Engineering Science
2022; 7(4): 54-62
http://www.sciencepublishinggroup.com/j/es
doi: 10.11648/j.es.20220704.11
ISSN: 2578-9260 (Print); ISSN: 2578-9279 (Online)

Economic Evaluation of Chemical Inhibitors for Hydrate Solution in Nigeria Oilfield Flowlines

Precious Joseph Ekpo, Uche Osokogwu, Solomon Williams

Department of Petroleum and Gas Engineering, Faculty of Engineering, University of Port Harcourt, Port Harcourt, Nigeria

Email address:
Preciousekpo46@bgmail.com (Precious Joseph Ekpo), oxgoodlt@yanhoo.com (Uche Osokogwu),
williele86@yahoo.com (Solomon Williams)

To cite this article:
Precious Joseph Ekpo, Uche Osokogwu, Solomon Williams. Economic Evaluation of Chemical Inhibitors for Hydrate Solution in Nigeria Oilfield Flowlines. *Engineering Science*. Vol. 7, No. 4, 2022, pp. 54-62. doi: 10.11648/j.es.20220704.11

Received: February 10, 2022; **Accepted**: June 6, 2022; **Published**: December 29, 2022

Abstract: Oil and gas companies across the world have expanded their operations to cold environments like the Offshore Deep-water for more conventional and economical reservoirs as a result of global demand for energy. As Hydrocarbon production continues to increase from both conventional and unconventional reservoirs in harsh environments, Hydrates presents a huge problem in the oil and gas industry because it leads to production losses, and is very expensive in trying to prevent its formation or removal. The hydrate blockage during Deepwater oil and gas exploration will also damage the equipment and threaten personal safety. It also leads to flow interruptions, environmental and safety problems, the interruptions leads to plugging of the flowline, Hydrates still cost the oil and gas industries millions of dollars annually. This paper discusses the existing chemical inhibitors used to mitigate hydrates as well as evaluating economically the cost implication for twelve years in Niger-Delta. In this study, three different types of chemical inhibitors (i.e. Methanol, Mono-ethylene glycol and KHI) were economically evaluated through a cash flow model and eventually the Net Present Value, Internal Rate of Return, Profitability Index, Present Value Ratio and Payback Period were determined and Monte Carlo Simulation was also used to get NPV, IRR and their uncertainties. Their charts show that KHI will generate an NPV of $20.34MM if invested in at Return of Investment of 28% and will also take a period of 3.76 years to recover the investment made into the project. From the analysis, KHI is a better project to invest in because it generates more profit and has a lesser risk than Methanol and Mono-ethylene glycol.

Keywords: Offshore, Inhibitors Economics, Hydrate Problems, Chemical Inhibitors, Risks

1. Introduction

Hydrates are flow assurance issues which presents a huge impediment in the petroleum and gas sector because it makes the facility owners to lose production, however, it is very expensive in trying to prevent its formation or removal [l] The hydrate formation and clogging of the pipe line when petroleum and gas is exploited in deep water could cause the facilities to go bad and could also become a threat to lie [2]. It could also lead to flow interruptions, environmental and safety problems, the interruptions, environmental and safety problems could lead to plugging of the flow line [3]. The use of hydrate inhibitors are employed in preventing the hydrate not to form or used to manage the effect of the hydrate when formed. The choice of picking hydrate inhibitors must not only be based on cost effectiveness, but must also be safe, oil companies across the world have expanded its operations to deep water environment which is cold, for more conventional cum economical reservoirs as a result of global demand for energy. As hydrocarbon production continues to increase from both reservoirs that are conventional and unconventional in harsh environmental conditions, petroleum and gas companies are facing huge operational challenges, as a result of the many or few flow assurance problem during the production and transportation of the fluid in pipe lines in environment that is cold [4].

In order to overcome these challenges, flow assurance issues should be considered in detail. ‘Flow assurance can be seen as a process which ensure that flow of hydrocarbon is successful and from the reservoir to the sales point putting economics into perspective [5, 6]. The issues that could obstruct flow include formation of hydrate, formation of wax, slugs, asphaltene, hapththenate, corrosion, scaling erosion and emulsion [7, 8]. In this research work, hydrates will be the principal and primary focus. Hydrates presents a huge problem in the petroleum and gas sector because it reduces production, and is very expensive in trying to prevent its formation or removal [1]. The plugging of flow line by hydrate during the exploitation of hydrocarbon in deep water or offshore will also pose a threat to life and facilities, as facilities tend to go bad more rapidly in deep offshore environment [2]. It also leads to flow interruptions, environmental and safety problems, the interruptions leads to plugging of the flow line [3]. Methane hydrates are solids in nature, looks whitish and are crystalline in form, they are formed by the interactions of hydrocarbons that are gaseous in nature and vapor from water (also gases that are non-hydrocarbon) while free water is present at low temperature and high pressure. Hydrates resemble ice but are different in their structures [1].

Currently, the risks management procedures adopted in deep water pipelines for hydrate mitigation include to dehydrate,, separation of gas components and injecting inhibitors, etc. To dehydrate means to remove and separate the produced free water from the gas stream produced from the reservoir before transportation through the pipeline, the hydrocarbons that are light in nature can be separated from the gas mixture by depressurizing, which involves constant compressing and pumping, which leads to high operational cost and poses difficulties in operations. Injecting inhibitors could ensure the movement of the equilibrium condition of the hydrate phase skewed towards low temperature and high pressure to prevent hydrates not to form [2].

Hydrate management and prevention methods are physical and chemical method. The physical method includes, heat insulation, heat stimulation, depressing, coating, dehydrating, gravity pipe heating and down hole gas valve throttling method. The chemical method, include the use of chemical inhibitors which tend to alter the equilibrium phase of the gas hydrate or nucleation, growth and aggregation inhibition of the gas hydrate. Mostly used chemical inhibitors are thermodynamic inhibitors, kinetic inhibitors and anti-agglomerates, which are cost effective when compared with the physical methods [2]. Generally, Chemical inhibitors are classified into two different forms, used for prevention of hydrate from blocking the pipeline. They are: Thermodynamic hydrate inhibitors (THIs) and Low Dosage Hydrate Inhibitors (LDHIs) [9].

Thermodynamic hydrate inhibitors (THIs): The mechanism of hydrate-prevention of the thermodynamic hydrate inhibitors are in two forms. They can minimize the activity of water, alter the thermodynamic equilibrium between gas and water molecules, and change the chemical capability of the hydrates or aqueous solution, encouraging the equilibrium curve of the hydrate phase to shift to the left. Thermodynamic inhibitors consist mainly of alcohol and inorganic salt. The alcohols chiefly include methanol, ethylene glycol, isopropanol, di-ethylene glycol and so on. The most used alcohols which includes methanol, ethylene glycol and di-ethylene glycol have much physical properties. Again the substances that contain salt are chiefly that of chlorides of sodium, calcium, magnesium and lithium. However the chlorides of sodium and calcium are the most common and mostly used on site. And because of their high corrosion rate, their application is limited [10]. Furthermore, there are diverse issues associated with these classes of chemicals, which includes problem due to corrosion, health safety and environment issues and concerns of logistics, high operating cost and capital cost [11]. Because of the shortcomings of THIs, several researchers have made effort in developing a generation of new chemicals. The new developed chemicals are Low Dosage Hydrate Inhibitors (LDHIs). They are so referred to, because they can be utilized in very low concentration than THIs. LDHIs are of two main classes: Kinetic inhibitor (KHIs) and Anti-agglomeration (AAs). The key differences between THIs and KHIs are the lower concentration needed for KHIs and the hydrate inhibition mechanism [12].

1.1. Low Dosage Hydrate Inhibitors (LDHIs)

1.1.1. Kinetic Inhibitors

They are primarily adsorbed onto the hydrate crystal and water interface, which leads to reduction of the rate of formation of hydrate, prolonging the hydrate nucleation time of induction and alters the hydrate crystal aggregation process. Kinetic inhibitors primarily include two forms of surfactants and polymers [13, 14]. KHIs are polymers that are in water and mostly comprise of other smaller molecules that are organic which are added to enhance or improve efficiency. (synergists). KHIs mostly have cyclic group of amide that are small as the units that are active [9, 15]. KHIs serve to prolong nucleation of gas hydrate and the growth of the crystal. As a result of low consumption of KHIs compared to THIs, KHIs are mostly utilized and it affects the operating and capital expenditure, savings and extends the life span of the field [11]. Furthermore, KHIs are more clean and safe compared with THIs and more environmentally friendly. Common examples of KHIs are polyvinylpyrrolidone (PVP) and polyvinylcaprolactam (PVCap) [9, 16]. A copolymer of vinylmethylacetamide (VIMA) and vinylcaprolactam (VCAP), or poly (VIMA/VCAP) show better advantage of these copolymer than methanol and safe to dispose [17].

1.1.2. Anti-Agglomerants

AAs belongs to a class of LDHI and there effective concentration is less than 1 wt.% [12]. They ensure that hydrate crystals are not of larger sizes by preventing agglomeration. However, gas hydrate still forms but the crystal are not able to plug and can be transported through the flow line because of the presence of small gas hydrate crystals, again, they can only perform when hydrocarbon phase that is liquid is present, for example crude-oil or condensate. furthermore, AAs are not mostly time independent and the level of sub-cooling of the system compared with KNHIs is more. Anti-agglomerants consists of surfactants and polymers and are mostly used as oil-water emulsifier to disperse the water contained in the oil phase into droplets and hydrates are formed from these droplets and are soluble in the solution as emulsion which prevents the hydrate coalesce and agglomerate which represents the lower hydrate blockage risk [2].

1.2. Economic Analysis of Hydrate Inhibitors

1.2.1. Why LDHIs Can Lower Costs

As with several paradigm shifts, the turn from thermodynamic hydrate inhibitors to Low Dosage Hydrate Inhibitor is a result of economics and some of these economic driving forces are noticeable and can be quantified readily, such as the LDHIs which gives raise to high rate of production in a MeoH volume system that is limited while others are more complex, subtle and /or hard to quantify, such as the negative impact of MeoH on topside processing. And as seen in details below, the sudden lower volumes needed for LDHIs as compared with MeoH led to a lot of possible cost savings. It is usual to minimize volume of hydrate inhibitor by 90% when moving from THIs to LDHIs. In few cases, especially sub-cooling that is high in deep offshore system, a reduction in volume up to 95-99% is obtained, typically, more water can be treated by an operator in a system that exist with a LDHI than MeoH. Extensive cost savings is mostly realized or achieved if a system is designed for LDHi, as the key components size minimized. LDHIs has secondary benefits and an advantage is simply to eliminate MeoNH or MEBG from the system again LDHIs can be tailored to have multifunctional formulations, hence taking care of flow assurance issues by utilizing one chemical injecting line [18].

1.2.2. Reducing Costs in Existing Systems that Are in Existence

The largest part of LDHI tests and applications takes place in systems that are designed originally for either MeOH or MEG utilization. The positive outcome from this test and the reasons for which operators choose to expand these tests into constant application varies. Most times, the operator considers the convenience of utilizing LDHIs, in the other hand, the operator comes to terms that LDNHIs cost less per barrel of water treated than the traditional systems.. this is however true in low water content system, where the bulk of MeoH is lost to the hydrocarbon or sub cooling that is low, where KHI that has low dosage becomes in control of the hydrate in the system otherwise, LDHIs are implemented where applicable water is made by the system, most times, rate of production of water outweigh the capability of the system to inject thermodynamic inhibitors or the means of transport, store and the continuous supply until the thermodynamic inhibitor proves onerous. A study of the way in which LDHIs could lower the cost of existing system is given below, these potential grain are given for the purpose of illustration only, results may be different in other systems [18].

1.2.3. Lower Operating and Intervention Costs

Cost of Lower Chemical: the price of special chemical like LDHIs are obviously higher than commodity chemical like MeoH and MEG. LDHI, s are given for ten dollar per gallon whereas MeoH and MEG tends to be lower these prices that needs capital expenditure that is upfront. However, it is pertinent to bear in mind that it is the rate of treatment multiplied by the price of the chemical per gallon that determines the cost of the whole treatment, hence for example, a MeoH price of 50 cent per gallon and the rate of treatment of 1 bbl of crude oil per barrel of water adds up to a total cost of treatment of 21 dollars per barrel of water. A LDHI that mitigates hydrate at 0.70 gal/bbl of water and cost $30/gal will also give rise to a total cost of treatment of $21/bbl of water and hence has an equivalent cost to MeoH, in this illustration [18].

Lower Transportation Costs. The cost of treatment is a merge part of the total cost to mitigate hydrate. Another cost is the transport charges that are incurred in the transportation of the inhibitors to field or platform. In locations that are easily accessed, the charges may be smaller than locations that are remote. Transportation cost will exceed MeoH cost, for deep water environment, MeoH is supplied via boats; which requires special licenses and permits. high cost of supply is applicable to field that are located in remote areas, since transport costs are basically at a fixed $/gal, LDHI transport fare could be as low as 99% of the MeoH transport fare.

Lower Manpower Costs for Handling Hydrate Inhibitor. One of the cost that is not properly accounted for is the manpower time necessary for handling huge amount of thermodynamic hydrate inhibitor. Any time there is a supply of MeoH, operators must handle the transmission of the inhibitors from the transport container to the storage tank, noting the hazards that comes with the handling of low flash point chemicals, however, this process disrupts other platform operations. For system that recycles and regenerates, it requires manpower to monitor and maintain such system [18].

No MeoH in topsides and downstream operations: some side effects that are unintended and not desirable have sprung up as the use of MeoH for deep water hydrate mitigation has become more prevalent, particularly; MeoH usually affects oil/water separation techniques adversely. this is comprehended by the realization that MeoH lower the density of the aqueous phase thereby reducing the difference in density between the hydrocarbon and water phase and hence affecting one of the forces that drives phase separation. Again, in high API gravity gas condensate system with high MeoH needs. it is possible that the aqueous /MeoH phase in the separator to float on the gas condensate. MeoH also affect the hydrocarbon/aqueous interfacial tension, experiences acquired as a result of operations shows that it is explicitly hard to meet overboard water quality specifications in systems that are treated continuously with high volumes of MeoH. Because of the prolific nature of most deep water wells, most operators' have sought ways of removing the obstacles in their topside processing. As seen above, the presence of MeoH could hinder the separation of oil/water, which limits the efficiency of the process facility and topside chemical treatments, additionally; each barrel of MeoH injected is processed as a barrel of liquid when returned to the platform through the flow lines. in several other systems, this gives rise to hundreds of barrel per day of excess liquid, filling reasonable capacity in the flowline and topside equipment used for processing, making a LDHI switch not only lowers the quantity of liquid required for processing, but in other cases enhances the separation of oil and water (especially in black oil system).

Nonetheless, LDHI increases the formation tendency of emulsion in some crude oil system. In this regard, added demulsifier and /or water clarifiers are utilized occasionally if necessary. high concentration of MeoH, and lesser extent of MEG could exacerbate tendency of scale formation in brine used by the oil field, again high salinity system are vulnerable to salt (nhalide0 which precipitate, if it is treated with MeoH and MEG, problems due to scale have been experienced in both the flowline and topside of the system which are treated on a continuous basis with THIs, in systems that has heavy presence of scale, high concentration of MeoH in the environment of the MeoH injection mandrel could lead to localized precipitation of scale and plugging of the point of injection. MeoH solubility in hydrocarbon gives rise to a finite volume of MeoH which leads to downstream operation contamination, this is very worrisome during the period of high MeoH utilization, as such restarting deep water platform after a hurricane evacuation. Not quite long in the Gulf of Mexico, few refineries gave discounts for hydrocarbon containing MeoH, because the MeoH generate different issues in crude oil processing, particularly, MeoH affects the bioreactors waste water performance. Typically the specification are <50-200 ppm MeoH in the hydrocarbon platform which has such MeoH specifications are faced with additional expenses in monitoring the content of MeoH in the hydrocarbon. This is done on site and/ or onshore.

There is however costs which are tied to both the monitoring operations and testing services. Additionally, if the crude oil does not meet the required specification, the operator is compelled to either accept the rise of discounts given to him or wash the crude oil offshore with any available water source either MeoH free produced water or sea water. Crude oil wash is also an integral part of MeoH recovery facility. The washing procedure leads to it own issues especially if the topside equipment is not designed for such operations if the necessary rule is not applied to by-pass contaminants from the washing operation and/or if the wash water is not compatible or if there is no compatibility of the wash water with the produced brine, depending on the water source, other processing chemicals are often required, including biocides scale inhibitors, corrosion inhibitors and/or oxygen scavengers.

Some LDHIs are formulated in MeoH, because it has low cost, low viscosity solvent. however, since the quantity utilized are so smaller than the traditional treatment of MeoH,. The resulting MeoH absorption into the oil phase is mostly below the limit that cannot be detected, additionally if it is necessary, the LDHIs can be used in a non-MeoH solvent [18].

Table 1. *Approximate Price for Hydrate Inhibitors [19, 20].*

Products	**Base Price**	**Adjusted Price**		
	(US Dollar)	**(US Dollar)/gal**	**(Canadian Dollar)/kg**	**(Canadian Dollar)/L**
Methanol	532/tonne	1.60	0.53	0.42
Ethanol	3.30/USgal	3.30	1.10	0.87
EG	0.63/lb	5.87	1.39	1.55
DEG	0.32/lb	7.00	1.65	1.85
TEG	0.90/lb	8.44	1.98	2.23

Table 2. *Economic Analysis of MEG and KHI (LDHI) [21].*

	MEG	**KHI (LDHI)**
Cost	$3.75/Gal	$10/Gal
Injection Rate	250 Gal/Day	40 Gal/Day
Total Days	12 Days	14 Days
Total Cost	250 x 12 x 3.75 = $11,250	40 x 14 x 10 = $5,600

Table 3. *Cost Analysis of Cationic Starch as Compared to Methanol [22].*

Detail	**Cationic Starch**	**Methanol**
Cost per lb	$5.73	$0.1
Water in hydrocarbon	1.356lb/1000m^3 (say)	1.356lb/1000m^3 (say)
Concentration of inhibitor	0.003 to 0.3% of water	40 to 70% of water
Total Cost	0.0034-0.034 Dollars/day	0.082-0.142 Dollars/day

Table 4. *Potential Impact of LDHI on Subsea System Design [18].*

	MeOH	**LDHI**
Dosage Rate (Vol% of Water)	41%	1.2%
Injection Rate (bpd)	350	10
Umblical ID (inch)	1	0.375
14 Day Supply Volume (bbl)	4900	146

14 Day Supply Weight (lbs)	1,400,000	44,000

2. Methodology

The material that was used for this project were non-programmable software which are:

i. Microsoft Excel
ii. Monte Carlo Simulation

2.1. Microsoft Excel

It is a software program created by Microsoft that uses spreadsheets to organize numbers and data with formulas and functions. It is also used for financial analysis and used across all business functions and at companies from small to large.

The main uses of Excel include: Data entry, Data management, Accounting, Financial analysis, Charting and graphing, Programming, Time management, Task management, Financial modeling etc [24].

2.2. Monte Carlo Simulation

It is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making. This technique is used across fields such as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation and the environment. Monte Carlo simulation lets you see all the possible outcomes of your decisions and assess the impact of risk, allowing for better decision making under uncertainty. It furnishes the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action. It shows the extreme possibilities, the outcomes of going for broke and for the most conservative decision along with all possible consequences for middle-of-the-road-decisions [23].

2.3. Procedures

The procedure used to determine the most economic chemical inhibitor between Methanol, Monoethylene glycol and KHI (Polyvinylcaprolactam) for a twelve year period for hydrate solution is as follows:

2.3.1. Use of Excel Spreadsheet as a Deterministic Approach to Develop a Cash Flow Model

Assumptions include:
CAPEX = $100MM
OPEX = $1.2/Mscf
Discount Rate = 15%
Tax = 30%
Depreciation Method = Straight Line Method for 5 years

2.3.2. Calculating the Profitability Measures/Indicators from the Model

The profitability indicators that were estimated includes: Net Present Value, Internal Rate of Return, Profitability Index, Present Value Ratio and Payback Period.

i. Using Monte Carlo as a probabilistic approach to get the uncertainties and sensitivity analysis.
ii. The results were analysed.

3. Results

Below are results generated from the analysis in the cash flow model.

Table 5. *Profitability Indicator of Various Chemical Inhibitors.*

Indicator	MeOH	MEG	KHI
NPV ($MM)	19.86	19.61	20.32
IRR (%)	28	27	28
PI	1.199	1.196	1.203
PVR	0.199	0.196	0.203
PB TIME (YRS)	3.81	3.83	3.76

NPV: The net present values for all the investments are all greater than zero and so any can be chosen but KHI has more profit valued of $20.32MM than MeOH and MEG.
IRR: KHI and MeOH are the same so they are good to go. This means that the business return rate is 28% and is greater than the bank's interest rate of 15% and so the debt can be paid back within 3.81 years of payback time for MeOH and 3.76 years of payback time for KHI.
PVR: It means that for every $1M invested, we gain $0.199M for MeOH, $0.196M for MEG and $0.203M for KHI. KHI yields a higher profit.
PI: Since KHI is ranked higher than MeOH and MEG, the investment can go for KHI project first before others.
Payback Period: KHI project shows that it will take a lesser time of 3.76 years to recover the original investment.

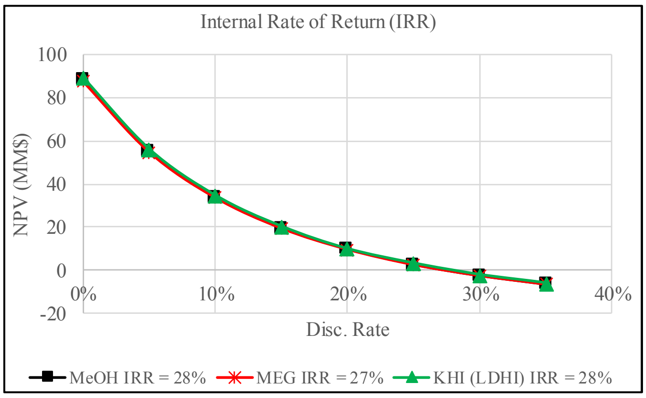


Figure 1. *Plot of NPV against Discount Rate.*

Figure 1 shows that as NPV reduces, discount rate increases. NPV hits the zero axis at discount rates of 28%, 27% and 28% for MeOH, MEG and KHI respectively. This means that Methanol, Monoethylene glycol and KHI gives an Internal Rate of Return of 28%, 27% and 28% respectively. The graph also tells us that any of the three different project can be invested in since each of their returns are greater than the discount rate of 15% but Methanol (MeOH) and KHI are more preferred because they have the same Internal Rate of Return.

Figure 2 shows that the year increases with a resulting increase in the Cumulative Net Cash Flow. Cumulative NCF hits the zero axis or changes from negative to positive at years 3.81, 3.83 and 3.76 for MeOH, MEG and KHI respectively.

This means that Methanol will take 3.81 years to recover the initial investment of $100MM, Monoethylene glycol will take 3.83 years to recover the investment of $100MM and KHI will take 3.76 years to recover the investment of $100MM. This further means that investing in KHI will eventually be more profitable than the other chemicals.

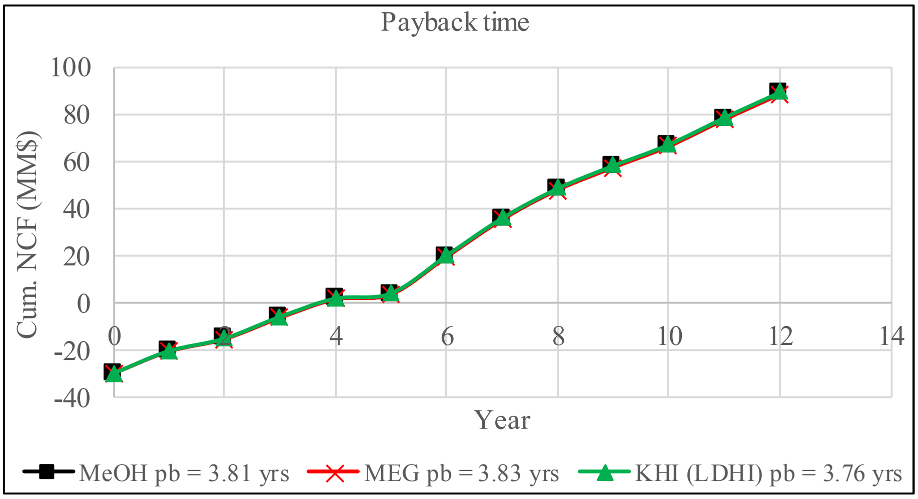
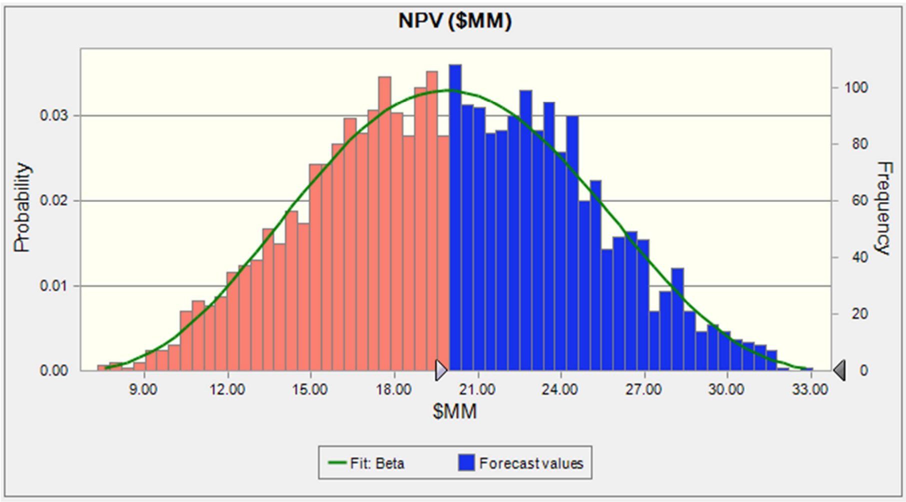
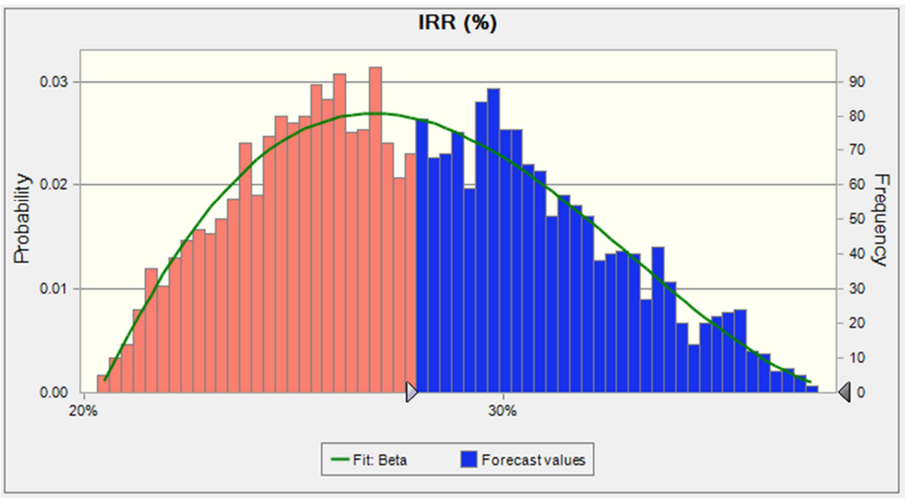


Figure 2. *Plot of Cumulative NCF against Time.*



Mean $19.98MM, Uncertainty = 49.98 %

Figure 3. *Methanol NPV Chart.*



Mean 28 %, Uncertainty = 52.56 %

***Figure 4.** Methanol IRR Chart.*

Figures 3 and 4 give the frequency distribution of NPV and IRR for Methanol. It explains that there is a 49.98 % probability of the net present value of $19.98MM not to occur and also has a high uncertainty level of 52.56 % for an IRR of 28% to occur. The first condition of NPV is good for investors but the second condition of IRR is not good for investors. Therefore, this project is risky for investors to invest.

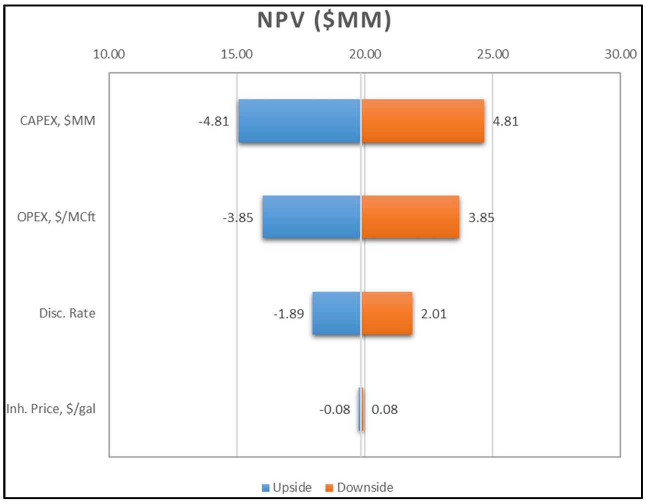


Figure 5. Methanol Sensitivity Chart for NPV.

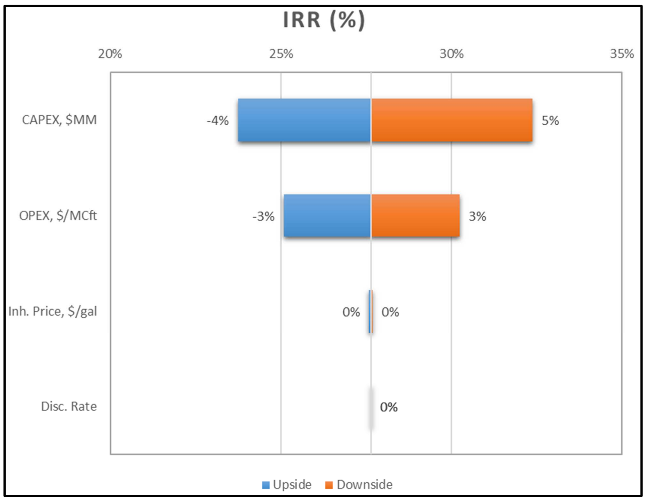
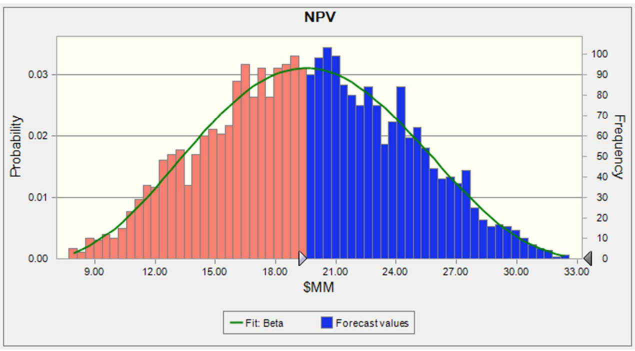


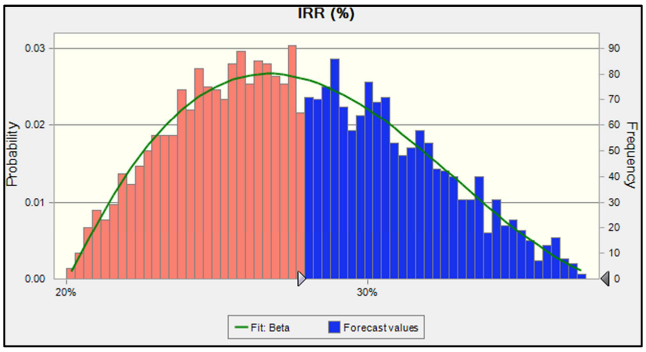
***Figure 6.** Methanol Sensitivity Chart for IRR.*



Mean = $19.63MM, Uncertainty = 51.28 %

***Figure 7.** Monoethylene glycol NPV Chart.*

The Sensitivity Analysis for Figures 5 and 6 shows that CAPEX and OPEX has more impact on the uncertainties for NPV and IRR of the Hydrate inhibition operations using Methanol. Discount rate also impacts on the NPV.



Mean = 28 %, Uncertainty = 45.06 %

***Figure 8.** Monoethylene glycol IRR Chart.*

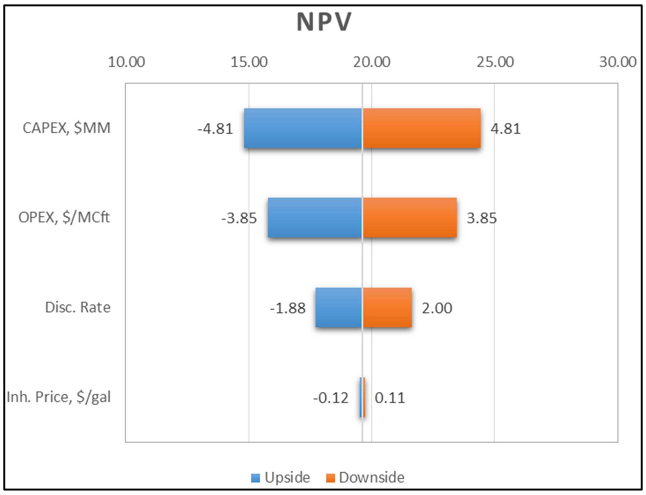


***Figure 9.** MEG Sensitivity Chart for NPV.*

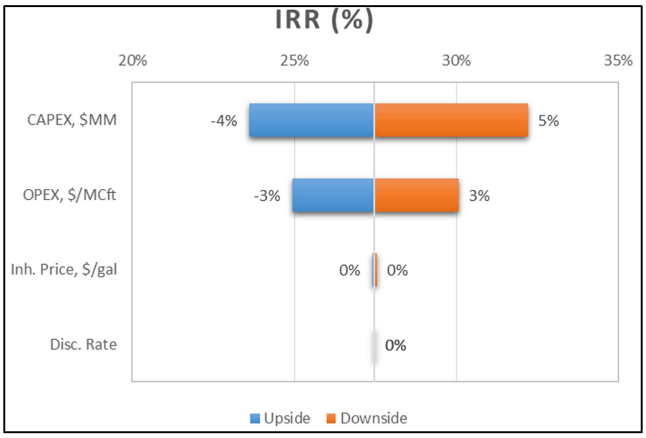
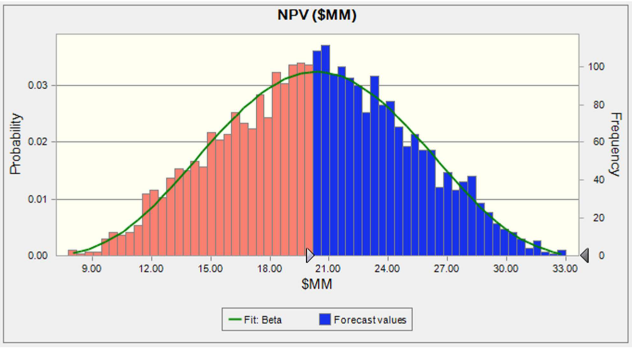


***Figure 10**. MEG Sensitivity Chart for IRR.*

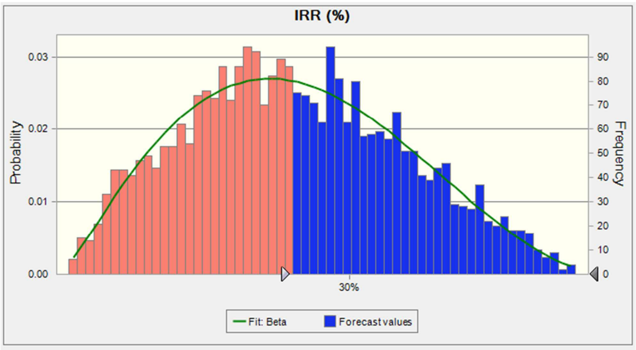
Figures 7 and 8 give the frequency distribution of NPV and IRR for Monoethylene glycol. It explains that there is a 51.28 % probability of the net present value of $19.63MM not to occur and also has a low uncertainty level of 45.06 % for an IRR of 28% to occur. The first condition of NPV is not good for investors, but the second condition for IRR is good for investors and therefore, this project is also going to be risky for investors.

The Sensitivity Analysis for Figures 9 and 10 shows that CAPEX and OPEX has more impact on the uncertainties for NPV and IRR of the Hydrate inhibition operations using Monoethylene glycol. Discount rate also impacts on the NPV.



Mean = $20.34MM, Uncertainty = 49.41%

Figure 11. *KHI NPV Chart.*



Mean = 28 %, Uncertainty = 49.07 %

Figure 12. *KHI IRR Chart.*

Figures 11 and 12 give the frequency distribution of NPV and IRR for KHI. It explains that there is a 49.41% probability of the net present value of $20.34MM not to occur and also has a low uncertainty level of 49.07% for an IRR of 28% to occur. Both the first and second condition for NPV and IRR respectively shows that this project is very attractive to investors because it is very profitable and less risky.

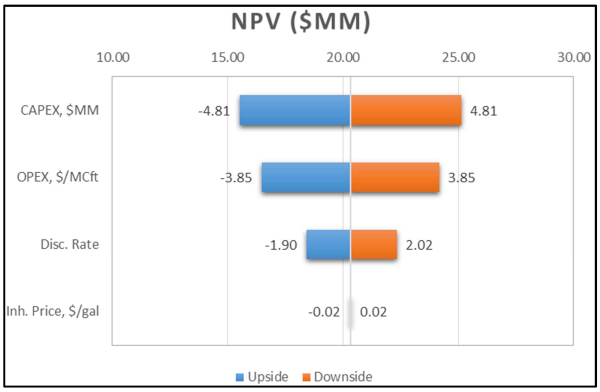


Figure 13. *KHI Sensitivity Chart for NPV.*

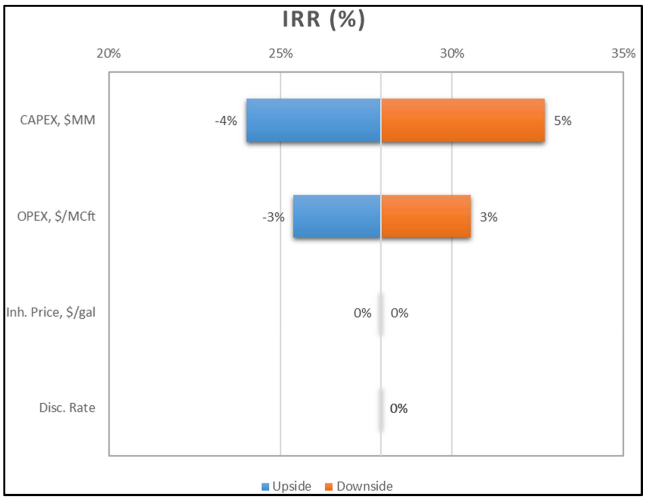


Figure 14. *KHI Sensitivity Chart for IRR.*

The Sensitivity Analysis for Figures 13 and 14 shows that CAPEX and OPEX has more impact on the uncertainties for NPV and IRR of the Hydrate inhibition operations using Methanol. Discount rate also impacts on the NPV.

4. Discussion on the Comparative Analysis of the Three Chemicals

By deterministic analysis, KHI will be selected since it has the highest NPV ($20.32MM) and the highest IRR (28%) amongst the three type of inhibitors. However, Monte Carlo Simulation shows the uncertainty level imposed on the NPV and IRR of the various hydrate inhibition operations. The uncertainty levels for Methanol and MEG are high for IRR and NPV respectively, this shows a lot of risk to investors. On the other hand, KHI has a low uncertainty level for NPV and IRR of 49.41% and 49.07% respectively. This two conditions for KHI make the KHI project very attractive for an investor to invest because it will be economically profitable and less risky. From the three sensitivity analysis of Methanol, MEG and KHI, it shows that CAPEX and OPEX impacted more on the uncertainties. The Uncertainties better known as Financial Uncertainties is caused by various factors which include: Discount Rate, Inflation and Exchange Rate.

5. Conclusion

The choice of any hydrate inhibitor is dependent on the economic viability of the twelve year project. The investors should be able to recover the cost of investment and make profit. The economic viability of hydrates is not only dependent on the cost but also the risk attached to it. The result from this study shows that KHI (Polyvinylcaprolactam) is a better choice of chemical for hydrate inhibition than Methanol and Monoethylene Glycol because it generates more net present value, internal rate of return and has lesser uncertainties than the other inhibitors.

References

[1] Buzatoiu B., and Popp, V. V. (1999). "Hydrate Problem in the Oil Production Industry". SPE, PETROM SA - ICPT - Campina, I. R. Loas PETROM S. A. - SPP Targu Jiu ROMANIA,

[2] Wang, Z., Zhao, Y., Zhang, J. et al (2020). "Natural Gas Hydrate Management in Deepwater Gas Well Chen G, Sun C, Qinglan M. A (2008) "Gas Hydrate Science and Technology. Chemical Industry Press.

[3] Majid, A. A., Lee, W., Strivestava, V. et al. (2016). "The Study of Gas Hydrate Formation and Partial Transportability using a High Pressure Flowloop". In Offshore Technology Conference.

[4] Theyab, M. A. (2018). "Fluid Flow Assurance Issues: Literature Review". SF J Petroleum 2:1.

[5] Irmann-Jacobsen Tine Bauck (2013). "Flow Assurance – A System Perspective. MEK4450 FMC Subsea technologies". [http://www.uio.no/studier/emner/matnat/math/MEK445

[6] CFI (2021). Excel Definition. The Ultimate Software Tool for Financial Analysis. Retrieved August 11, 2021, from *https://www.corporatefinanceinstitute.com*

[7] Kutlik, R. (1998). "Flow Assurance Instrumentation. Offshore Technology Conference". Houston Texas.

[8] McMullen, N. D. (2006). "Flow-Assurance Field Solutions (Keynote)". Offshore Technology Conference. Houston, Texas, USA.

[9] Kelland, M. A. (2009). "Production chemicals for the oil and gas industry". Boca Raton, Fla.: CRC Press. XVII, 437 s.

[10] Li, X. S., Liu, Y. J., Zeng, Z. Y. et al (2011). "Equilibrium hydrate formation conditions for the mixtures of methane + ionic liquids + water". J Chem Eng Data 56: 119–123.

[11] Tian, J. et al. (2011). "Low Dosage Hydrate Inhibitors (LDHI): Advances and Developments in Flow Assurance Technology for Offshore Oil and Gas Productions, in Offshore Technology Conference". Offshore Technology Conference: Houston, Texas, USA.

[12] Igboanusi U. P., A. C. O. (2011). "The Advancement from Thermodynamic Inhibitors to Kinetic Inhibitors and Anti-Agglomerants in Natural Gas Flow Assurance". International Journal of Chemical and Environmental Engineering. 2 (2): p. 131-134.

[13] Karisiddaiah, S. M (2003) Report: fourth International Conference on Gas Hydrates. Held at Yokohama, Japan, 19-23 May 2002.

[14] Chen G, Sun C, Qinglan M. A (20080 Gas Hydrate science and Technology, chemical industry press.

[15] Guan, H. (2010). "The Inhibition of Gas Hydrates and Synergy of the Inhibiting Molecules, in International Oil and Gas Conference and Exhibition in China". Society of Petroleum Engineers: Beijing, China.

[16] Villano, L. D (2009) "A Study of the Kinetic Hydrate Inhibitor Performance and Seawater Biodegradability of a Series of Poly (2-alkyl-2-oxazoline)" Energy & Fuels. 23 (7): p. 3665-3673.

[17] Fu, B., et al. (2001). "Novel Low Dosage Hydrate Inhibitors for Deepwater Operations". In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers Inc.: New Orleans, Louisiana.

[18] Frostman, L. M, Thieu, V., Crosby, D. L. and Downs, H. H. (2003). "Low-Dosage Hydrate Inhibitors (LDHIs): Reducing Costs in Existing Systems and Designing for the Future". Paper SPE 80269 presented at SPE International Symposium on Oilfield Chemistry, Houston, 5-8 February.

[19] ICIS (Independent Commodity Intelligent Services). Retrieved April, 2008, from *https://www.icis.com/explore/commodities/chemicals*

[20] Methanex, Retrieved March, 2008 from, https://www.methanex.com/our-business/pricing

[21] Okereke, N., Edet, P., Afolabi, F., Baba, Y., Izuwa, N., Kanshio, S., Nwogu, N., Nwanwe, O., and Odo, J. (2020). "Techno-Economic Assessment of the Hydrates Mitigation Potential of LDHI and MEG in Deepwater Scenario". Paper SPE-203665-MS presented at the Nigeria Annual International Conference and Exhibition originally scheduled to be held in Victoria Island, Lagos, Nigeria, 11 - 13 August 2020. Due to COVID-19 the physical event was not held. The official proceedings were published online on 11 August 2020.

[22] Kannan, K., and Punase, A. (2009). "Low-Dosage, High Efficiency and Environment Friendly Inhibitors: A New Horizon in Gas Hydrates Mitigation in Production Systems". Paper SPE 120905 presented at SPE International Symposium on Oilfield Chemistry held in the wood lands, Texas, USA, 20-22 April.

[23] Palisade (2021). Monte Carlo Simulation. Retrieved August 8, 2021, from *https://www.palisade.com/risk/monte_carlo_simulation.asp*

[24] Kelland, M. A. (2006). "History of the Development of Low Dosage Hydrate Inhibitors. Energy & Fuels". 20 (3): p. 825-847.