



Experimental Assessment of Moringa Oleifera as an Environmentally Friendly Inhibitor Solution for Gas Hydrate Control

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ABSTRACT

Research efforts have long been focused on developing low-dose hydrate inhibitors (LDHIs) due to their accessibility, reduced quantity requirement, and cost-effectiveness. This study explores the potential of Moringa oleifera extract as an alternative LDHI, leveraging its established applications in the pharmaceutical and cosmetic industries. Utilizing a mini hydrate flow loop comprising 316 stainless steel pipes covered with polyvinyl chloride (PVC) mounted on a steel frame, hydrate formation conditions are simulated. Moringa Leaf Extract (MLE) concentrations of 0.02%, 0.04%, and 0.06% by water volume are compared against Methanol concentrations of 2%, 4%, and 6%. Performance evaluation entails analyzing pressure, temperature, inhibition efficiency, and pressure-time plots. Results indicate that 0.04wt% MLE surpasses all Methanol concentrations, exhibiting an inhibition efficiency of 60%, while the optimal Methanol concentration is found to be 2%, with an efficiency of 56.7%. MLE emerges as a promising alternative to traditional hydrate inhibitors, being readily available, environmentally friendly, and cost-effective.

1. Introduction

Gas hydrates, crystalline compounds formed by water and gas molecules under specific pressure and temperature conditions, pose significant challenges in various industries, particularly in oil and gas extraction operations. Traditional methods for controlling gas hydrates often involve the use of chemical inhibitors, which can be environmentally harmful and economically burdensome. Consequently, there is a growing interest in exploring green alternatives for gas hydrate mitigation

[1,2]. Extensive endeavors have been dedicated to comprehending gas hydrates, with potential applications spanning gas exploitation, transportation, and separation [2, 3-6]. With the energy industry pivoting towards gas, pipeline transport technology is assuming greater importance. Yet, these transport conduits frequently create conducive environments for gas hydrate formation, leading to pipeline obstructions that entail substantial financial losses, along with environmental and safety concerns [7]. Consequently, ensuring flow assurance for gas transportation has emerged as a paramount challenge within the contemporary energy sector [2, 7, 8].

Over time, the utilization of chemical inhibitors, known as conventional inhibitors, has been employed to hinder or eradicate the formation of gas hydrates. However, the implementation of these chemicals has led to increased costs within the Oil and Gas industry. It is pertinent to acknowledge that these expenses stem from the high initial introduction costs for compounds such as E-glycol, as well as the ongoing need for repurchasing, particularly evident in the case of Methanol. Furthermore, numerous studies have underscored the adverse effects of these inhibitors on aquatic life, particularly in deep-sea regions, and on the environment as a whole [9-13].

In Farhadian et al.'s [14] study, a novel approach utilizing sulfonated chitosan as a green kinetic hydrate inhibitor was introduced. Through high-pressure autoclave and micro-differential scanning calorimeter evaluations, a significant 30% decrease in hydrate formation compared to water was observed. Rao et al. [15] Research on efficiently inhibiting hydrate blockage in deep-sea oil and gas pipelines is crucial for ensuring safe operations. Applying swirl flow technology shows promising engineering applications in controlling hydrate risks, expanding the safe flow boundaries, and understanding hydrate flow characteristics. Experimental studies reveal insights into gas hydrate flow, transport, deposition, and plugging under various swirl flow conditions, elucidating the mechanisms behind hydrate growth and coalescence in different flow regimes.

Zhang et al. [16] explored typical hydrate plug phenomena using experimental loop setups, revealing insights into hydrate node formation mechanisms. They concluded that anticoagulant agents could effectively mitigate hydrate deposition and plugging in pipelines.

Saikia & Mahto [17] studied the impact of soybean lecithin as an anti-aggregant on tetrahydrofuran (THF) hydrates, showing a significant delay in agglomeration time. This biosurfactant proved effective in preventing hydrate clogging in oil/gas pipelines and drilling mud flow lines. Also Prasad et al. [18] recent efforts in storing greenhouse gases as gas hydrates face challenges due to slow formation rates and inefficient water-to-hydrate conversion. This study investigates the impact of two amino acids, l-methionine and l-phenylalanine, on methane, carbon dioxide, and their mixtures' hydrate formation under varied conditions. The addition of amino acids significantly enhances hydrate formation kinetics, achieving over 90% gas uptake within an hour, with efficient water-to-hydrate conversion (>85%), making amino acid systems suitable for storing both methane and carbon dioxide gases. Characterization using powder x-ray diffraction and Raman spectroscopy confirms the formation of sI hydrates encapsulating gas molecules.

Moringa oleifera, a fast-growing tree native to tropical and subtropical regions, has gained attention for its versatile applications in various fields, including water treatment, agriculture, and

health. Rich in bioactive compounds, *Moringa oleifera* exhibits properties that may offer a sustainable solution for gas hydrate control. However, despite its promising attributes, the potential of *Moringa oleifera* in mitigating gas hydrates remains largely unexplored [19]. This study aims to investigate the efficacy of *Moringa oleifera* as a green alternative for gas hydrate management. By examining its inhibitory effects on gas hydrate formation and dissociation, we seek to contribute to the development of environmentally friendly strategies for addressing gas hydrate-related challenges. Through experimental analysis, we aim to elucidate the mechanisms underlying the interactions between *Moringa oleifera* extracts and gas hydrates, providing insights into its potential applications in the oil and gas industry. By harnessing the sustainable properties of *Moringa oleifera*, we anticipate offering a novel approach to gas hydrate control that is both ecologically responsible and economically viable. This research tends to show the importance of exploring nature-inspired solutions to address pressing industrial challenges while minimizing environmental impact.

2.Materials and Method

2.1 Materials

The materials used in this study include water, blocks of ice to promote the low temperatures required for the formation of hydrates, CNG (mass of 14.5g and S.G of 0.5), methanol as chemical hydrate inhibitor, and *Moringa Oleifera* leaf extract for use as novel green hydrate inhibitor alternative.

2.2 Materials preparation

The *Moringa olifera* were sourced from a residential area, measured and divided into two portions, with the first portion used for the phytochemical tests while the other was crushed and mixed to get the required percentage to be used for hydrate inhibition in the hydrate mini flow loop.

2.3 Phytochemical screening

The first sample for the phytochemical tests weighing 2.83g was dried in solid state, pulverized to powder, and extraction was carried out using a Soxhlet extractor with methanol as the extracting solvent. The methanol solvent was allowed to evaporate at a moderate temperature, leaving a semi-liquid extract which was then employed for use in the phytochemical analysis.

Figure 1 shows the ground leaves of the *Moringa oleifera* and the extraction process of leaf extracts is shown below:

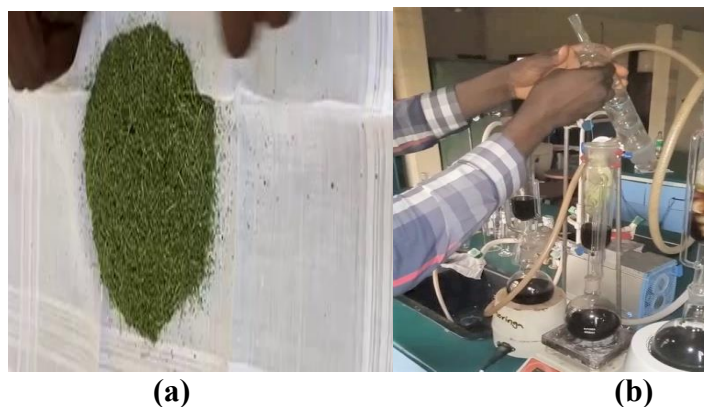


Figure 1. (a) Dried moringa leaves used for qualitative analysis test, (b) Soxhlet Extractor employed in phytochemical screening of the methanolic extracts of *Moringa oleifera*

2.4 Experimental Setup

The experimental setup used was a locally fabricated 0.5-inch I.D., 39.5-m-long, housed in a hydrate Mini flow loop with a diameter of 4 inches. The flow loop is made up of several pressure (psi), and temperature (oC) gauges and a differential pressure gauge (bar). The table for values include values for gauges for temperature (T1, T2, and T3), pressure (P1, P2, P3, P4, P5, P6) and differential pressure (P4). T1 represents the temperature of the cooling water as it simulates sea water temperature; it is transported around the PVC pipe but not the inner line of the unit which simulates the pipeline. T2 represents the inner line temperature; the gauge is directly attached to the cooling unit, wherein the liquid is mixed with the blocks of ice and circulates the outer PVC pipe for T1 to measure. T3 represents the outer temperature. P1 values are used to ascertain the performance of the inhibitors as it is connected to the coldest unit. If hydrates form, they should be at the coolest region for the major parts of the analysis, P1 and T2 are used. It is important to note that a relatively higher P1 at the end of the experiment indicates that the CNG was not consumed as much in forming hydrates whilst a lower value for the same indicates that hydrates were formed. In its entirety, the flow loop components included; a CNG gas tank, Inhibitor Vessel, Control Panel, Pumps, Agitator (screw pump), a Cooling unit, Valve couplings, PVC pipe segments and Inner line. In conclusion, three pumps, five pressure gauges, two differential pressure gauges, three temperature gauges, seven valves, a visual flowmeter, an inhibitor mixing vessel, and a CNG bottle make up the loop configuration (100 bar). A schematic of the mini hydrate flow loop is shown in Figures 2,3 and 4

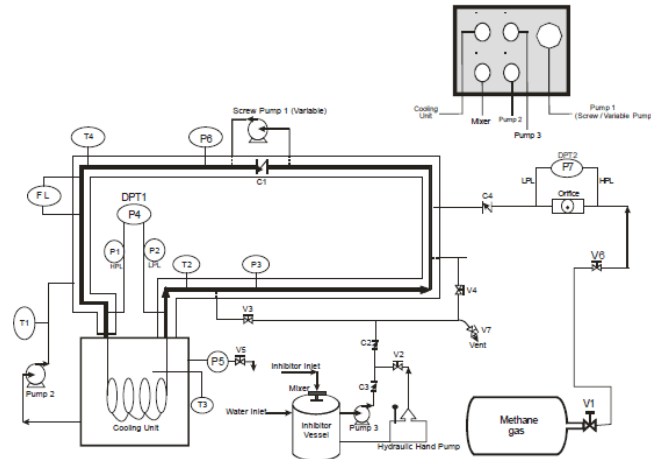


Figure 2. A schematic representation of the hydrate mini flow loop (Elechi et al., 2018)



Figure 3. Hydrate flow loop used for experiment



Figure 4. (a) Mixing chamber for water and percentage composition of hydrate inhibitor, (b) CNG cylinder composed of gas with weight 14g and specific gravity of 0.5

2.5 Experiment process

Before commencing the experiments, the system undergoes flushing to remove any debris that could affect the results. For hydrate formation, a measured volume of water is added to the mixing vessel, then pump 3 is activated to send 2880ml of water into the inner line at 25psi, followed by closing the pump and valve. Pressure buildup to 150 psi in the inner line is achieved by opening and closing valve 1, circulating water through the PVC system via the pump, with continuous addition of ice blocks to mimic subsea temperatures. Agitation is initiated by activating pump 1, while pressure and temperature readings are monitored every 2 minutes for 120 minutes to detect gas hydrate formation indicators. For hydrate inhibition experiments, a specified inhibitor percentage is mixed with water in the mixing vessel, and the same procedure is followed after flushing the system and adjusting the water-inhibitor ratio.

3.Result and Discussion

3.1 Phytochemical Analysis

Table 1 presents the outcomes of the phytochemical analysis conducted on the derived from methanolic extracts of *Moringa oleifera*. These results reveal the presence of various phytochemical compounds, including flavonoids, saponins, and tannins, among others, all of which play pivotal roles in the inhibition process.

Table 1. Phytochemical analysis profile

Test Performed	Results
Total sample volume	2.83g
Appearance	Liquid
Colour description	Dark green
Saponin	+
Alkaloids	-
Protein(Amino Acids)	+
Steroids	+
Tannins	+
Anthraquinones	+
Phenolic Compounds	+
Carbohydrate	+
Glycoside	+
Flavonoids	+

(+) indicates present, (-) indicates absent

3.2 Data Analysis

Pressure against time plots was generated for both uninhibited experiments (no inhibitor present) and experiments with various weight percentages of Moringa leaf extract (MLE) and Methanol (MEOH). These plots are crucial for monitoring pressure changes over the 120-minute duration, where a rapid decrease in P1 from the initial 150psi indicates gas consumption for hydrate formation, highlighting the efficacy of the hydrate percentage relative to water volume. Conversely, a slower change in pressure suggests more effective hydrate inhibition. In Figure 5, which depicts the uninhibited experiment, a sharp pressure drop from 150 to 90 psi is observed. This suggests the formation of gas hydrates, where gas molecules are consumed and become trapped within the water lattice. This process is further supported by the observed temperature rise, indicating exothermic gas consumption during hydrate formation.

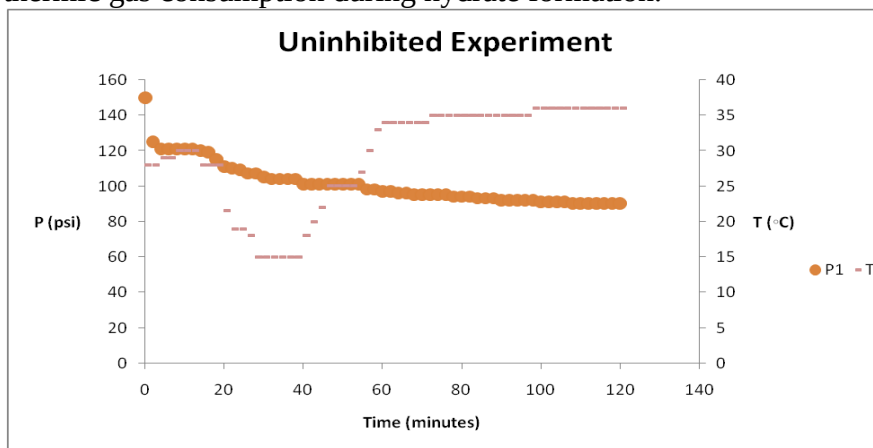


Figure 5. Plot showing uninhibited experiment values of pressure and temperature against time

Figure 6 for 0.02wt% MLE & 2wt% MEOH indicates a relationship between 0.02wt% MLE and 2wt% MEOH. The 2wt% percent MEOH outperforms the 0.02wt% by a small margin. The degree of performance is measured by the margin of disparity between the initial and final pressure values. From all initial pressure values of 150psi as per the requirements of the experiment, we can observe that the final pressure of the 2wt% tanks at 124 psi while that of the low-dosage 0.02wt% follows at 119psi.

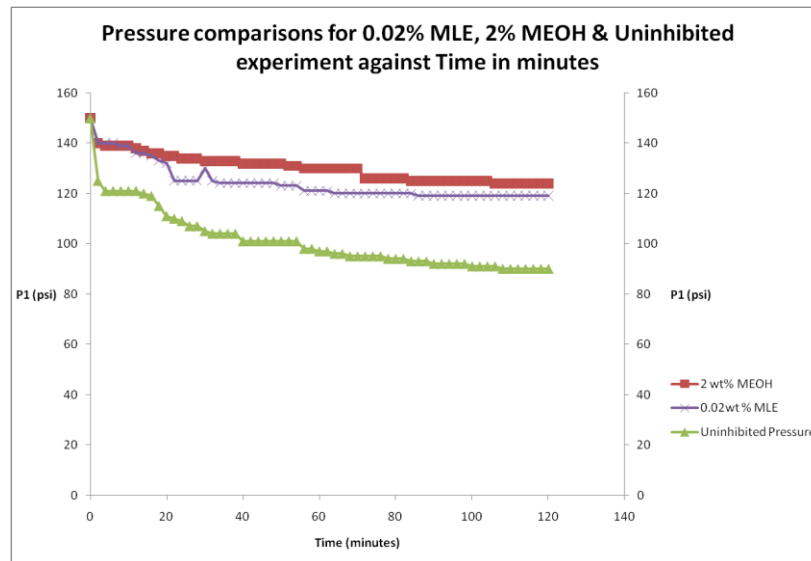


Figure 6. Showing pressure comparisons for 0.02wt% MLE, 2%wt MEOH and uninhibited experiment.

Figure 7 for 0.04wt% MLE & 4wt% MEOH shows a higher disparity in pressure for the 4wt% compared to the 0.04wt% MLE. 0.04wt% MLE was more effective at inhibiting hydrate formation as the final pressure tanked at 126psi, while that of the 4wt% MEOH tanked at a final pressure of 104psi. As earlier explained, the MLE did more work in inhibiting the formation of hydrates.

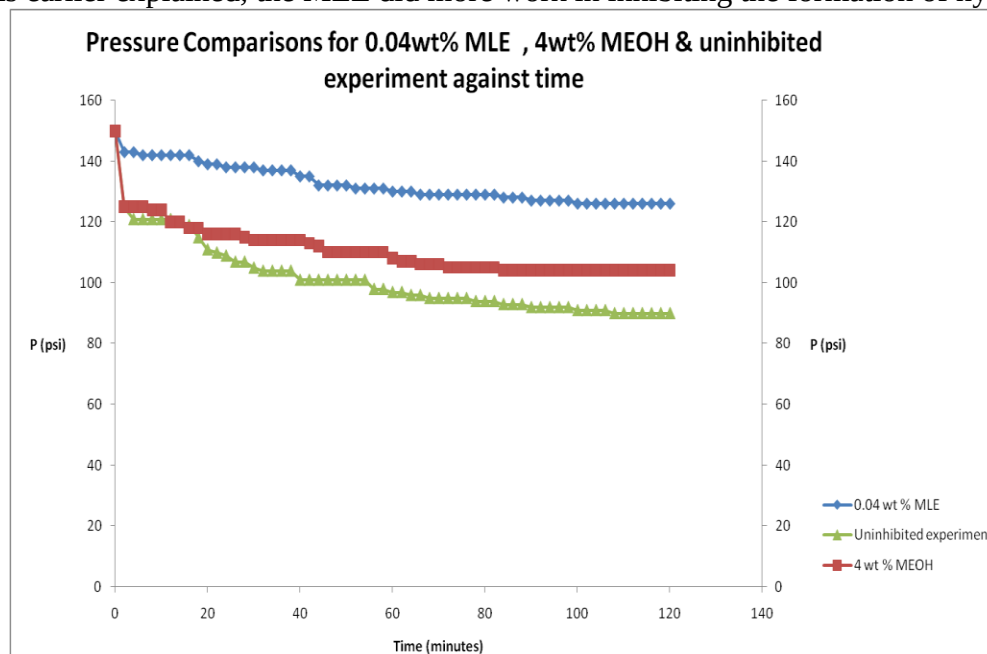


Figure 7. Showing pressure comparisons for 0.04wt% MLE, 4%wt MEOH and uninhibited experiment.

Figure 8 for 0.06wt% MLE & 6wt% MEOH shows a higher decrease in pressure for the 6wt% compared to the 0.06wt% MLE (100 & 117 psi respectively). 0.06wt% MLE was more effective

at inhibiting hydrate formation. Figure 9 shows pressure comparisons for all weight percentages, including the uninhibited experiment.

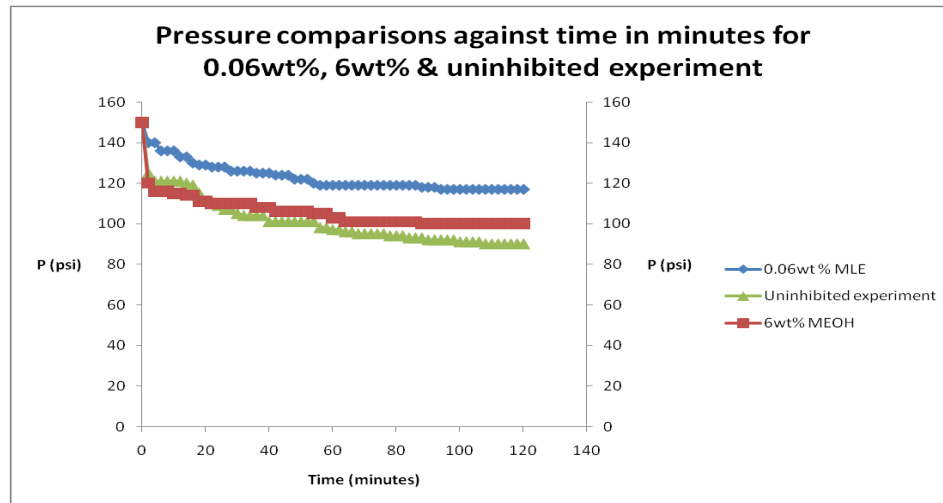


Figure 8 showing pressure comparisons for 0.06wt% MLE, 6wt% MEOH and uninhibited experiment.

Figure 9 shows pressure comparisons for all weights of MLE-inhibited and MEOH-inhibited experiments, alongside the uninhibited experiment. From the figure, it is clear to see that the 0.04wt% MLE outperforms all weight percentages of MEOH, with the nearest in performance to it being the 2wt % MEOH-inhibited experiment.

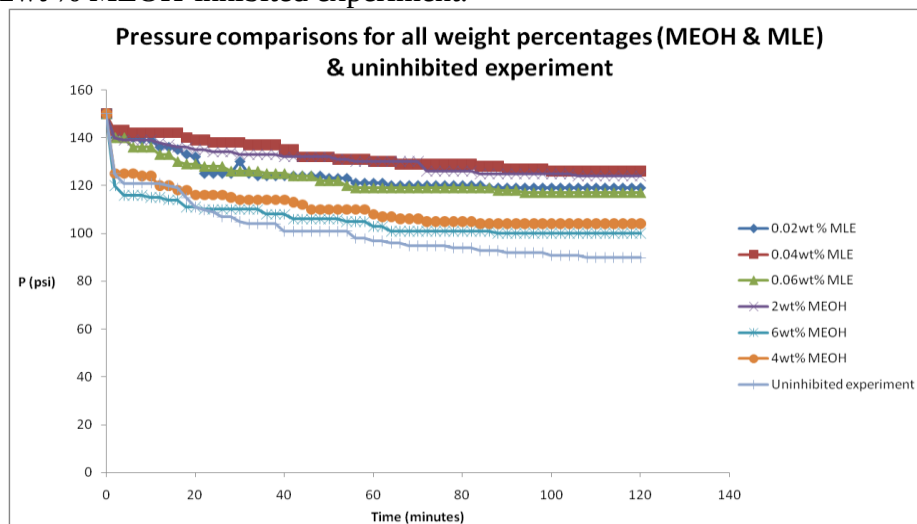


Figure 9 showing pressure comparisons for all weight percentages and uninhibited experiment

Figure 10 shows a combined plot of temperature against time for all weight percentages used. Whereas Thermodynamic hydrate inhibitors work by shifting the thermodynamic equilibrium to the left to prevent the system from entering the hydrate formation bracket, low-dosage hydrate inhibitors (LDHIs) have no such effect on temperature as their mode of inhibition differs. Low dosage hydrate inhibitors can either be kinetic in action (they delay hydrate induction time and nucleation for a period of time) or act as Anti-agglomerates (they allow hydrates to form but not

agglomerate into large chunks that can restrict flow). The kinetic hydrate inhibitors (THIs) showed better temperature responsiveness (keeping a relatively higher temperature) than the LDHIs. As should be the case, the uninhibited experiment showed a decrease in temperature until about 40 minutes in. Gradual temperature increases until a point of constancy is noticed for the remainder of the time. This satisfies a condition for hydrate formation presence which is an increase in temperature and a decrease in pressure.

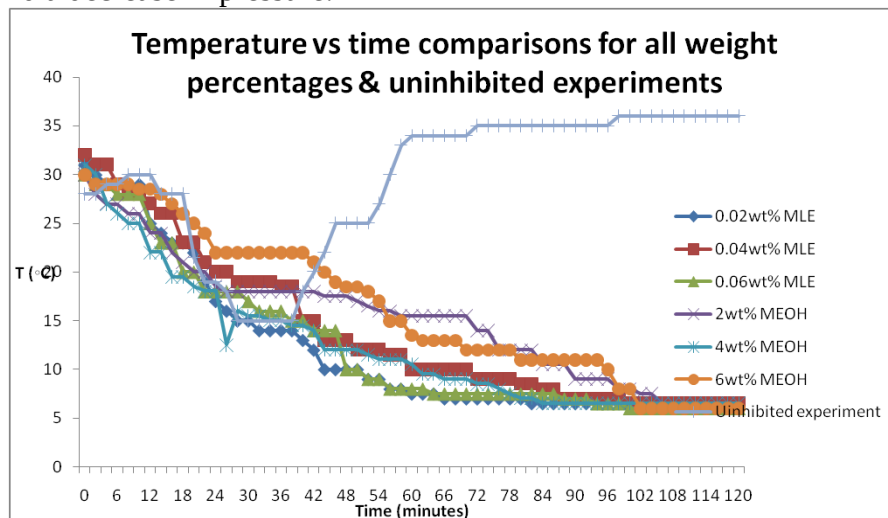


Figure 10 temperature vs time comparisons for all weight percentages and uninhibited experiment

As depicted in Figure 11, the solution containing 0.04wt% MLE exhibited the highest inhibition efficiency at 60%, when combined with 2% wt MEOH, which is 50 times greater than its quantity, achieving 56.67% inhibition. A greater inhibition efficiency suggests the superior ability to suppress hydrate formation. Upon reviewing the data, it becomes evident that the 0.04wt% MLE solution demonstrated superior inhibition performance overall. The 2 wt% MEOH solution showed comparable performance, closely trailing the 0.02wt% and 0.06wt% MLE solutions. It is noteworthy that the optimal methanol inhibition concentration (2 wt%) is 50 times higher than the optimal concentration of the hydrate inhibitor used in this experiment (0.04 wt% MLE). Generally, LDHIs outperformed THIs in inhibiting hydrate formation, as evidenced by pressure differential calculations, hydrate inhibition effectiveness calculations, and pressure loss over time. Increasing the LDHI concentration beyond 0.04wt% would be impractical and result in unnecessary costs. Methanol, primarily employed as a THI, should theoretically exhibit better suppression effectiveness with increasing concentration. However, it displayed abnormal behavior during the experiment duration.

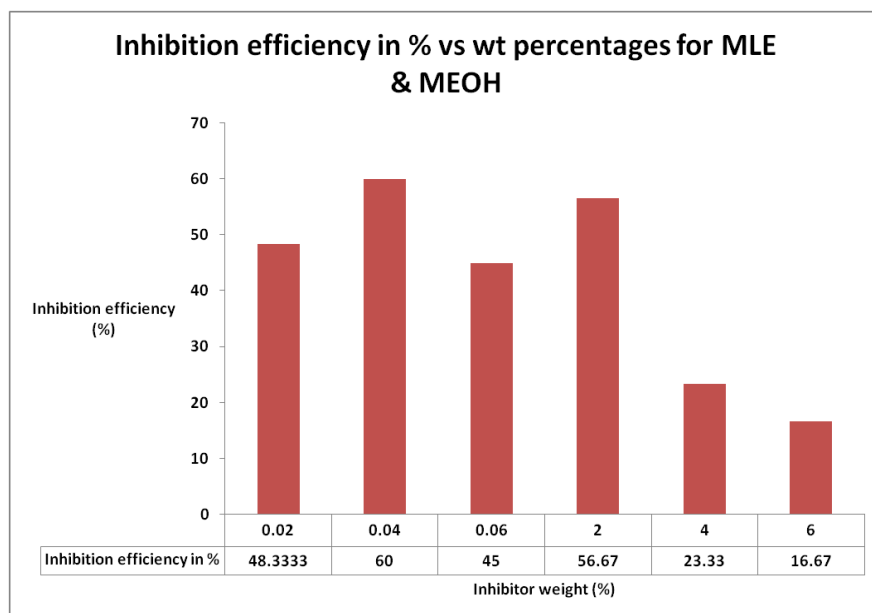


Figure 11 Plot of inhibition efficiency in percentage against weight percentages for MLE and MEOH

4. Conclusion

The experiment analysis revealed the following result. Comparing pressure versus time for varying concentrations of MLE and MEOH reveals intriguing findings. At 0.04wt% MLE, superior inhibition is observed, emphasizing the delicate balance between efficacy and cost-effectiveness. However, increasing the dosage beyond this point becomes counterintuitive economically. Additionally, while 0.04wt% MLE exhibits strong inhibition, it responds differently to temperature changes compared to THI, suggesting a complex relationship between concentration and environmental factors. Analysis of differential pressure readings further highlights the nuanced influence of inhibitor type and concentration. LDHIs outperform KHIs, with 0.04wt% MLE identified as the optimal concentration. The non-toxic and cost-effective nature of *Moringa oleifera* makes it a promising candidate for hydrate inhibition, with potential benefits in storage, production, and health applications, advocating for strategic investment in its utilization within oil and gas industrial settings.

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