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Investigation of Local Inhibitor for Dissociating Hydrate Formation in Offshore Flowlines in Nigeria

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Abstract: Gas hydrate has been one the major flow assurance challenges in natural gas production, storage and delivery to the end users. The aim of this research was to conduct an experimental investigation of a locally formulated chemical for the inhibition of gas hydrates. The research entails identifying an adequate local inhibitor using an n-vinyl caprolactam (N-VCAP) as additives with pressure/temperature analysis to assess the effectiveness of the formulated local inhibitor. In this study, experiments were conducted using a mini loop with a diameter of 0.5inch and total length of 12 m. In the experiments, local materials were used to create "Sample A" a biodegradable and water-soluble hydrate inhibitor. Experiments were further carried out to establish that the local inhibitor has a high inhibitory potential as compared to traditional inhibitors, N-Vinylcaprolactam (N-VCap). Different weight percentages of these inhibitors tested were 0.01wt%, 0.02wt%, 0.03wt%, 0.04wt%, 0.05wt%, 0.06wt%, and 0.07wt%. Plots of pressure, temperature and time of the formulated and conventional inhibitors were made and the results obtained were analyzed. 0.01wt%, 0.02wt% 0.04wt%, 0.05wt%, 0.06wt%, and 0.07wt% of Sample A clearly showed better inhibitory performance than the conventional ones. Sample A is environmentally friendly, biodegradable, affordable, efficient, and water soluble. As a result, it has been approved for field testing.

Keywords: Gas Hydrate, Flow Assurance, Pressure, Temperature, Inhibitor

1. Introduction

Gas hydrates are glassy solids formed when hydrocarbon gases like methane, ethane, propane, and butane, as well as impurities/non-hydrocarbon gases like carbon dioxide, hydrogen sulphide, or nitrogen, react with water at low temperatures (0-40°C or 32-104°F) and high pressures (> 200 psig) [46]. Natural Gas Hydrates (NGH) have become a major source of concern in terms of oil and gas quality flow assurance from the wellhead to the production site [4]. It is said to be the most serious problem in ensuring fluid flow through pipelines, especially in deep offshore oil and gas production [45]. From the time of Hammerschmidt [12] to the present, the basic rationale has always been to completely suppress or avoid the creation of hydrates. This is accomplished by maintaining subsea pipelines out of the hydrate zone during steady state. Gases are dehydrated by removing water, and flow lines are sealed to help maintain the temperature above the hydrate forming temperature to minimize heat losses to the environment. Pressures are often held below those needed for hydrate formation. From a flow assurance standpoint, gas hydrate formation is unquestionably feared as the most serious danger of clogging the oil and gas production system. This is why several studies are typically conducted to compare many ways in order to choose the one that provides the best balance of cost and risk. Controlling the potential for hydrate formation is critical and must be avoided at all costs, as they can choke flow strings, surface lines, and other equipment, lower measured well head pressure in flow strings, and completely block flow lines and surface equipment.

Gas hydrates are crystal-like structures whose composition are gas and water particle [45]. The formation of any of the three types of hydrate structures, S.I, S.I.I, and S.H hydrate, relies on the size and properties of the gas particles engaged by the water component. CH_4 and CO_2 gas molecules form SI molecules, while larger gas molecules form S.I.I particles such as Propane can also form S.I.I structure. Pentanes, paraffin, and cycloalkanes combine to form S.H structures [48]. The van der Waals

bond holds the water and gas molecules together, while hydrogen bonding holds the water molecules together. The composition of hydrates in pipelines is one of the flow assurance difficulties that is thought to be chronic. Hydrates account for nearly 70% of the operational costs associated with flow assurance. Its accumulation clogs the flowlines and disrupts hydrocarbon traffic, in addition to posing potential hazards, [30]. Complications with flow assurance, such as wax deposition and hydrate composition, are big issues that cost the industry billions in lost production and maintenance operations [37]. Hydrate extraction in hydrocarbon pipelines causes around a million shut downs every day, Koh [23], and hydrate mitigation strategies and techniques cost the oil and gas industry a lot of money yearly [7].

Because of the harsh offshore climate and the high carbon dioxide content of the gases, discovery and transportation of these reserves are complicated. One of the most significant problems in carbon dioxide-rich gas systems is the formation of hydrates in the production lines [42, 43, 22]. To provide safe flow assurance operations during their transportation, an in-depth understanding of these natural gas mix systems is needed. Basic understanding is also needed in order to design carbon dioxide separation systems and provide storage facilities for the carbon dioxide generated by these natural gas mixtures [47, 6, 20]. Various methods such as fluid segregation to remove hydrate formers using heat application, pressure control, mechanical scrapping or pigging, thermal insulation, electrical heating, and chemical injection are used to prevent hydrate formation. Chemical injection is the most popular and simplest method, mainly in places where access is challenging, such as deep offshore [47, 3, 53, 37]. Chemical injection is thought to be more cost-effective, particularly in remote areas with limited access [46, 44]. Chemical inhibitors that alter the phase activity of mixtures by relocating the locus of hydrate formation to lower temperatures and/or higher pressures are often used can be pumped, thus widening the hydrate-free zone [46].

Literature of the use of locally available natural compounds as inhibitors of gas hydrate is hardly used. In the course of the gas expansion, Odutola et al. [34] conducted a comparative analysis to determine the efficacy, during gas expansion, of methanol (MeOH) and of monoethylene glycol (MEG). Using C.S.M Gem tools, they developed the hydrate formation and inhibition curves. Methanol did much better than mono-ethylene glycol because 10wt% avoided hydrate forming at an expansion of 3,338 psias, while 10wt% of M.E.G did not extend above 3,750 psia when gas was extended. The use of Plant Extract (PE) as a gas hydrate inhibitor stated by [10]. In a virtual offshore atmosphere with a mini flow-loop device, the experiment took place in a 4-inch Polyvinylchloride (P.V.C) pipe skid fixed on a metal frame works 39.4 inches long with an internal diameter of 0.5 inches [33]. The weight percentages of local inhibitors (1, 2 and 3wt percent) recorded to contain bioactive compounds such as alkaloids, saponins, tannins and flavonoids were used

for various water levels. The efficiency of plant extract was assessed using compared plots of pressure to time, temperature to time, differential pressure and pressure and temperature to time for both inhibited and uninhibited scenarios (P.E). 120% and 2W% of plant extract (P.E) were found to be higher than the same Monoethylene glycol weight per cent. The inhibitory potential was close to 3wt percent, both Plant Extract and Mono Ethylene Glycol. The P.E is also recommended for field tests because it is environmentally stable and biodegradable. Elechi et al. [11] conducted a plant extract analysis as an inhibitor of gas hydrate.

Through their analysis the Costaceae Family Extract (C.F.E), which has been deemed optimum for C.F.E, was found to perform favorably well in all the weight percentage with the traditional Hydrate Mono Ethylene Glycol (M.E.G), while it has done marginally better than M.E.G in 2wt%.

The use of agro algae-based materials of local origin as inhibitors of gas hydrate was also investigated by [35]. The locally developed kinetic hydrate inhibitor, N-VinylCaprolactam (N-V.Cap), and 2-Di (methylamino) ethyl methacrylate were best performed as traditional gas hydrate inhibitors (2-DMEM). Elechi et al, [11] and Okon et al., [35] all concluded that there are local usable inhibitors from plant sources of Costaceae Family Extract (C.F.E) and of agro-waste based gas hydrate. They are ecological (in the way it is biodegradable) as well as harmful to humans or to the atmosphere as a gas hydrate inhibitor in favour of M.E, N-V.Cap and 2-DMEM. Without special focus on inhibition effectiveness, the analysis carried out by Elechi et al., [10] showed the ability of a local inhibitor to inhibit hydrate with the Plant extract. This analysis therefore takes account of the plant extract inhibition efficiency (P.E) and the optimal plant extract weight percentage (P.E).

Talaghart [54] has shown that increased gas pressure within the under study structure leads to increased gas intake and reduced induction time in his studies on gas hydrate. He also observed that in the presence of inhibitors the level of hydrate forming decreased. LTyrosine was stronger than Poly Vinyl Pyrrolidone (PVP) in all the device investigations as an agent of gas hydrate inhibitor. Methanol was stronger than monoethylene glycol was observed. Synthetic gas hydrate inhibitors have been used in both of these trials. However these inhibitors are proved successful to mitigate gas hydrate in mammalian, terrestrial and aquatic life, posing environmental issues. There is a need to use local materials which are easily accessible and which are less threatening to life and environment in our environment.

Hydrate formation is a serious flow assurance issue in the petroleum industry, especially in offshore environments where access is limited. In this article, gas hydrate inhibition is assessed and studied in a stable setting using locally sourced materials such as leaf extracts (L.E) as a local inhibitor. This research looks for an efficient biodegradable gas hydrate inhibitor made from locally available materials and compares it to a traditional hydrate inhibitor called polyvinyl capiolactam (N-V.C.A.P).

1.1. Categories of Inhibitors

Thermodynamic Hydrate Inhibitors (THI): They shift the gas hydrate curve's equilibrium conditions to lower the hydrate formation temperatures and higher pressures, making hydrate formation less likely. THIs are typically expected in high concentrations of 10–50 wt% of water cuts [19]. THIs such as methanol (MeOH) and ethylene glycol (EG) are widely used. Despite the fact that thermodynamic hydrate inhibitors are still used in fields, they have several limitations. High operating costs due to transportation, storage, injection and pumping volumes needed, and replication units in the case of glycols are just a few of the drawbacks [40, 56]. Low Dose Hydrate Inhibitors (LDHIs) are named after the amount of volume needed to inhibit gas hydrates. They are used in water cuts in doses as low as 0.01-1wt percent. Low-dosage hydrate inhibitors L.D.H.I, unlike thermodynamic hydrate inhibitors T.H.I. like methanol or glycols, do not induce a hydrate-curve change, so they do not fully prevent hydrate formation. Since the operating conditions cannot be modified (lowering pressures or raising temperatures), hydrate cannot be removed by L.D.H.I once it has formed. As a result, a well remains at risk when L.D.H.I are used. T.H.I. must remain on site, especially when closing in or beginning a well.

Kinetic Hydrate Inhibitors (KHIs) are water-soluble polymeric compounds that impede the formulation of hydrates by increasing the energy needed to shape them through structural distortion [52], they inhibit or hinder the development of hydrates. This could also be accomplished by gas diffusion to water face obstruction, which causes hydrate crystallization around and between the polymer strands [27].They can cope with a wider range of water cuts, but they are vulnerable to brine salinity [59]. Poly Vinylpyrrolidone and Vinylcaprolactam, were reported in the early 1990s by the Colorado College of Mines [18]. While K.H.I reduces costs in terms of C.A.P.E.X and O.P.E.X, their use in the field on a wide scale poses significant problems due to their low biodegradability, [17]. In this regard, and in order to address the issue of environmental footprints, scientists are working to develop environmentally stable and biodegradable inhibitors. Green inhibitors are the name given to these inhibitors. Green Inhibitors (G.I): These are non-polluting, biodegradable, and environmentally safe inhibitors. Anti-Freeze Proteins (A.F.P), Natural and Biodegradable Polymers (N.B.P), and Ionic Liquids (I.L), which are mostly imidazolium-based liquids that have been studied for gas hydrate reduction, are among them.

Anti-Agglomerants (A.A.S): Anti-Agglomerants (A.A.s) are surface active agents (surfactants) that inhibit hydrates from clumping and binding together. Because of the limited crystal size, the hydrate also forms, but the crystals do not clog or plug pipelines and can be shipped via pipelines. They only function where there is a liquid hydrocarbon process present, such as crude oil or condensates. Alkyl aromatic sulphates are one example.
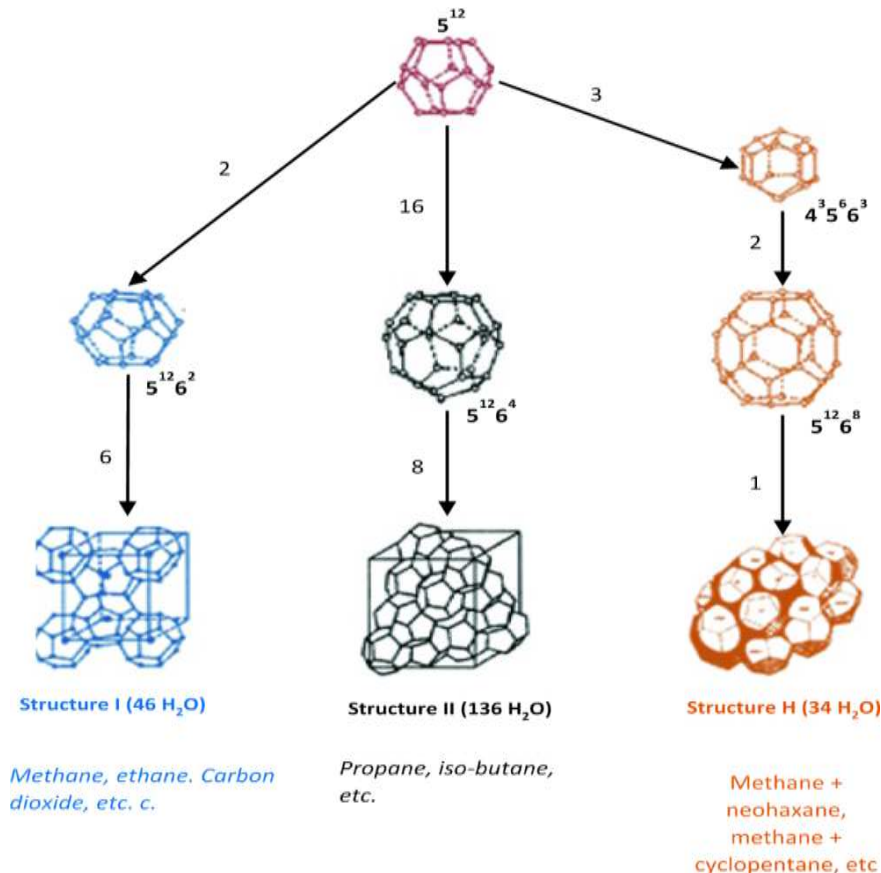

Figure 1. *Cavities for hydrates of SI, SII, and SH [15].*

1.2. Hydrate Structures

Hydrates are commonly classified under their structures into Type I, Type II and Type H according to [14], but the most common hydrates in gas pipes are Type I and Tyme II. The hydrate structure was investigated by the X-ray diffraction system of [58]. The two structures of hydrates, Structure I (S.I) and Structure II (S.II), which both have two cavity sizes, were described during their study in collaboration with the works of Classes. The S.I hydrates are made up of 46 molecules of water for each eight cavities, 2 small spherical cavities with 12 pentagonal faces (512), and 6 big cavities of oblates with 2 hexagonal faces and 12 pentagonal (51262) faces (Heriot 2005). SII hydrates consists of 136 water molecules per 32 cavities, 16 small pentagonal cavities (512) and 8 wide cavities (51264), all in spherical form, with 12 pentagonal and four hexagonal sides. Figure 1 shows these cavities.

From 1959 to 1967 researched crystallography in hydrates S.I and S.II. done by [29, 26]. A description of the hydrates shows "tiny" hydrates. Tiny gas molecules such as CH_4, C_2H_6 and CO_2 are well known to form hydrate Structure I but hydrate Structure II is formed by gas molecules of greater size such as C_3H_8 and i-C_4H_{10}. Any small gas molecules such as Ar. and Kr. nevertheless shape hydrate structures [31]. The third kind of hydrate structure was found by [41] (S.H). The development of hydrate S.H needs to be stabilized in small as well as large molecules. S.H. hydrates contain 34 water molecules, each six cavities, three cavities made up of 12 pentagons (5, 12), two cavities, two squares of three, six pentagonal and three hexagonal facets (435,663), [15]. The formulation of hydrate S.H involves massive gas molecules such as methylcyclopentane, commonly found in gas condensate systems and in petroleum systems. My research focuses on Structure I and Structure II, which consist essentially of natural gas. Although none of these variables represent hydrate structures of the regression model, the structure of hydrates is not involved directly in the development of new correlations. We however assume that our correlations have taken into account the specific gravity of the hydro electron structure, since components of different dimensions form different types of hydroelectronic structures. Becke et al., [2] in their binaries and ternaria with methane and/or nitrogen, tested S.H for methane+methylcyclohexane and likewise [36]. Mehta and Sloan [35] gave an analysis of the cutting-edge S.H hydrates with a focus on its consequences for the petroleum industry.

1.3. Hydrate Formation Condition

Water molecules have peculiar properties through the boiling point, vaporization enthalpy and freezing expansion relative to most related molecules. That's explained by its two unlimited pairs of (oxygen) electrons which cause hydrogen bonding to the electrostatic charges of the molecules. While in alcohols and group 6A compounds with hydrogen hydrogen bonds are also present, they are especially stronger in water [57, 50]. Due to its hydrogen-bonding properties, water may develop hydrates. This combination allows water molecules to stabilize the lines of the alignment with the van der Waal forces (which need to be heavy enough) so they precipate a firm hydrate mixture as noted by Cwiklik and Devlin [5], but no connection exists between guest molecules and host. The molecules are aligned by the guests or former molecules (CH_4, C_2H_6, C_3H_8, Cl_2, H_2S, CO_2). Guest molecule solubility is also of the utmost significance as it cannot be excessively water soluble [28, 16]. The upper limits of CO_2, H_2S and SO_2, which are substantially soluble, while ammonia and HCl that are strongly water soluble cannot create hydrates. Turbulence or agitations, nuclear sites and water-free improves hydrate formation in the pipelines. Gas is usually delivered at high speed and, due to flow conditions, causes agitation in the pipeline. Thus, gas that often flows through the throat of valves, could cause Joule Thompson effects which may decrease temperature and hence promote hydrates in the line.. The existence of soldered areas (bows, tee etc.) gravel, skids, slits and sand also strengthen the coarsened of free water as the interaction between gas and water is a strong core.

1.4. Gas Hydrates and Problems in the Oil and Gas Industry

Hammerschmidt1 found that natural gas hydrates often obstruct pipelines above the freezing point of the gas transmission at temperature. This finding emphasized the role of hydrates in the oil and gas industry and marked a beginning of modern science. In oil exploration and production activities, gas hydrates represent an expensive challenge. Hydrate clathrates can plug gas collecting systems and pipelines on the surface and below sea. The primary challenge for offshore drilling is the multi-phase transition lines from the well to the production site, where the deposition of gas hydrates is facilitated by low seabed and high operating pressure.

1.5. Hydrate Implications on Subsea Transport System

If the shaped hydrate was not removed immediately, so the inner opening of the subsea transmission lines would be plugged [25]. The result is high pressure accumulation inside the line and subsequent failure of the line, which poses a grave danger to the safety of working staff and machinery. The failed pipeline even frees the fluid material into the surrounding atmosphere, causing many issues with the environment.

1.6. Hydrate Formation Problems Along Offshore Gas Pipelines

During the distribution through offshore pipelines, the low paraffin compositions (C_1-C_4) of natural gas generally mix non-hydrocarbon gas (such as N_2, CO_2, H_2S) and water vapor to produce gas hydrate, a big concern in natural gas extraction, refining and transport. Gas hydrates are icy, crystal lattice, stable structures formed by combining water molecules with small hydrocarbon molecules with high

pressure and low temperature components that contain non-hydrocarbons, due to the poor strength of the Van der Waals and hydrogen binding effects of water [13, 8, 24]. A smaller guest in diameters such as CH_4 and C_2H_6 is used for stabilization of the crystalline compound, which is stuck in the microstructures of the crystal grid of the host water.

A standard hydrogen is 90% H_2O, while the remaining 10% are other components [1]. Ethane gas can, in particular, form gaseous hydrate under 4C at 1 M.Pa, while hydrate can readily form under 14C at 3 M.Pa [55]. Underwater pipelines frequently provide the conditions for thermodynamic transportation [38, 25], when the gas is delivered in high pressure and very low atmospheric temperatures at supersonic speed. Due to the accelerated formation of gas hydrates, flow insurance in the case of deep sea shipping in comparison to other solid depots is much more serious and general [45]. Dues to the natural properties of hydrates, in particular, non-fluxing crystalline solids that make them denser than standard fluids, the flow and safety concerns of oil and gas pipelines are significantly affected [44].

2. Experimental Setting

Fresh Water (pH 7) was poured into the Freezer. The water was above the spiral 0.5 inch tubing in the refrigerating unit. The freezer contained a combination of fresh water and some pieces of ice-block. The ice-block aids in quickening the cooling of water in the freezer. A cylinder containing the compressed natural gas with a specific gravity of 0.5 is used for conducting the experiment.

The inhibitor used consists of: Low-dose hydrate inhibitor was locally developed which consists of local materials and renders certain essential components a very strong hydrate inhibitor, and the traditional control inhibitor was N vinyl caprolactam (n-v.cap).

A mini flow loop was used in figure 2 which displays the entire procedure flow diagram. The circle consists of 316 stainless steel, with a diameter of 0.5inch and is enclosed by a 4inch polyvinyl chloride (P.V.C) pipe formed in an external frame. The mini flow loop's overall length is about 12 m (39.4"). Three separate switches are integrated in a control panel to control the procedure. The refrigerating device and the P.V.C pipe with a diameter of 4-inch simulate an offshore environment. The refrigeration unit, the loop has three pumps, a manual pump and three temperature controls. An inhibitor and water mixing box is provided to mix the weight of each inhibitor, the machine consists of a C.N.G bottle and a flow meter.
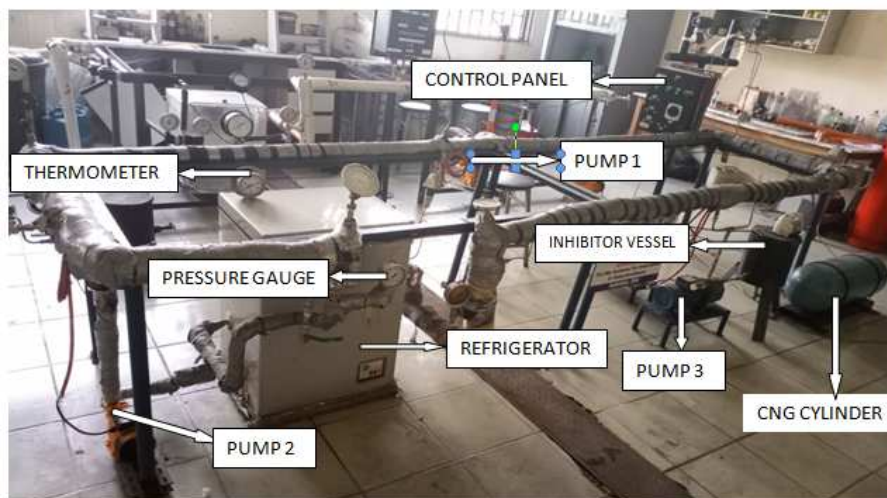
Figure 2. Gas hydrate mini flow loop.

2.1. Describing the Key Part of the Loop

The control panel is an equipment stores and supplies electric current to the whole system. It is directly connected to the AC or DC source, in this experiment, DC source used was a generating set. The control panel supplies electricity to the freezer, pump and the mixer. There is another one for controlling the flow rate of fluid flowing in the loop. The flow meter displays the flow rate of the fluid in the circle. A pump is a device that pumps fluids (liquids) or sometimes slurries by mechanical action. In this research, electrically operated were utilized. Pump 1, style QB60 and rating 0.5 hp. Pump 1. This pump is located along the circuit and its duties are to flow the fluid along the circuit. Pump 2 is considered to be pump 1. The cooling water is moved from the cooling device by pulling the cooling water from the cooling device, which is placed near the cooling unit. The water is actively pumped to refrigerate the 316 tube, which is concentrated in the 4-inch PVC tube, in an internal diameter of 0.5 inches. Pump 3 is ATP 1.25 with a ranking of 1 hours. The machine operates at 220 volt, 4.8 amperes, 50 hertz and 2850. This pump drags the liquid in the inhibitor container in the 0.5 inch ID stainless steel tubing.

Vessel inhibitor is made of metal. It has a cover and a stand for trombones. Vessel length is 0.1ft. (0.34 meters) and vessel length is 0.875ft. (0.2667 meters) and the vessel capacity is 0.26513ft. In the inhibitor vessel, a certain weight percentage of the inhibitor is drained into the water medium.

The mixture is then admitted through the pump3 into the loop. The valve under the vessel drains the unwanted or left liquid (mixture or water inhibitor) when released. The pump is fastened to the inhibitor container manually. The pump works on the general principle of driving the inhibitor blend up and down its handle by using force. A fridge is attached to the column, the power supply required to decrease the water temperature. The freezer contains some water and ice blocks are stored in the water. When pump 2, the fresh water in the freezer rounds the circle begins to circulate. The water temperature leaving the freezer is lower than that of the same water. This follows from the water's absorbing heat as it passes through the circle for a while. In the refrigeration cell of the ring sits about 0.7-meter spiral 0,5-inch tubing [32]. In this region of the loop hydrate formation begins, since it is the coldest part.

2.2. Sample Point Pressure Gauge

The 0.5 inch inner pipe line, which stretches beyond the freezer, is connected to this pressure gauge. The tap to control effluent or fluid pressure is mounted on that side. This pressure gage is calibrated to allow users to determine the different effluent or fluid pressure in this place as the last realistic one.

2.3. Outlet Point Pressure Gauge

In a 0.5-inch stainless steel tubing flowing from the freezer region of the effluent pressure or liquids is measuring.

2.4. Inlet Point Pressure Gauge

The inlet Point Pressure Gauge records the pressure of effluents or fluids in the 0.5 inch stainless steel tubing flowing to the freezer region. It comprises of the pressure gauge along the loop and the differential pressure transmitter.

2.5. Pressure Gauge along the Loop

This gauge measures the pressure of effluent or fluids flowing along the 0.5 inch stainless tubing.

2.6. Different Pressure Transmitter

It measures the deviation in pressure between high pressure line and low pressure line and low pressure line of fluids flowing the tubing.

2.7. Outlet Point Temperature Gauge

This equip measures the temperature of effluent or fluids flowing away from the Freezer region.

2.8. Inlet Point Temperature Gauge

This gauge records the temperature of the effluent or fluids returning to the Freezer. Its temperature reading is higher relative to the temperature recorded on the Outlet Point Temperature Gauge. This is because the water returning to the Freezer gains a significant quality of heat as it travels along the loop.

2.9. Cooling Water Temperature Gauge

This gauge records the temperature of water in the freezer. The water in the freezer constantly undergoes cooling because of ice pieces dropped into the Freezer. In fact, in the whole set-up, the lowest temperature as recorded by this gauge is encountered in the refrigerating unit and it is in this region that there is likelihood of gas hydrate formation.

Natural gas comprises mainly of methane (above 90%). Frequently, trace amount of gases such as ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulfide and water vapour are present. Natural gas is compressed, for it to be kept and applied as compressed natural gas (CNG). To store a larger volume of natural gas as CNG, the lofty pressure of approximately 200 bar or 2900 psi is required [51]. According to Total Support Gas Company, the specific gravity of CNG utilized in this study is 0.5 with composition as seen in Table 1 below.

Table 1. *Composition of the Compressed Natural Gas (CNG) Used.*

Composition	Formula	Mole percent
Carbon dioxide	CO_2	1.50
Methane	CH_4	98.44
Total		99.94

The components of natural gas keep varying over different time durations and locations (poulton, 1994). At the recognition range of temperature and pressure, natural gas exist as a gas with low density. The volumetric energy density (joules/m^3) of natural gas is extremely reduced; consequently, the gas is always compressed at high pressure and kept in pressure vessels. The properties of CNG fuel are as shown in Table 2 below.

**Table 2.** *Properties of CNG [9].*

CNG Properties	
Density (kg/m^3)	0.72
Flammability Limits (volume % in air)	4.3-15
Flammability Limits (Ø)	0.4-1.6
Auto ignition temperature in air (℃)	723
Minimum ignition energy (mJ)	0.28
Flame velocity (ms^{-1})	0.38
Adiabatic flame temperature (K)	2214
Quenching distance (mm)	2.1
Stoichiometric fuel/air mass ratio	0.069
Stoichiometric volume fraction (%)	9.48
Lower heating value ($MJ|kg$)	45.8
Heat of combustion (MJ/kg $_{air}$)	2.9

Table 3. *CNG Characteristics.*

| CNG Characteristics	Value
Vapour density	0.68
Auto ignition	700℃
Octane rating	130
Boiling point (Atm. Press)	-162℃
Air-Fuel Ratio (Weight)	17.24
Chemical Reaction with Rubber	No
Storage Pressure	20.6 MPa
Fuel Air Mixture Quality	Good
Pollution CO-HC-NO_X	Very Low
Flame Speed (m/sec)	0.63
Combustion ability with air	4-14%

3. Results and Discussion

Various plots were used to analyze this work. The different plots were done for the inhibited experiments (hydrate mitigation as seen in figures 3-20). The plots are pressure versus time, temperature versus time and pressure and temperature versus time. For the inhibited experiment, the initial temperature was 31°C at the pressure of 150 psi. For the first 10 minutes and steady temperature of 31°C, no temperature drop or increment was observed, for the next 40 minutes there was a drastic decrease in temperature from 31°C to 15°C, from 40 minutes to 120 minutes there was a little decrease in temperature indicated in figure 3. The steady temperature drop noticed during the experiment shows that gas was being encapsulated by water molecules in the 0.5 inch 316 stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.
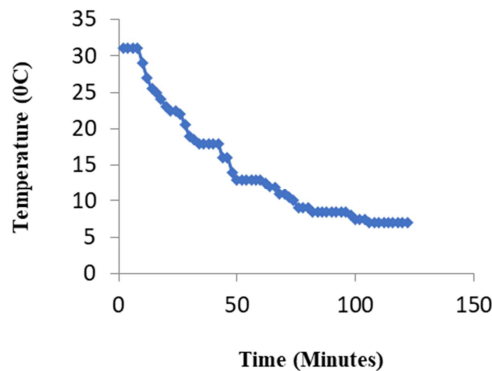
Figure 3. Temperature versus Time for inhibited system at 0.01% of SAMPLE A.

For the first 5 minutes recorded a pressure decline from 150 to 134 psi for the 0.01% of SAMPLE A for the next 5-120 minutes there was a decrease in pressure from 134 to 110 psi as shown in Figure 4.
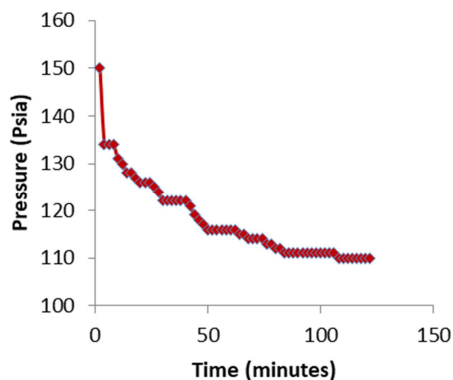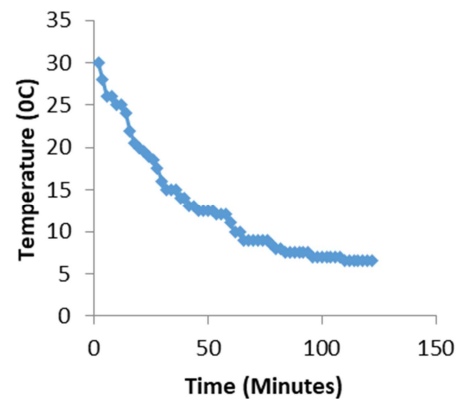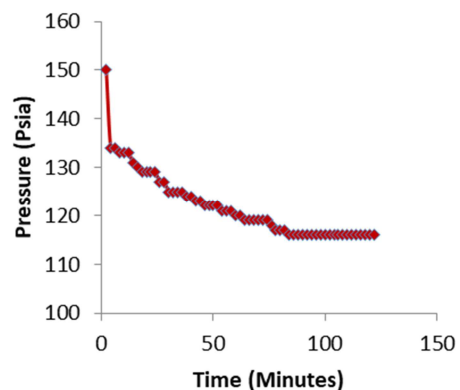

Figure 4. Pressure versus Time for inhibited system at 0.01% of N-VCAP.

Temperature versus Time for inhibited system at 0.02% of SAMPLE A (Figure 6). For the inhibited experiment, the initial temperature was 30°C at the pressure of 150 psi. From 10 to 120 minutes and there was a drastic decrease in temperature from 30°C to 6°C, as indicated in figure 10. The steady temperature drop noticed during the experiment shows

that gas was being encapsulated by water molecules in the 0.5 inch 316 stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.
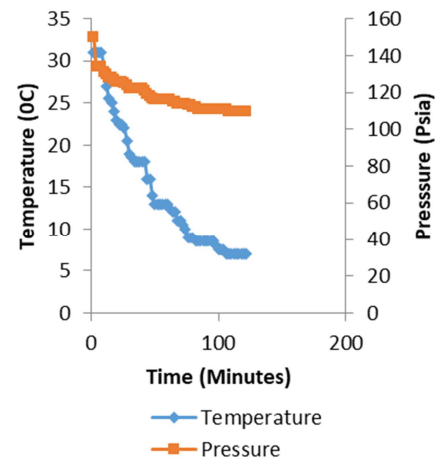
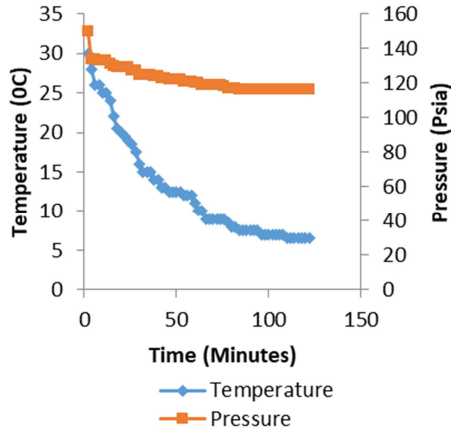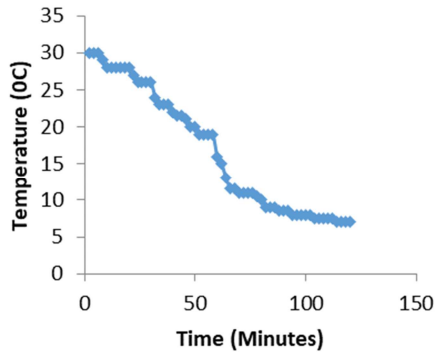Figure 5. Pressure and Temperature versus Time for inhibited system at 0.01% of SAMPLE A.

Figure 6. Temperature versus Time for inhibited system at 0.02% of SAMPLE A.

Pressure versus Time for inhibited system at 0.02% of SAMPLE A (Figure 7). For the first 5 minutes recorded a pressure decline from 150 to 134 psi for the 0.02% of SAMPLE A for the next 5-120 minutes there was a decrease in pressure from 134 to 110 psi.

Figure 7. Pressure versus Time for inhibited system at 0.02% of SAMPLE A.

Pressure and Temperature versus Time for inhibited system at 0.02% of SAMPLE A (Figure 8).
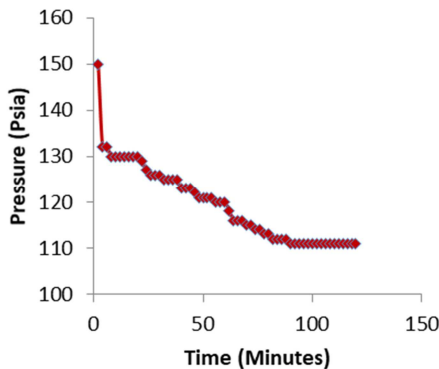

Figure 8. *Pressure and Temperature versus Time for inhibited system at 0.02% of SAMPLE A.*

Temperature versus Time for inhibited system at 0.03% of SAMPLE A (Figure 9). For the inhibited experiment, the initial temperature was 30°C at the pressure of 150 psi. From 0 to 120 minutes and there was a drastic decrease in temperature from 30°C to 6°C. The steady temperature drop noticed during the experiment shows that gas was being encapsulated by water molecules in the 0.5 inch 316 stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.
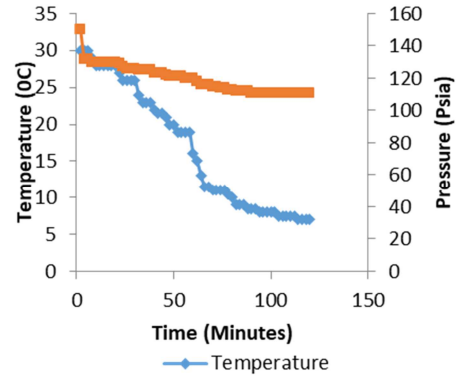

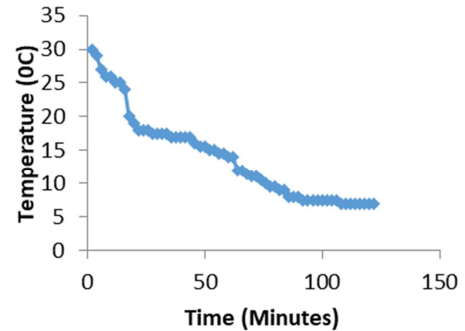***Figure 9.*** *Temperature versus Time for inhibited system at 0.03% of SAMPLE A.*

Figure 10. *Pressure versus Time for inhibited system at 0.03% of SAMPLE A.*

Pressure versus Time for inhibited system at 0.03% of SAMPLE A (Figure 10). For the first 5 minutes recorded a pressure decline from 150 to 132 psi for the 0.03% of SAMPLE A for the next 5-120 minutes there was a decrease in pressure from 132 to 110 psi.
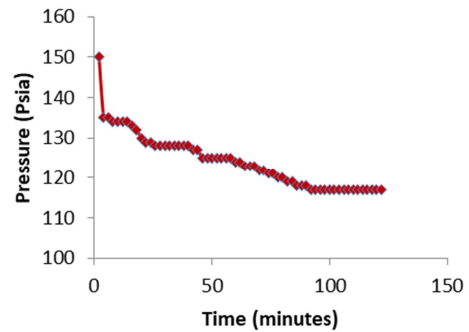

Figure 11. *Pressure and Temperature versus Time for inhibited system at 0.03% of SAMPLE A.*

Temperature versus Time for inhibited system at 0.04% of SAMPLE A (Figure 12). For the inhibited experiment, the initial temperature was 30°C at the pressure of 150 psi. From 0 to 120 minutes and there was a drastic decrease in temperature from 30°C to 6°C. The steady temperature drop noticed during the experiment shows that gas was being encapsulated by water molecules in the 0.5 inch 316 stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.
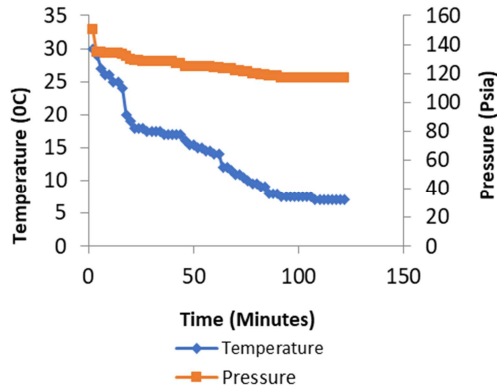

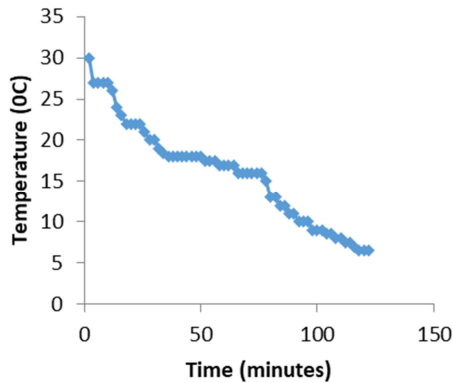***Figure 12.*** *Temperature versus Time for inhibited system at 0.04% of SAMPLE A.*

Figure 13. *Pressure versus Time for inhibited system at 0.04% of SAMPLE A.*
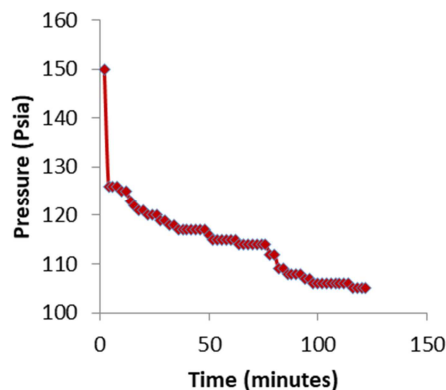
Pressure versus Time for inhibited system at 0.04% of SAMPLE A (Figure 13). For the first 3 minutes recorded a pressure decline from 150 to 134 psi for the 0.04% of SAMPLE A for the next 3-120 minutes there was a decrease in pressure from 134 to 110 psi.

Figure 14. Pressure and Temperature versus Time for inhibited system at 0.04% of SAMPLE A.

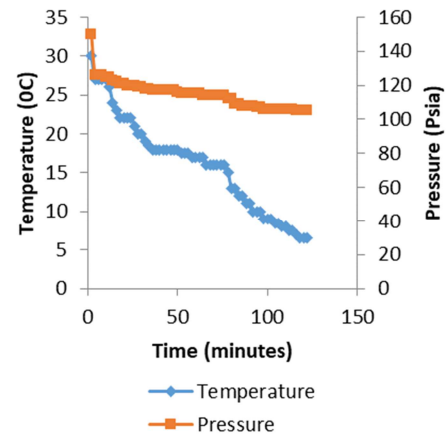*Figure 15. Temperature versus Time for inhibited system at 0.05% of SAMPLE A.*

Figure 16. Pressure versus Time for inhibited system at 0.05% of SAMPLE A.

Temperature versus Time for inhibited system at 0.05% of SAMPLE A (Figure 15). For the inhibited experiment, the initial temperature was 30°C at the pressure of 150 psi. From 0 to 120 minutes and there was a drastic decrease in temperature from 30°C to 6°C. The steady temperature drop noticed during the experiment shows that gas was being encapsulated by water molecules in the 0.5 inch 316

stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.
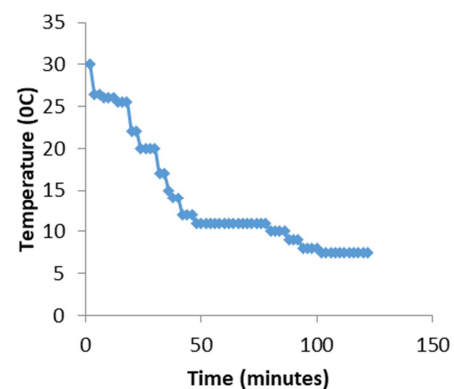
Pressure versus Time for inhibited system at 0.05% of SAMPLE A (Figure 16). For the first 2 minutes recorded a pressure decline from 150 to 135 psi for the 0.05% of SAMPLE A for the next 2-120 minutes there was a decrease in pressure from 135 to 105 psi.

Pressure and Temperature versus Time for inhibited system at 0.01% of SAMPLE A (Figure 17).

Figure 17. Pressure and Temperature versus Time for inhibited system at 0.01% of N-VCAP.

Temperature versus Time for inhibited system at 0.01% of N-VCAP (Figure 17). For the inhibited experiment, the initial temperature was 30°C at the pressure of 150 psi. From 0 to 120 minutes and there was a drastic decrease in temperature from 30°C to 6°C. The steady temperature drop noticed during the experiment shows that gas was being encapsulated by water molecules in the 0.5 inch 316 stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.

Figure 18. Temperature versus Time for inhibited system at 0.02% of N-VCAP.

Pressure versus Time for inhibited system at 0.02% of N-VCAP (Figure 18). For the first 1 minutes recorded a pressure decline from 150 to 142 psi for the 0.02% of N-VCAP for the next 1-120 minutes there was a decrease in pressure from 142 to 122 psi.
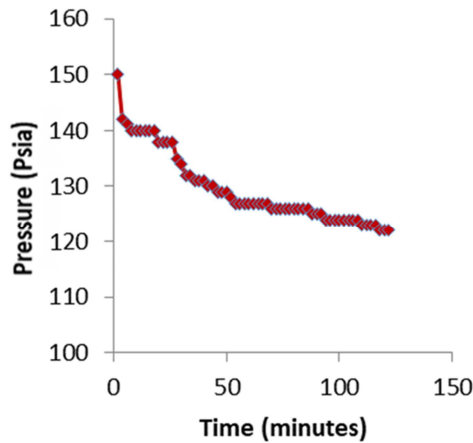
Figure 19. *Pressure versus Time for inhibited system at 0.03% of N-VCAP.*

Figure 21. *Temperature versus Time for inhibited system at 0.04% of N-VCAP.*

Pressure and Temperature versus Time for inhibited system at 0.03% of N-VCAP (Figure 19).

Temperature versus Time for inhibited system at 0.03% of N-VCAP (Figure 20). For the inhibited experiment, the initial temperature was 30°C at the pressure of 150 psi. From 0 to 120 minutes and there was a drastic decrease in temperature from 30°C to 6°C. The steady temperature drop noticed during the experiment shows that gas was being encapsulated by water molecules in the 0.5 inch 316 stainless steel tubing which gives rise to hydrate formation because the process of hydrate formation is exothermic in nature.
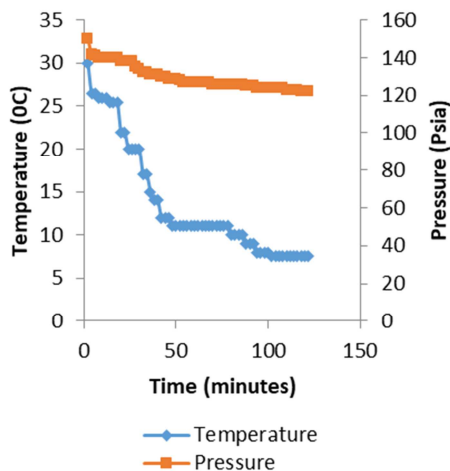

Figure 22. *Pressure versus Time for inhibited system at 0.05% of N-VCAP.*

Pressure and Temperature versus Time for inhibited system at 0.06% of N-VCAP (Figure 23).

Figure 20. *Pressure and Temperature versus Time for inhibited system at 0.03% of N-VCAP.*

Pressure versus Time for inhibited system at 0.04% of N-VCAP (Figure 21). For the first 1 minutes recorded a pressure decline from 150 to 135 psi for the 0.04% of N-VCAP for the next 1-120 minutes there was a decrease in pressure from 135 to 112 psi.
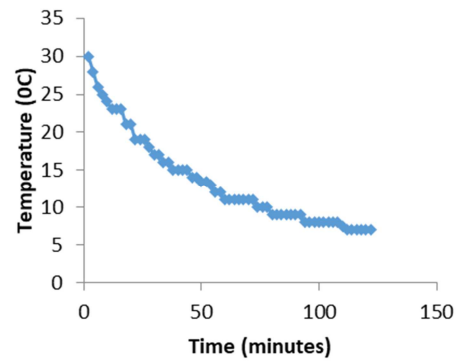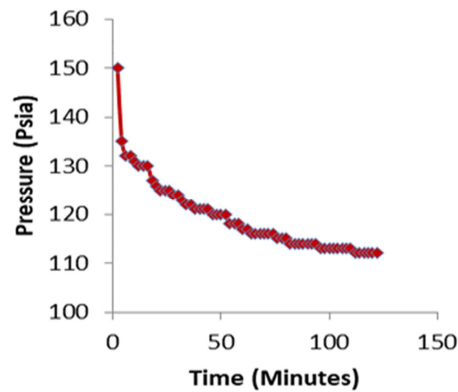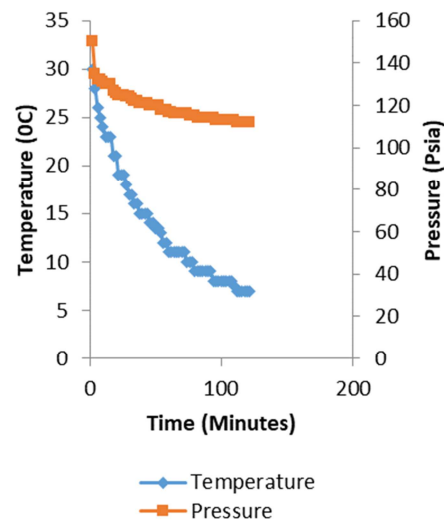

Figure 23. *Pressure and Temperature versus Time for inhibited system at 0.06% of N- VCAP.*

Table 4. *Initial and final pressure values and change in pressure for gas & water of sample A.*

	1 wt % (Change in p) psia	2 wt % (Change in p) psia	3 wt % (Change in p) psia	4 wt % (Change in p) psia	5 wt % (Change in p) psia	6 wt % (Change in p) psia	7 wt % (Change in p) psia
SAMPLE A	150-110 (40)	150-116 (34)	150-111 (39)	150-117 (33)	150-105 (45)	150-122 (28)	150-122 (38)

Table 4 shows the initial and final pressures and change in pressures for the inhibited system, 1, 2, 3, 4, 5, 6, and

7wt% of N-VCAP. For the system with gas and water only, the Pressure decreased from 150 psi to 110 psi in 120 minutes giving a change in pressure of 40 psi at 0.1wt% of N-VCAP, the Pressure decreased from 150 psi to 116 psi in 120 minutes giving a change in pressure of 34 psi at 0.2wt% of N-VCAP, the Pressure decreased from 150 psi to 111 psi in 120 minutes giving a change in pressure of 39 psi at 0.3wt% of N-VCAP, the Pressure decreased from 150 psi to 117 psi in 120 minutes giving a change in pressure of 33 psi at 0.4wt% of N-VCAP, the Pressure decreased from 150 psi to 105 psi in 120 minutes giving a change in pressure of 45 psi at 0.5wt% of N-VCAP, the Pressure decreased from 150 psi to 122 psi in 120 minutes giving a change in pressure of 28 psi at 0.6wt% of N-VCAP, the Pressure decreased from 150 psi to 122 psi in 120 minutes giving a change in pressure of 38 psi at 0.7wt% of N-VCAP. This shows that of N-VCAP did better in inhibiting hydrates especially in 0.6wt%.

4. Conclusion

A gas hydrate inhibitor termed SAMPLE A was developed from a waste product of a local source. The said the SAMPLE A is environmentally friendly having been gotten from edible plant waste as an alternative to imported gas hydrate inhibitors. Since the results of experimental runs indicate clearly that SAMPLE A perform very well, it therefore means that it will inhibit hydrate formation effectively when applied in the field. The SAMPLE A is very cheap compared to the imported or conventional inhibitors used in this research work.

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