Journal of Science and Technology
ISSN: 2456-5660 Volume 10, Issue 08 (Aug -2025) *DOI: https://doi.org/10.46243/jst.2025.v10.i08.pp01- 07*
www.jst.org.in

Performance Evaluation of Red Onion (*Allium Cepa*) and Ginger (*Zingiber Officinale*) Extracts as Low-Dosage Green Inhibitors for Gas Hydrate Formation

Udoessien Emmanuel[1] | Okologume Wilfred Chinedu[2] | Okon Efiong[3] | Appah Dulu[4] | Daramola Peter Odunayo[5]

[1]Department of Petroleum Engineering, Federal University of Petroleum Resource Effurun, Nigeria
[2]Department of Petroleum Engineering, Federal University of Petroleum Resource Effurun, Nigeria
[3]Department of Petroleum and Gas Engineering, University of Port harcourt, Nigeria
[4]Department of Petroleum and Gas Engineering, University of Port harcourt, Nigeria
[5]Department of Petroleum Engineering, Federal University of Petroleum Resource Effurun, Nigeria

To Cite this Article
Udoessien Emmanuel, Okologume Wilfred Chinedu, Okon Efiong, Appah Dulu, Daramola Peter Odunayo, "Performance Evaluation of Red Onion (*Allium Cepa*) and Ginger (*Zingiber Officinale*) Extracts as Low-Dosage Green Inhibitors for Gas Hydrate Formation"*, Journal of Science and Technology*, Vol. 10, Issue 08, August 2025, pp.-01-07.

Article Info
Received on 20-June-2025, Revised on 22-July-2025, Accepted on 25-Aug-2025.

ABSTRACT:

Gas hydrates present a significant challenge for the production, handling, and transportation of natural gas. This study focuses on experimentally investigating selected plant extracts as eco-friendly alternatives to chemicals for inhibiting gas hydrate formation. Specifically, the research explores the effectiveness of red onion (Allium cepa) and ginger (Zingiber officinale) extracts as biodegradable and water-soluble Low Dosage Hydrate Inhibitors (LDHIs).

Experiments were carried out using a Mini Flow Loop to evaluate the effectiveness of these natural extracts compared to traditional chemical inhibitors. The findings indicate that both red onion and ginger extracts significantly reduce hydrate formation rates and increase induction times, demonstrating promising properties as hydrate inhibitors. Performance comparisons show that these natural extracts are comparable to conventional inhibitors, highlighting their potential as viable, environmentally friendly alternatives.

This research emphasizes the importance of utilizing sustainable and non-toxic solutions to mitigate hydrate formation, which could lead to reduced environmental impacts and lower operational costs in the oil and gas industries.

KEYWORDS: *Gas hydrates, Low-dosage hydrate inhibitors, Red onion extract, Ginger extract, Flow assurance*

I. INTRODUCTION

Gas hydrates are solid structures that form when water molecules trap low-molecular-weight gases like methane under high pressure and low temperature (Bozorgian, 2021). These ice-like formations usually occur in offshore pipelines and do not dissolve easily in surrounding fluids (Ruppel & Waite, 2020). Gas hydrates in oil and gas pipelines create challenges for flow assurance, including blockages, reduced production efficiency, increased maintenance costs, and potential environmental risks (Nasir, 2024; Zhao et al., 2023; Okologume & Appah, 2015).

Historically, the petroleum industry has used chemical inhibitors to tackle hydrate formation (Bozorgian, 2020; Koh et al., 2002; Kvenvolden, 2000). These include thermodynamic hydrate

inhibitors (THIs) and low-dosage hydrate inhibitors (LDHIs). THIs, like methanol, monoethylene glycol (MEG), and diethylene glycol (DEG), are generally injected in high concentrations (10–60 wt.%) to change hydrate equilibrium conditions (AlHarooni, 2017; Teixeira et al., 2017; Sloan, 1998). On the other hand, LDHIs, which include kinetic hydrate inhibitors (KHIs) and anti-agglomerants (AAs) are applied at much lower concentrations (less than 1 wt.%) and work by delaying nucleation or stopping crystal agglomeration (Ning et al., 2022; Aminnaji et al., 2019).

While these inhibitors work well, many are costly, non-biodegradable, and can be toxic to the environment. Therefore, recent studies have aimed to develop greener options, such as modified starches, biopolymers, and natural plant extracts, which are more sustainable. For example, PVCap-based blends and ionic liquids have shown promising dual-function inhibition (Richard & Adidharma, 2013; Kelland, 2006; Daraboina et al., 2019).

In this context, plant-based inhibitors have gained interest because they are renewable, locally available, and biodegradable. Several studies have demonstrated the potential of Nigerian locally sourced plant extracts for inhibiting hydrates using mini flow loops (Asikoko et al., 2024; Onyekachi et al., 2024; Elechi et al., 2021; Elechi et al., 2020; Efiong et al., 2018). However, there is limited research on inhibitors derived from agro-waste, such as red onion (*Allium cepa*) and ginger (*Zingiber officinale*), within the field of hydrate management.

Red onion and ginger contain many bioactive compounds, including flavonoids and polyphenols, known for their antioxidant and surface-active properties (Zhang et al., 2025; Maryuni et al., 2022). These traits make them strong candidates for inhibiting hydrates, as they can interfere with the crystal growth process and delay nucleation. Additionally, both are cost-effective, water-soluble, and widely available in agricultural markets, making them practical for local use.

This study aims to experimentally evaluate and compare the effectiveness of red onion and ginger extracts as low-dosage natural gas hydrate inhibitors against a conventional inhibitor, 2-(Dimethylamino) ethyl methacrylate (2-DIMETH). The study measures their efficacy using pressure-temperature profiles, induction times, and inhibition performance on a mini flow loop setup. The results are expected to provide insights into sustainable strategies for managing hydrates while supporting environmental protection and Nigeria local development.

II. METHODOLOGY

This experimental research was conducted at the Hydrate Section of the Petroleum Production Engineering Laboratory at the University of Port Harcourt. The study simulated gas hydrate formation and inhibition using a closed-loop hydrate flow system. This system was designed to mimic offshore pipeline conditions.

Equipment and Setup

The mini flow loop system used for this experiment has a 12-meter-long stainless-steel tube with a 0.5-inch internal diameter. This tube is placed inside a 4-inch PVC pipe, as shown in Figure 1. The system can work at pressures up to 3,500 psi and temperatures up to 50°C. The cooling system features a deep freezer and recirculating pumps. Its other parts include the Control Panel, Pumps, Inhibitor Vessel, Pressure and Temperature Gauges, and Flowmeter.

Figure 1. Gas Hydrate Mini Flow Loop (Odutola *et al.*, 2017)

Key Equipment Description

The system has three pumps, including manual and electric options, to help with fluid circulation and injecting inhibitors. An inhibitor vessel holds and dispenses inhibitor mixtures into the system

loop. A deep freezer uses water and ice blocks to keep temperatures low.

To monitor system conditions, pressure and temperature gauges are placed at different points in the setup. A differential pressure transmitter measures pressure differences across the loop, and a flowmeter records the fluid flow rate. Power is sent to all system components through the control panel.

Materials Used

The materials used in the system include fresh water and ice blocks, which cool the loop. Compressed natural gas (CNG), mainly made up of methane at about 98.44%, acts as the hydrate-forming agent. The inhibitors consist of locally formulated kinetic hydrate inhibitors (LFKHIs) derived from extracts of red onion (*Allium cepa*) and ginger (*Zingiber officinale*). They also include a standard chemical inhibitor known as 2-DIMETH.

Extract Preparation and Characterization (GC-MS)

In terms of equipment and reagents, the process involves a GC-MS system, specifically the Agilent 6890N, which includes a 5975 MS detector. The reagents used are helium as the carrier gas, n-hexane, methylene chloride, and anhydrous sodium sulfate.

For sample preparation, a 10 g plant sample was spiked, dried, and extracted with methylene chloride using Soxhlet extraction. The resulting extracts were then cleaned and analyzed with GC-MS under set temperature and flow rate conditions.

GC-MS Procedure

The GC-MS procedure included setting the injector temperature to 250 °C and the oven temperature between 200 °C and 230 °C. Helium served as the carrier gas at a flow rate of 1 mL/min. The scan mode detected mass-to-charge ratios (m/z) from 35 to 450. Phytochemicals in the extracts were identified using the NIST library.

Plant Materials

The plant materials chosen for this study include red onion, which is known for its high levels of quercetin and antioxidants that have surface-active properties. Ginger contains bioactive compounds like gingerol, recognized for its anti-inflammatory and antioxidant benefits. To explore potential synergistic effects, equal volumes of red onion and ginger extracts, each 10 mL, were mixed for testing.

Inhibition Efficiency Calculation

The inhibition efficiency (IE) was calculated using pressure drop data Eq. 1:

$$IE = (1 - X)\% \qquad \text{eq. 1}$$

$$X = \Delta P_{inhibited} / \Delta P_{uninhibited}$$

$$\Delta P_{inhibited} = (P_i - P_f)_{inhibited}$$

$$\Delta P_{uninhibited} = (P_i - P_f)_{uninhibited}$$

Where,

X is the change in pressure of inhibited system divided by change in uninhibited system

P_i refers to initial pressure of the system (inhibited or uninhibited)

P_f is the final pressure of the system (inhibited or uninhibited)

$\Delta P_{inhibited}$ is the initial pressure minus final pressure of inhibited system

$\Delta P_{uninhibited}$ is the initial pressure minus final pressure of uninhibited system.

This allowed quantification of how effective each inhibitor was in retarding gas hydrate formation.

III. RESULTS

Phytochemical Composition and GC-MS Analysis

The GC-MS analysis of the *Allium cepa* extract (ACE) from red onion and the *Zingiber officinale* extract (ZOE) from ginger showed a range of bioactive compounds that have surface-active

properties and prevent hydrate formation. The main types of compounds found include alkaloids, flavonoids, tannins, saponins, and sesquiterpene lactones.

In the ACE, we found compounds like quercetin, phytol, squalane, and pyrrole derivatives. In contrast, the ZOE had zingiberene, curcumene, alpha-terpineol, and beta-caryophyllene. These compounds can disrupt the nucleation and growth of hydrate crystals because of their amphiphilic nature and strong adsorption on hydrate surfaces.

Quantitative phytochemical screening, shown in Tables 1 and 2, indicated that ZOE had a higher concentration of saponins and tannins, while ACE was richer in flavonoids and alkaloids. All these compounds help explain the observed inhibition of hydrate formation.

Table 1. Quantitative Phytochemicals Screening of Allium Cepa Extract

Bioactive Components	**% in Allium Cepa Extract**
Alkaloid	++
Flavonoid	+++
Saponin	++
Sesquiterpene lactone	+
Tannin	++

Table 2. Quantitative Phytochemicals Screening of Zingiber Officinale

Bioactive Components	**% in Allium Cepa Extract**
Alkaloid	+
Flavonoid	++
Saponin	+++
Sesquiterpene lactone	++
Tannin	+++

Pressure and Temperature Profiles for the Uninhibited System Performance

The uninhibited system experiment showed a significant pressure drop. Values declined from 150 psi to 36 psi within 100 minutes. This sharp decline confirmed that nucleation and growth of hydrates were happening actively. At first, the system temperature went down because of cooling. However, it later rose slightly due to the heat released during hydrate formation. These findings clearly proved that the conditions in the system were very favorable for forming hydrates.

Pressure Suppression by Inhibitors

The investigation into pressure suppression by inhibitors tested various concentrations of substances. These included ACE, ZOE, their hybrid formulation, and 2-DIMETH at concentrations of 0.01 wt%, 0.02 wt%, and 0.03 wt%. The results showed that adding these inhibitors successfully delayed or suppressed hydrate formation at all tested concentrations. Among the inhibitors, ZOE consistently performed well, maintaining higher final pressures between 106 and 113 psi. This signified effective inhibition and reduced gas use. ACE showed its best results at a concentration of 0.02 wt%, where it maintained a pressure of 116 psi, surpassing even 2-DIMETH at the same concentration.

On the other hand, the hybrid inhibitor made of ACE and ZOE did not show any combined improvement. Its performance stayed moderate compared to the others. In this context, 2-DIMETH served as a standard, achieving final pressures similar to those of ZOE but without the environmental benefits that ZOE provides. The pressure-time profiles in Figures 2 to 4 clearly show the better suppression effects of ZOE and 2-DIMETH compared to the uninhibited run results.

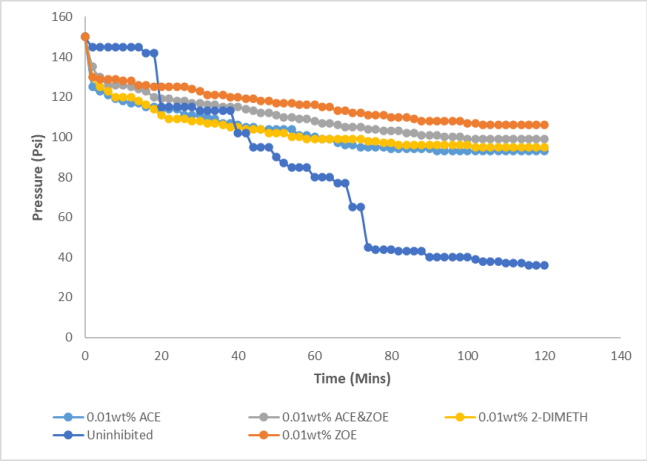

Figure 2. Pressure against Time for 0.01 wt.% of ACE, ZOE, ACE & ZOE, 2-DIMETH and Uninhibited System

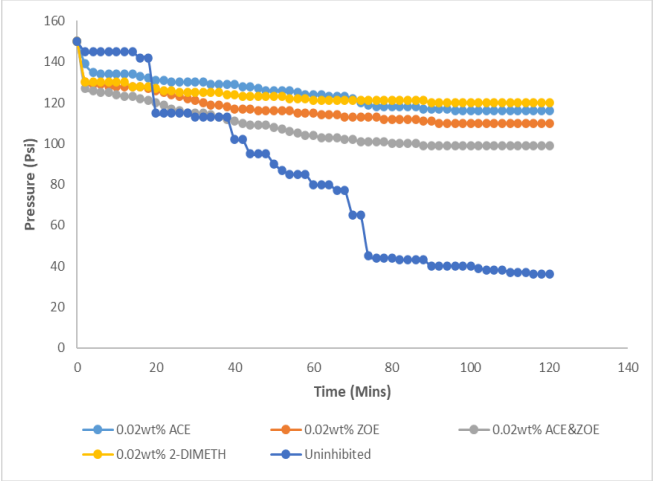

Figure 3. Pressure against Time for 0.02 wt.% of ACE, ZOE, ACE & ZOE, 2-DIMETH and Uninhibited System

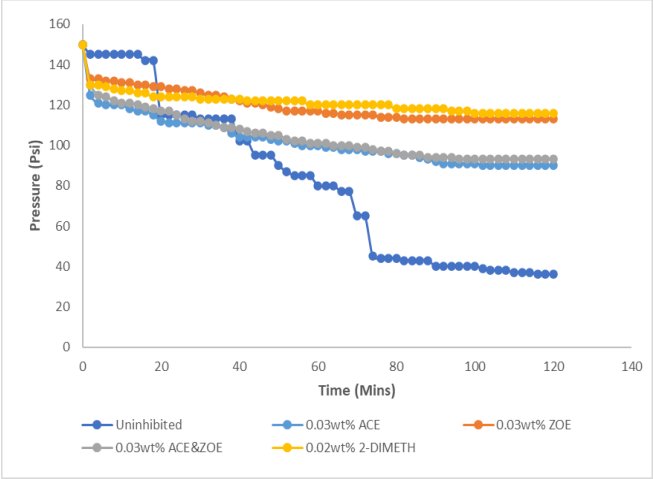

Figure 4. Pressure against Time for 0.03 wt.% of ACE, ZOE, ACE & ZOE, 2-DIMETH and Uninhibited System

Temperature Trends and Cooling Profiles

The temperature versus time graphs in Figures 5 to 7 show how the inhibitors controlled the system temperature. The data suggest that effective inhibition led to a stable temperature between 6 and 7°C, which helped to delay the formation of hydrates.

ZOE was especially effective, keeping a steady temperature of 6°C for 84 to 92 minutes. In contrast, ACE and ACE&ZOE showed similar, but slightly less effective, patterns of temperature control. Additionally, 2-DIMETH achieved similar cooling rates, showing an equal ability for thermal inhibition.

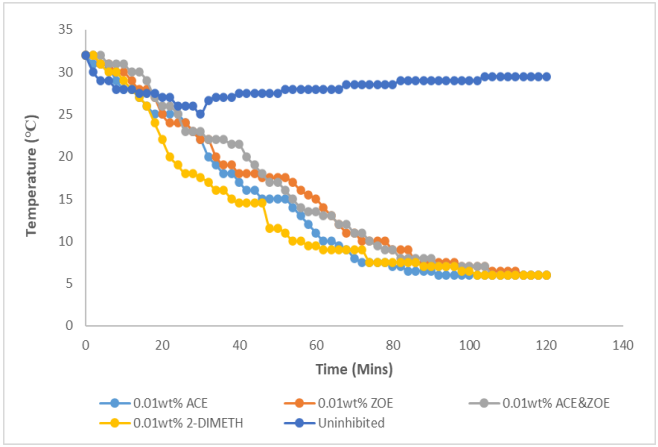

Figure 5. Temperature against Time for 0.01wt% of ACE, ZOE, ACE & ZOE, 2-DIMETH and Uninhibited System

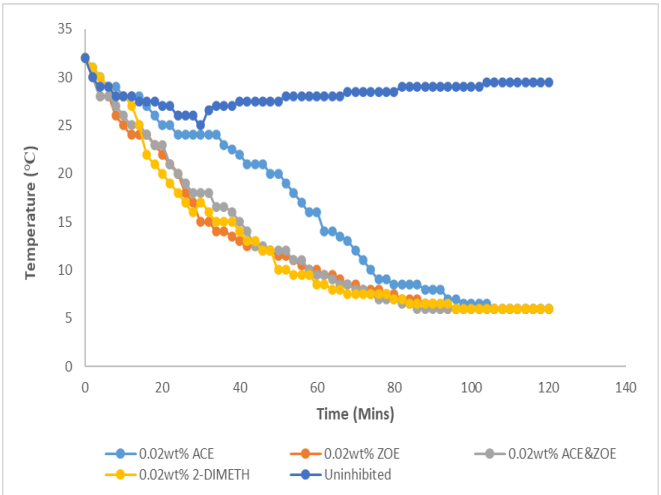

Figure 6: Temperature against Time for 0.02wt% of ACE, ZOE, ACE & ZOE, 2-DIMETH and Uninhibited System

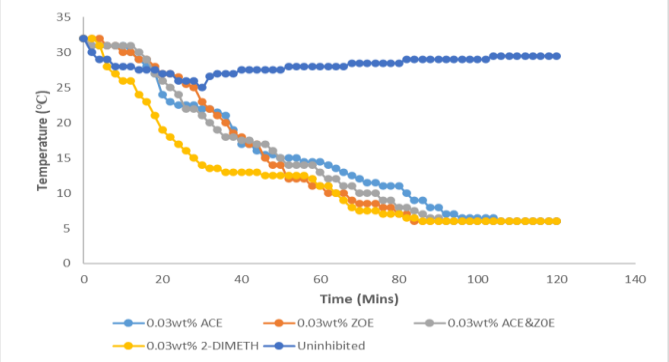

Figure 7. Temperature against Time for 0.03wt% of ACE, ZOE, ACE & ZOE, 2-DIMETH and Uninhibited System

Inhibition Efficiency Analysis

The inhibitive efficiency (IE) values gotten from Eq. 1 provides a way to measure how well different inhibitors perform. In this analysis, ZOE showed efficiencies of 61.40%, 64.91%, and 67.54% at weight concentrations of 0.01%, 0.02%, and 0.03%, respectively. ACE reached its highest efficiency of 70.18% at a concentration of 0.02% by weight.

When ACE and ZOE were used together, they produced moderate efficiencies that averaged around 55%. However, 2-DIMETH achieved the highest efficiency at 73.68%. ZOE followed this result closely, showing lower toxicity and better sustainability than the other options.

Figure 8 presents a comparison of the inhibition efficiencies at different concentrations. This figure shows ZOE as a competitive and more eco-friendly alternative to synthetic inhibitors.

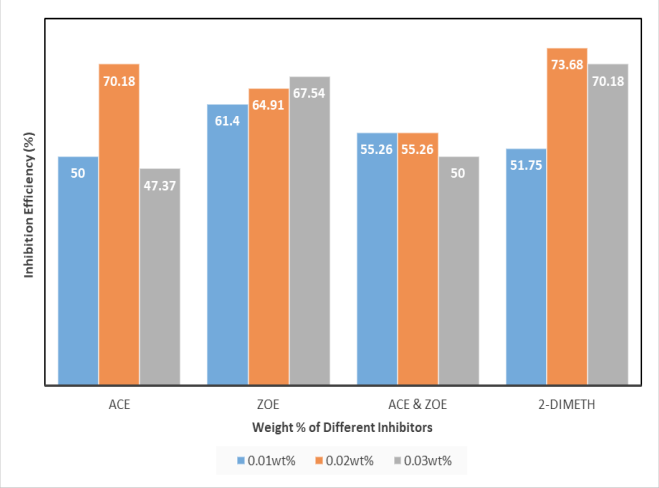

Figure 8. Inhibition Efficiency versus Weight Percent of Different Inhibitors

IV. CONCLUSION

In this study, it was found that that extracts from red onion and ginger have promising potential as natural, low-dose inhibitors of gas hydrate formation. Their ability to delay hydrate nucleation and slow down hydrate formation rates is similar to that of traditional synthetic inhibitors like 2-DIMETH.

These findings have important implications for the oil and gas industry. By using green and biodegradable alternatives, companies could significantly reduce their environmental impact and regulatory challenges. They could also lower the chemical costs tied to hydrate management.

This research is important for developing sustainable flow assurance strategies. It supports the idea that natural inhibitors can be effective tools for promoting environmentally responsible practices in petroleum operations worldwide. This change not only reflects the current trend towards eco-friendly solutions but also strengthens the industry's commitment to lowering its ecological footprint.

REFERENCES

[1] AlHarooni, K. M. A. (2017). Gas Hydrates Investigations of Natural Gas with High Methane Content and Regenerated Mono-Ethylene Glycol. Curtin University.

[2] Aminnaji, M., Anderson, R., & Tohidi, B. (2019). Anomalous KHI-Induced dissociation of gas hydrates inside the hydrate stability zone: Experimental observations & potential mechanisms. Journal of Petroleum Science and Engineering, 178, 1044-1050.

[3] Asikoko, F., Okologume, W. C., Appah, D., & Aimikhe, V. (2024). Experimental investigation of cassava (Manihot esculenta) leaf extract as a green inhibitor of gas hydrate formation. Biomass Conversion and Biorefinery, 14(16), 19383-19392.

[4] Bozorgian, A. (2020). Investigation of the history of formation of gas hydrates. Journal of Engineering in Industrial Research, 1, 1-18.

[5] Bozorgian, A. (2021). An overview of methane gas hydrate formation. Journal of Engineering in Industrial Research, 2, 166-177.

[6] Efiong, O. O., Atubokiki, A. J., Sunday, I. S., Urunwo, E. V., & Olabisi, O. T. (2018). Use of locally formulated inhibitor from agro waste for gas hydrate inhibition in a mini flow loop. Gas, 3(4), 5-6.

[7] Elechi, V. U., Ikiensikimama, S. S., Akaranta, O., Ajienka, J. A., Onyekonwu, M. O., & Okon, O. E. (2020, May). Gas Hydrate Mitigation Using an

Organic Extract in a Simulated Offshore Environment. In Offshore Technology Conference (p. D041S056R007). OTC.

[8] Elechi, V. U., Ikiensikimama, S. S., Ajienka, J. A., Akaranta, O. E., & Okon, O. E. (2021). Laboratory evaluation of caricaceae plant as a locally sourced surfactant for gas hydrate inhibition in a laboratory mini flow loop. Applied Petrochemical Research, 11(3), 295-303.

[9] Koh, C. A., Westacott, R. E., Zhang, W., Hirachand, K., Creek, J. L., & Soper, A. K. (2002). Mechanisms of gas hydrate formation and inhibition. Fluid Phase Equilibria, 194, 143-151.

[10] Kvenvolden, K. A. (2000). Natural gas hydrate: Background and history of discovery. In Natural Gas Hydrate: In Oceanic and Permafrost Environments (pp. 9-16). Dordrecht: Springer Netherlands.

[11] Maryuni, D. R., Prameswari, D. A., Astari, S. D., Sari, S. P., & Putri, D. N. (2022). Identification of active compounds in red onion (Allium ascalonicum L.) peel extract by LC-ESI-QTOF-MS/MS and determination of its antioxidant activity. J Teknol Has Pertan, 15(1), 20.

[12] Nasir, Q. (2024). Hydrate formation challenges in pipelines: A persistent threat to flow assurance. In Advances and Technology Development in Greenhouse Gases: Emission, Capture and Conversion (pp. 415-443). Elsevier.

[13] Ning, F., Guo, D., Din, S. U., Zhang, H., Ou, W., Fang, B., & Koh, C. A. (2022). The kinetic effects of hydrate anti-agglomerants/surfactants. Fuel, 318, 123566.

[14] Odutola, T. O., Ajienka, J. A., Onyekonwu, M. O., & Ikiensikimama, S. S. (2017). Design, fabrication and validation of a laboratory flow loop for hydrate studies. American Journal of Chemical Engineering, 5(3-12), 28-41.

[15] Okologume, W. C., & Appah, D. (2015). Analyzing thermal insulation for effective hydrate prevention in conceptual subsea pipeline design. International Journal of Current Engineering and Technology, 5(4), 2492-2499.

[16] Onyekachi, P. N., Ikiensikimama, S. S., Wachikwu-Elechi, V. U., & Okon, O. E. (2024, August). Deep Water Mitigation of Gas Hydrate Formation Using Alium Cepa Skin Extract (ACSE). In SPE Nigeria Annual International Conference and Exhibition (p. D021S003R003). SPE.

[17] Ruppel, C. D., & Waite, W. F. (2020). Timescales and processes of methane hydrate formation and breakdown, with application to geologic systems. Journal of Geophysical Research: Solid Earth, 125(8), e2018JB016459.

[18] Sloan, E. D. (1998). Offshore hydrate engineering handbook. Center for Hydrate Research, Colorado School of Mines. Golden, Colorado, 255.

[19] Teixeira, A. M., de Oliveira Arinelli, L., De Medeiros, J. L., & Araújo, O. D. Q. F. (2017). Monoethylene Glycol as Hydrate Inhibitor in Offshore Natural Gas Processing: From Fundamentals to Exergy Analysis. Springer.

[20] Zhang, D., Ahlivia, E. B., Bruce, B. B., Zou, X., Battino, M., Savić, D., & Shen, L. (2025). The Road to Re-Use of Spice By-Products: Exploring Their Bioactive Compounds and Significance in Active Packaging. Foods, 14(14), 2445.

[21] Zhao, J., Lang, C., Chu, J., Yang, L., & Zhang, L. (2023). Flow assurance of hydrate risk in natural gas/oil transportation: State-of-the-art and future challenges. The Journal of Physical Chemistry C, 127(28), 13439-13450.