its mixture with HCl. Although EDTA-2Na structurally contains several carboxylic acid groups, the resulting pH tends to be higher due to incomplete dissociation at certain concentrations (Martell et al., 1954). In the context of oil and gas applications, EDTA-2Na is more commonly used not as a direct reducing agent, but as a sequestrant or heavy metal ion binder in scale removal and well maintenance systems.

Of the three reducing agents tested, pure acetic acid derived from pineapple peel exhibited the lowest pH, thus demonstrating potential as a natural alternative to acidic chemicals in mild scale dissolver applications. Meanwhile, combining it with HCl does not directly increase the system's acidity, but may provide a synergistic effect on the scale dissolution process depending on the type of mineral and operational conditions. EDTA-2Na, although not as potent as HCl in terms of pH, remains a superior choice for treating sulfate or heavy metal scale due to its high complexation ability.

Results of the acetic acid test (pineapple peel) for scale reduction

The following are the results of testing pineapple peel extract with acetic acid at various soaking times. The results of the study show that the longer the crust is soaked in the acetic acid solution derived from pineapple peel fermentation, the greater the percentage of crust weight that is successfully reduced. Based on the data obtained, a 7% reduction in crust weight occurred after 30 minutes of soaking, increased to 9% after 60 minutes, and reached 12% after 90 minutes. The bar graph in Figure 1 illustrates this linear increase.

This increase in reduction efficiency can be explained by the mechanism of action of acetic acid as a scale-dissolving agent, particularly for carbonate-based scale such as $CaCO_3$. This compound contains a –COOH group that acts as a weak acid, capable of releasing H^+ ions into the solution and reacting with carbonate compounds to form water-soluble compounds, such as calcium acetate and carbon dioxide (Moghadasi et al., 2007). This reaction becomes more effective with longer contact time, as it allows sufficient time for H^+ ions to penetrate the pores of the scale.

The acidic nature of the solution also plays a role in accelerating scale dissolution, although acetic acid is relatively less potent than mineral acids such as HCl. Nevertheless, its use of natural materials such as pineapple peel waste makes this approach attractive in terms of sustainability and environmental safety (Lemigas 2016). This study demonstrates the potential of fermented acetic acid as an alternative agent in mild scale dissolver

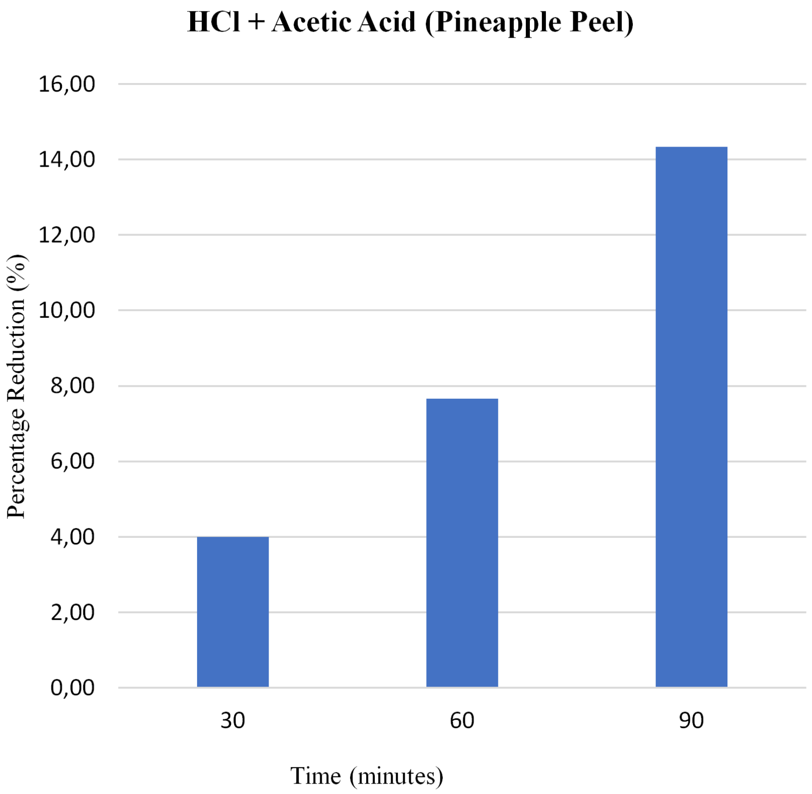

Figure 3. Effect of a mixture of pineapple peel extract and HCl on scale reduction

applications, particularly in production systems sensitive to the use of aggressive chemicals. The effectiveness of this solution can be further enhanced through pH adjustment, temperature control, or combination with complexing agents such as EDTA-2Na.

Test results of a mixture of acetic acid (pineapple peel) and HCl on scale reduction

The results of testing the mixture of pineapple peel extract and acetic acid with HCl at various soaking times are shown in Figure 3. Figure 3 shows the effect of soaking time on the effectiveness of a mixture of HCl and acetic acid derived from fermented pineapple peel in reducing scale weight. From the measurement results, it is evident that the longer the soaking time, the greater the percentage of scale reduced, with the following details: 4.0% at 30 minutes, 7.5% at 60 minutes, and 14.3% at 90 minutes. This trend indicates that the combination of a strong acid (HCl) and a weak organic acid (acetic acid) produces a synergistic effect in the scale dissolution process. HCl, which is corrosive and has a high ability to lower the system's pH, accelerates the dissolution of carbonate scale (e.g., $CaCO_3$) through the intensive release of H^+ ions (Zhang & Dawe, 2000). Meanwhile, acetic acid, as a weak acid, plays a role in maintaining reaction stability and gradually extending the reaction time against the scale without causing explosive reactions like pure HCl (Fredd & Fogler, 1998). The highest effectiveness occurs at a 90-minute soak, indicating that contact duration plays a crucial role in the acid diffusion process into the crust's pores and the chemical reactions taking place. In the context of oil and gas operations, this approach using the mixture can be considered safer, more economical, and more environmentally friendly compared to the use of HCl alone at high concentrations (Haris et al., 2021).

Results of EDTA-2Na (ethylene diamine tetraacetic acid) testing for scale reduction

The results of testing a mixture of pineapple peel extract and acetic acid with HCl at various soaking times are shown in Figure 4. Figure 4 shows the relationship between soaking time (30, 60, and 90 minutes) and the percentage reduction in scale using an EDTA-2Na solution. It can be seen that the longer the soaking time, the greater the percentage of scale reduced. The percentage of scale reduction increased from approximately 2.0% at 30 minutes to 2.4% at 60 minutes, reaching approximately 2.6% at 90 minutes. This increase indicates that the dissolution of scale by EDTA-2Na is time-dependent, suggesting that the complexation mechanism between metal ions in the scale (such as Ca^{2+} and Mg^{2+}) and the EDTA-2Na ligand requires sufficient diffusion and reaction time to proceed optimally. The longer the contact time, the deeper the penetration of EDTA-2Na into the crust's microstructure, which results in increased effectiveness of metal ion binding and crust dissolution. The effectiveness of EDTA-2Na as a chelating agent has been reported in several studies. According to Wanatabe (2021), environmentally friendly acid systems such as EDTA-2Na are capable of significantly reducing carbonate scale, with reaction rates increasing with time and temperature. Furthermore, (Fadillah 2020) states that soaking duration is a key factor in the success of the descaling process, particularly in complex production well environments.

Thus, this graph provides a strong basis that the use of EDTA-2Na with an optimal soaking time can be an effective and non-corrosive alternative in formation stimulation or production well maintenance processes, compared to conventional mineral acids such as HCl, which are aggressive and damaging to equipment.

Comparative analysis of the effectiveness of scale inhibitors using natural acetic acid, a mixture of acetic acid and HCl, and EDTA-2Na

The following is a comparison chart of Natural Acetic Acid, Acetic Acid–HCl Mixture, and EDTA. The figure above shows a comparison of the effectiveness of three types of scale-reducing solutions: acetic acid from pineapple peel extract (blue), a mixture of pineapple peel acetic acid and HCl (red), and EDTA-2Na (green), at soaking times of 30, 60, and 90 minutes. It can be seen that the percentage of scale reduction increases with longer soaking times for all three treatments.

At 30 minutes, EDTA-2Na produced the highest reduction of 7.00%, followed by the HCl-acetic acid mixture (4.00%) and natural acetic acid (2.00%). This trend was consistent at 60 minutes with a significant increase in the HCl-acetic acid mixture (7.67%) and EDTA-2Na (9.00%), indicating synergy between strong and organic acids in dissolving scale. At 90 minutes, the HCl-acetic acid mixture produced the highest reduction (14.33%), followed by EDTA-2Na (12.00%) and

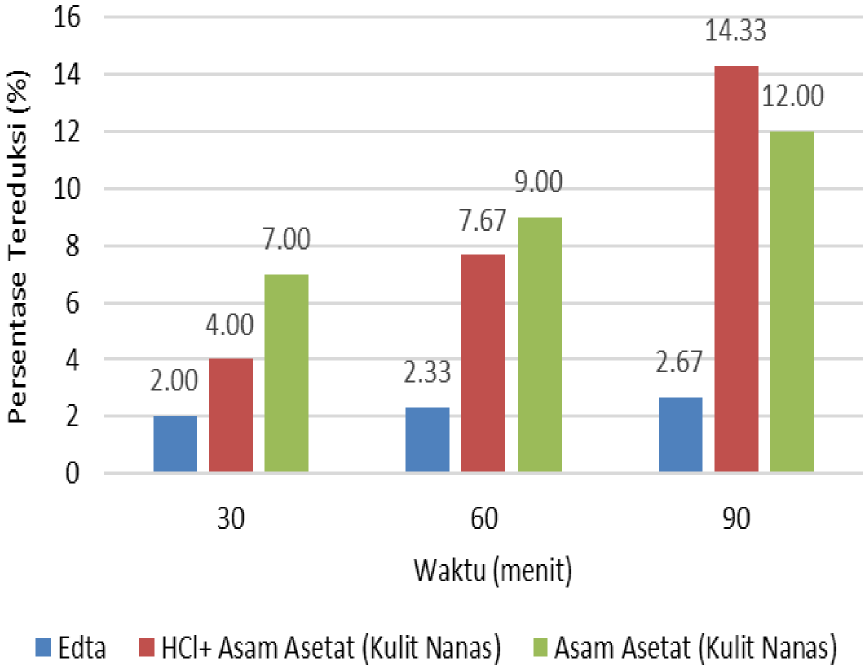

Figure 5. Comparison graph of scale reduction using organic acid from pineapple peel extract and pineapple peel extract + HCl and EDTA-2Na

natural acetic acid (2.67%). These results indicate that: EDTA-2Na is effective even with short soaking times, due to its complexation mechanism with metal ions (Ca^{2+}, Mg^{2+}) in the scale through the formation of stable complexes (Moghadasi et al., 2007). The mixture of HCl and acetic acid exhibits a strong synergistic effect with longer soaking times.

HCl aggressively dissolves the scale while acetic acid helps maintain solution stability and prolongs the dissolution action (Gamal et al., 2019). Natural acetic acid from pineapple peel, although environmentally friendly, has limited effectiveness over short to medium soaking times. This is likely due to low acid concentration and slow reaction rates.

A combined chemical approach that takes into account effectiveness, reaction time, and environmental impact is crucial in oil and gas well maintenance strategies. The use of organic acids derived from biomass waste, such as pineapple peels, offers a sustainable alternative, although formulation and contact time need to be optimized to ensure efficiency.

CONCLUSION

Based on the research results, pineapple peel extract contains O–H, C–H, C≡C, and C=O functional groups identified via FTIR, indicating the presence of organic acids such as acetic acid. Testing of $CaCO_3$ scale reduction showed that the longer the soaking time, the greater the amount of scale reduced.

Pineapple peel extract was most effective at 90 minutes with a reduction of 0.36 grams, while the mixture of acetic acid and HCl showed the best performance at 90 minutes at 0.43 grams. EDTA-2Na showed a stable but lower reduction. In percentage terms, pineapple peel extract was most efficient at 30 minutes (7.00%), the mixture of pineapple peel and HCl at 90 minutes (14.33%), and EDTA-2Na at 30 minutes (2.00%). Thus, it can be concluded that the combination of acetic acid and HCl provides the highest effectiveness in reducing scale at longer soaking times.

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GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
$BaSO_4$	Barium sulfate scale	
$CaCO_3$	Calcium carbonate scale	
$CaSO_4$	Calcium sulfate scale	
EDTA-2Na	Ethylenediaminetetraacetic acid disodium salt	
$FeCO_3$	Ferrous carbonate scale	
FTIR	Fourier transform infrared spectroscopy	
HCl	Hydrochloric acid	
XRF	X-ray fluorescence	
NaOH	Sodium hydroxide	

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