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International
Journal
Of Modern Engineering Research (IJMER)

Economic Analysis on Hydrate Inhibitors for Offshore Flowlines in Niger Delta

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ABSTRACT
Flow assurance is a significant issue when considering the production of hydrocarbon fluid from offshore gas systems. As production goes into deep water, hydrate control and prevention grows in importance hence, the optimum need for the selection of hydrate inhibitors. In this study, a Monte Carlo Simulation model was used to analyze five different hydrate inhibitors (Methanol, MEG, DEG, KHI and AA) and it showed the uncertainties involved in the profitability decisions. After the analysis, the inhibitors were ranked in an ascending order of the highest NPV and IRR (KHI>MEOH>AA>MEG>DEG). NPV and IRR tells if the project is feasible and profitable. The result showed that KHI has the highest mean NPV value and lowest uncertainty. MCS provides insights into the uncertainty variable with the highest effect on the NPV and IRR which is the CAPEX, although OPEX, discount rate and price of the inhibitors showed a significant effect too. Higher CAPEX resulted in a reduction in the NPV as well as IRR.

***Keyword**: Hydrate Inhibitors, Hydrocarbon, Flowlines, Temperatures, Water molecules,*

Date of Submission: 26-03-2023 Date of acceptance: 12-04-2023

I. INTRODUCTION

A key element of flow assurance problem is the hydrate formation possibility and its control subsequently. Hydrates are solid compounds that are formed at low temperature from organic materials and water or aqueous solutions such as brine (Ian, 2010). In 1934, Hammerschmidt found out that natural gas hydrate were responsible for blocking gas pipelines signaling a keen interest in hydrates by the energy industry. Hydrates develop from small crystals to large masses which block flowlines and pipelines that results to costly and often hazardous hydrate dissociation procedures (Sloan, 1998). Gas hydrates are crystals formed by water with natural gases and associated liquids in a ratio, 85% mole water of 15% hydrocarbons. Hydrate form spontaneously under certain conditions and do not always require a drop in temperature to form. Hydrates are classified by the crystal structure they form (John, 2020). Gas hydrates consist of guest gas molecules inside hydrogen bonded water lattices. When both guest molecules and water molecules are present, hydrate usually form at well above 32ºF (0ºC). Gas hydrate form at a temperature of up to 85ºF (Frostman et al., 2005). According to (Mokhatab, 2007), most natural gas hydrates are usually found in offshore and permafrost regions.

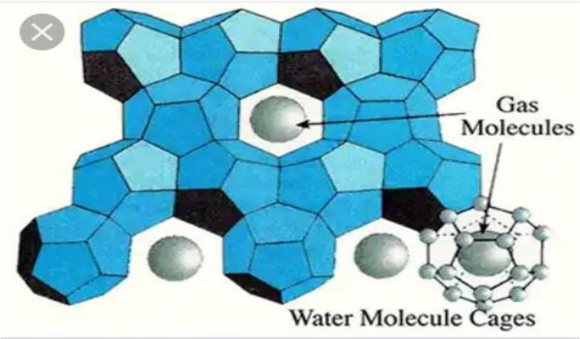

Figure 1: Gas molecule trapped in a cage of water molecule (Matyukhina, 2015)

PROBLEM DEFINITON

Gas hydrate formation is a very costly problem in production operations and a major concern in pipelines located in subsea or deep water oil/gas developments. The combination of many additives of crude oil or natural gas with water leads to the formation of hydrate at low temperature and high pressure conditions which can result to outbreaks or major accidents (hydrate plugs and line blockages). Therefore, the prevention of hydrate precipitation using hydrate inhibitors at minimum operating cost is of paramount importance for the safety of production process.

II. LITERATURE REVIEW

Hydrates of natural gas components and other similar compounds are usually classified by the arrangements of water molecules in the crystal and the structure of the crystal. The alignment of water molecules happens due to the hydrogen bonding into three dimensional sphere like structures usually referred to as a cage. A second molecule resides inside the cage and stabilizes the entire structure. Von 1949, discovered there were two types of hydrates commonly encountered in the industry. They are called Type I and Type II and sometimes referred to as Structure I and II. A third type of hydrate that also may be encountered is Type H also known as Structure H but it is less commonly encountered. A research group at the National Research council of Canada discovered Type H. Type I is the simplest of the hydrate structures. It consists of 46 water molecules. If a guest molecule occupies each of the cages then it is made from two types of cages, the Dodecahedron and the Tetrakaidecahedron. The dodecahedron is a 12-sided polyhedron where each face is a regular pentagon while the tetrakaidecahedron is a 14-sided polyhedron with 12 pentagonal faces and 2 hexagonal faces. The structure of the Type II hydrates is significantly more complicated than that of the Type I. The Type II hydrates are also constructed from two types of cages, they are Dodecahedron and Hexakaidecahedron. The dodecahedron is a 12 sided polyhedron where each face is a regular pentagon and it is smaller than the hexakaidecahedron cages, while the hexakaidecahedron is a 16 sided polyhedron with 12 pentagonal faces and 4 hexagonal faces. This class of hydrate is less common than the other two. A small molecule such as methane and a Type H former are usually required to form this hydrate. As such, type H hydrates are always double hydrates. The Type H hydrates are constructed from three types of cages, the dodecahedron which is a 12 sided polyhedron and each face is a regular pentagon. Then, the irregular dodecahedron with 3 square faces, 6 pentagonal faces and 3 hexagonal faces. The third is an irregular icosahedron which is a 20 sided polyhedron with 12 pentagonal faces and 8 hexagonal faces.

HYDRATE INHIBITION

Formation of hydrate is typically inhibited by a number of established methods. These methods include dehydration, heat management and chemical inhibition (Fu. et al 2002).

THERMODYNAMIC HYDRATE INHIBITORS (THI)

The injection of thermodynamic inhibitors is by far the most commonly used method for controlling hydrate. They are either done by heating the gas, decreasing pressure in the system, injecting a salt solution or injecting alcohol or glycol. They have the ability to shift hydrate equilibrium curves towards higher pressure and lower temperatures by reducing or lowering the activity of water molecules like the one encountered under normal production circumstances. As a result, the operating condition is forced out of the hydrates stable region (Fu. et al., 2002). The injection of these inhibitors is done using chemical system. If enough THI is injected hydrates will never be able to form in the system but the difficulty comes, in the being able to inject enough. MEG inhibitors are the most commonly used method for controlling hydrates as a result of their widespread availability. They compete with water molecules in terms of hydrogen bonding, making the formation of hydrates thermodynamically less likely (Okereke et al., 2020). Methanol (MEOH) is as well commonly used. The main factor making methanol and MEG the most commonly used thermodynamic inhibitors is hydrate suppressor performance (Brustad et al., 2005). Both MEG and DEG could be regenerated, the biggest drawbacks when using them is the cost, making the system cost higher than those of a methanol injection system. The higher capital investment and the more they both cost makes the other systems more economical than the Glycol system based on an annual injection. When the injection frequency per year increases, it is evident that the operational cost increases too. (Paz et al., 2020).

LOW DOSAGE HYDRATE INHIBITORS (LDHI$_S$)

Low dosage hydrate inhibitors are alternative, method to mitigate the risk of forming a hydrate blockage and these LDHI$_S$ can be effective at significantly lower level than THI$_S$ (Braniff, 2013). Low dosage hydrate inhibitors can be categorized into Kinetic hydrate inhibitors or threshold hydrate inhibitors and Anti-agglomerates.

KINETIC HYDRATE INHIBITORS (KHIs)

This is a type of LDHIs which works by delaying the nucleation of the hydrate and/or growth for a period of time usually known as the induction time. The dosage rates are usually a fraction of that required for thermodynamic inhibitors. This inhibitors are highly effective in low to moderate sub-cooling applications. (Sloan et al, 1998) characterized the inhibition performance of PVCap. The lower molecular weights of PVCap were more effective. Salt effects on PVCap were minor at low concentrations but tended to be positive at higher salt concentrations. The first generation KHIs were based on polymers of pyrrolidinone or caprolactum ring-based structures. The drawbacks for kinetic inhibitors included sub-cooling limits and also time limits of the effectiveness of KHI. The first generation KHI effectiveness at controlling hydrates was limited to approximately 24hours. The first generation KHIs had upper limits on the sub-cooling and they could effectively control up to 18ºF (Ke and Kellard, 2016).

ANTI-AGGLOMERATE HYDRATE INHIBITORS (AAs)

This type of LDHI allows hydrate to form but usually keeps the particles well dispersed and small in the hydrocarbon fluid. Viscosities of the fluid remains low thereby allowing the transporting of hydrates with the produced fluid without depositing. (Koh et al., 2002), compared the kinetic inhibitors (PVP and VC-713) and an Anti-agglomerate inhibitor (QAB) concluded that VC-713 is found to be more effective at both bulk and surface inhibition and is effective in delaying hydrate nucleation. The following, are the limitations of using anti-agglomerates hydrate inhibitor (Okereke., 2020): Require liquid hydrocarbon phase, Do not protect gas phase, May not be effective at temperature below 38ºF (Deka et al., 2020) converted propylene glycol which is a known thermodynamic inhibitor into a low dosage hydrate inhibitor by transforming it to quantum dots. Instead of using hundreds of gallons of thermodynamic inhibitors only a low quantity was proved to be sufficient which was quite cost effective.

(Okereke et al., 2020) carried out an economic analysis based on typical volumes/rates of MEG and LDHI for mitigating hydrates on sample offshore assets and concluded that the cost of using MEG was significantly higher than that of low dosage hydrate inhibitor although LDHI had an initial relatively high CAPEX, in the long run its OPEX is relatively low. Making it cost effective for hydrate inhibition in deep water.

III. METHODOLOGY

In this study, five different hydrate inhibitors (Methanol, MEG, DEG, KHI and Anti-agglomerates) were analyzed using Monte Carlo Simulation.

Assumptions:
CAPEX = $100M
OPEX = $1.2/MCft
Discount rate = 15%
Tax = 30%
Depreciation Method = Straight line Method for 5years

NET PRESENT VALUE:

It is the sum of the present value of the individual annual net cash flow over the life time of the project. It is represented mathematically as (Mian, 2010).

$$NPV = \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t}$$

If NPV is positive, accept the proposal; if it is negative, reject the proposal. The more the positive value the outcome.

INTERNAL RATE OF RETURN (IRR):

It is the discount rate at which the net present value is exactly equal to zero. It is a measure of profitability. It can represented mathematically as (Mian, 2010).

$$NPV = \Sigma_{t=1}^{n} \frac{NCF}{(1+IRR)^t} = 0$$

If IRR is greater than discount rate accept, if less than the discount rate reject the proposal.

IV. RESULT AND DISCUSSION

METHANOL

In Figure 2a & 2b below, the Beta distribution of NPV and IRR are presented graphically for methanol. The NPV chart can be noted to vary from $8.5MM to $33.0MM giving us a mean of $19.98MM and an uncertainty of 49.98% hence, the certainty of getting the exact mean is 50.02%. While the IRR chart below varies from about

20.5% to 42.5% giving us a mean of 28% and an uncertainty of 52.56% hence, the certainty of getting the mean (IRR) is 47.44%.
Mean = $19.98 MM
Uncertainty = 49.98 %

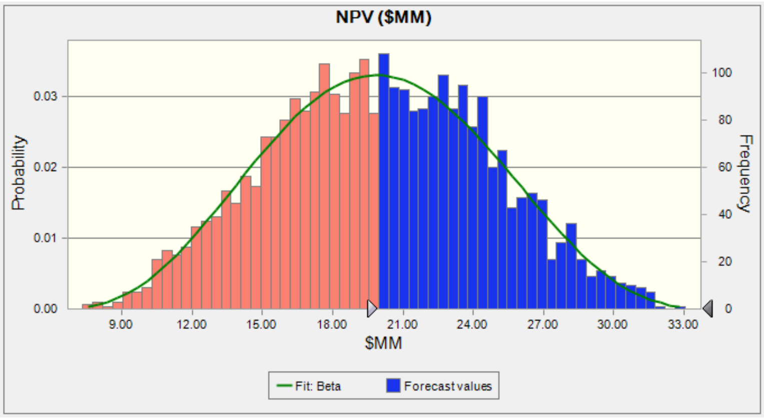

Figure 2a: METHANOL NPV chart

Mean =28 %
Uncertainty = 52.56 %

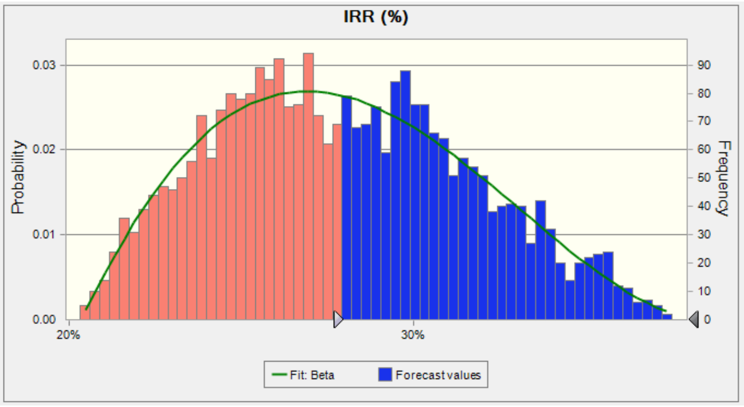

Figure 2b: METHANOL IRR chart

MEG

In Figure 3a & 3b below, the Beta distribution of NPV and IRR are presented graphically for MEG. The NPV chart can be noted to vary from $8.5MM to $33.0MM giving us a mean of $19.63MM and an uncertainty of 51.28% hence, the certainty of getting the exact mean is 48.72%. While the IRR chart below varies from about 20.2% to 45.5% giving us a mean of 28% and an uncertainty of 45.06% hence, the certainty of getting the mean (IRR) is 54.94%.
Mean = $19.63MM
Uncertainty = 51.28 %

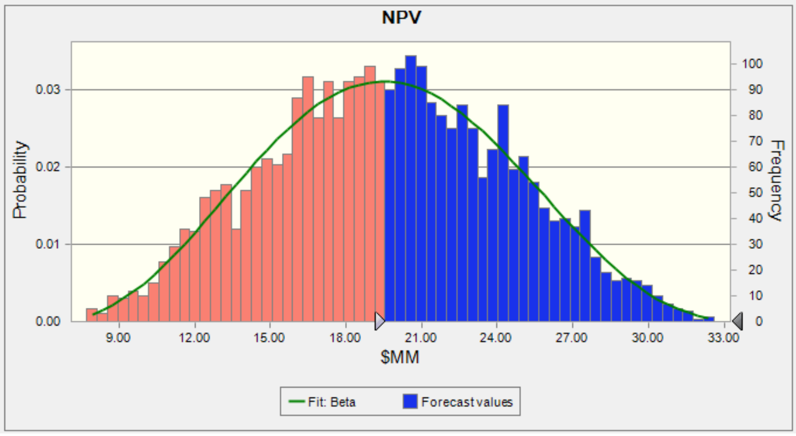

Figure 3a: MEG NPV chart

Mean = 28 %
Uncertainty = 45.06 %

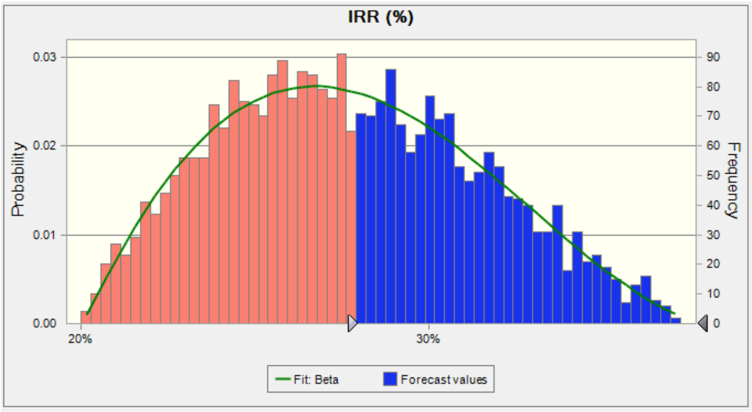

Figure 3b: MEG IRR chart

DEG

In figure 4a & 4b below, the Beta distribution of NPV and lognormal distribution of IRR are presented graphically for DEG. The NPV chart can be noted to vary from $-2.5MM to $33.3MM giving us a mean of $15.47MM and an uncertainty of 48.77% hence, the certainty of getting the exact mean is 51.23%. While the IRR chart below varies from about 22.5% to 42.5% giving us a mean of 25% and an uncertainty of 51.09% hence, the certainty of getting the mean (IRR) is 48.91%.

Mean NPV = $15.47MM
Uncertainty = 48.77%

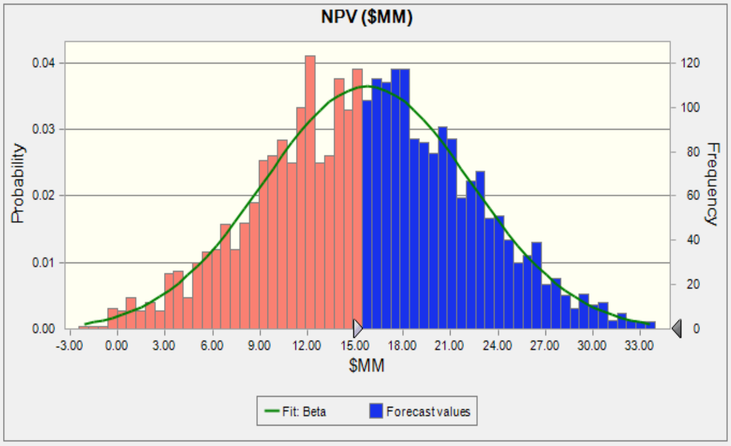

Figure 4a: DEG NPV chart

Mean IRR = 25%
Uncertainty = 51.09%

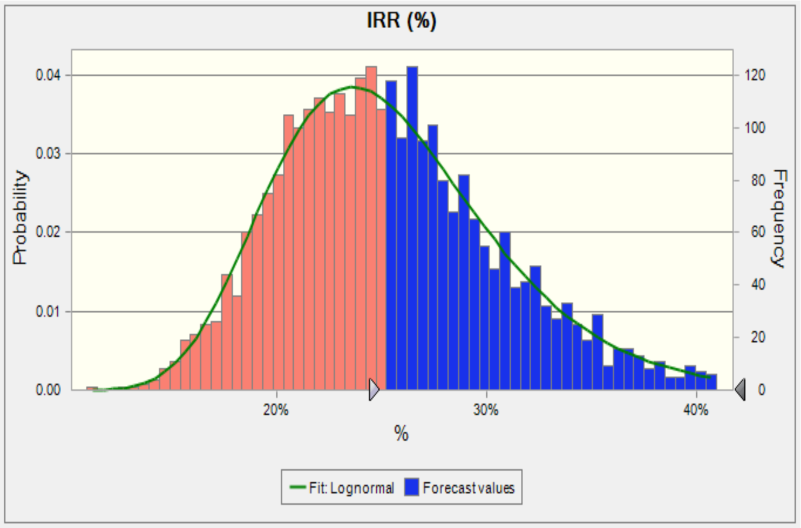

Figure 4b: DEG IRR chart

KHI (PVP)
In Figure 5a & 5b below, the Beta distribution for both NPV and IRR are presented graphically for KHI. The NPV chart can be noted to vary from $8.5MM to $33.3MM giving us a mean of $20.34MM and an uncertainty of 49.41% hence, the certainty of getting the exact mean is 50.59%. While the IRR chart below varies from about 20% to 40% giving us a mean of 28% and an uncertainty of 49.07% hence, the certainty of getting the mean (IRR) is 50.93%.
Mean = $20.34MM
Uncertainty = 49.41%

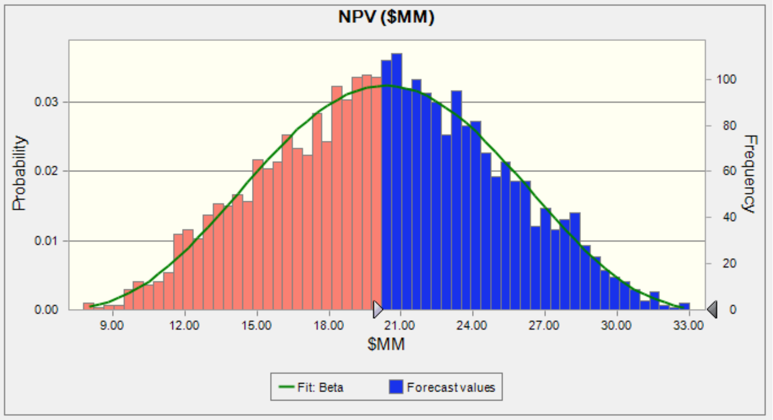

Figure 5a: KHI NPV chart

Mean = 28 %
Uncertainty = 49.07 %

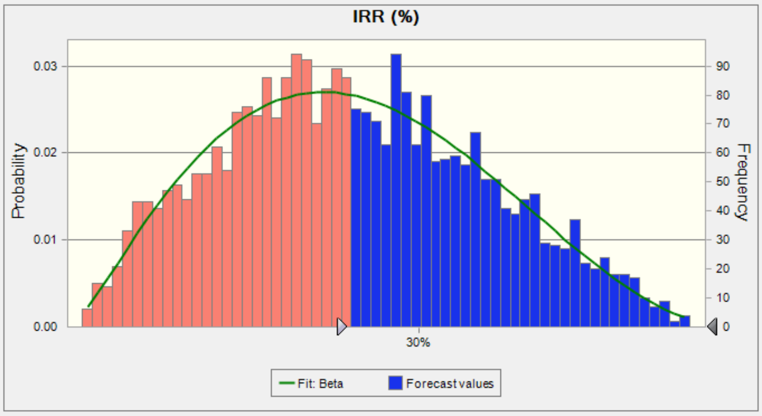

Figure 5b: KHI IRR chart

ANTI-AGGLOMERATES

In figure 6a & 6b below, the Beta distribution of NPV and triangular distribution of IRR are presented graphically for AA. The NPV chart can be noted to vary from $8MM to $31MM giving us a mean of $19.7MM and an uncertainty of 50.39% hence, the certainty of getting the proposed mean is 49.61%. While the IRR chart below varies from about 21% to 38% giving us a mean of 28% and an uncertainty of 55.57% hence the certainty of getting the mean (IRR) on the graph is 44.43%.

Mean NPV = $19.7MM
Uncertainty = 50.39%

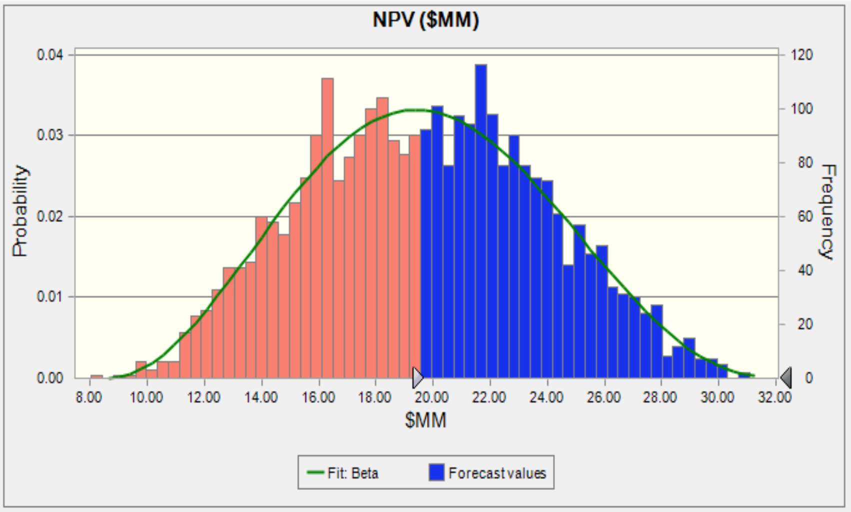

Figure 6a: AA NPV chart

Mean IRR = 28%
Uncertainty = 55.57%

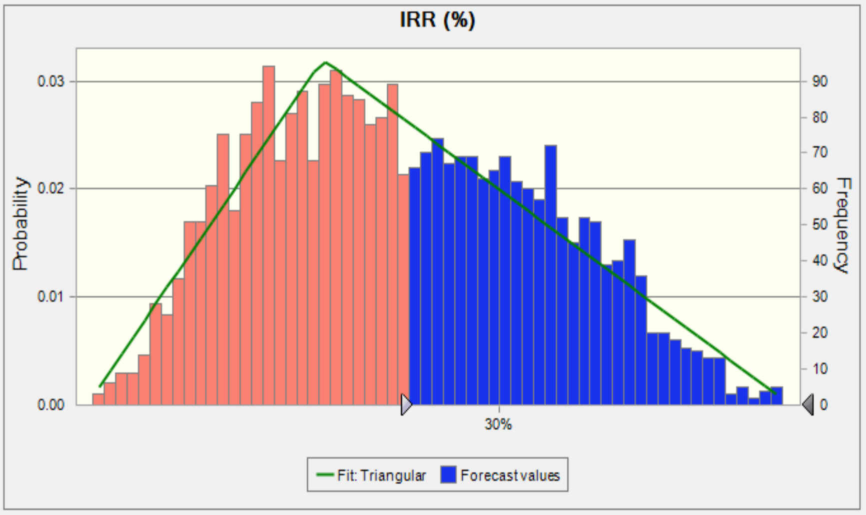

Figure 6b: AA IRR chart

SENSITIVITY ANALYSIS

Sensitivity is the amount of uncertainty in a forecast caused by model assumption and model uncertainties. The charts show the influence each assumption has on a particular forecast output. Here, the input parameters in the forecast calculations are varied around a base value.

METHANOL

From the analysis in Figure 7a, CAPEX and OPEX has more uncertainty on the NPV of the Hydrate inhibition operations using methanol. Discount rate also impacts on the NPV. Lastly, the effect of the price of the inhibitor on the uncertainty is minimal. In Figure 7b below, CAPEX and OPEX still has more uncertainty on the IRR of the Hydrate inhibition operations using methanol. Discount rate and price of the inhibitors have no effect on the uncertainty.

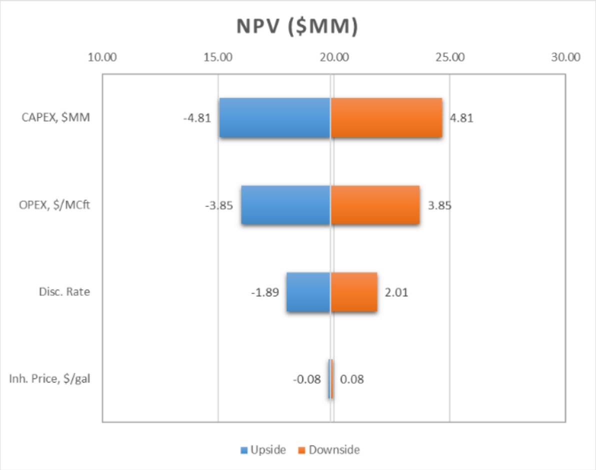

Figure 7a: Sensitivity chart for NPV of METHANOL

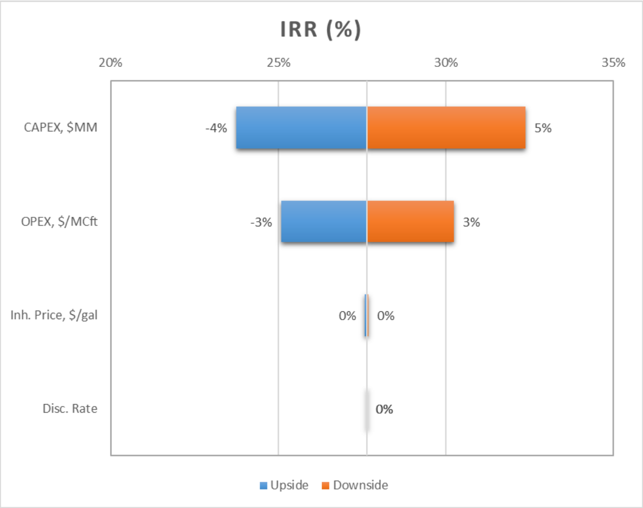

Figure 7b: Sensitivity chart for IRR of METHANOL

MEG

From the analysis in Figure 8a, CAPEX and OPEX has more uncertainty on the NPV of the Hydrate inhibition operations using THI (MEG). Discount rate also impacts on the NPV. Lastly, the effect of the price of the inhibitor on the uncertainty is minimal. In Figure 8b below, CAPEX and OPEX still has more uncertainty on the IRR of the Hydrate inhibition operations using THI (MEG). Discount rate and price of the inhibitors have no effect on the uncertainty.

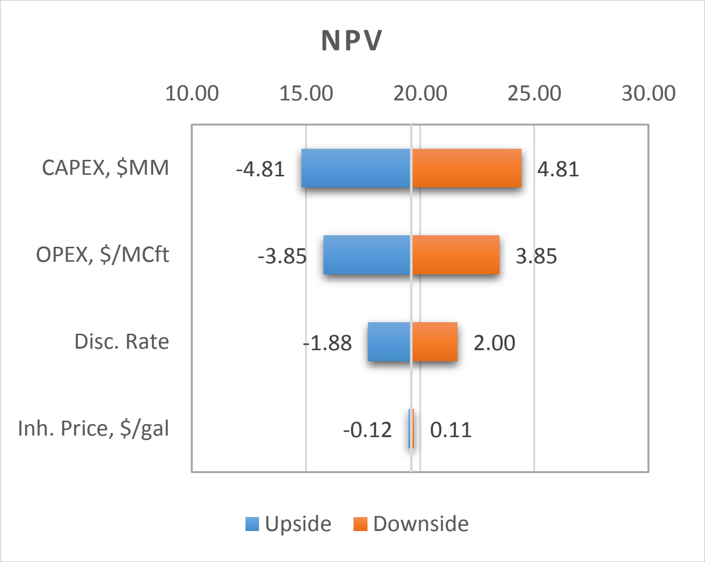

Figure 8a: Sensitivity chart for NPV of MEG

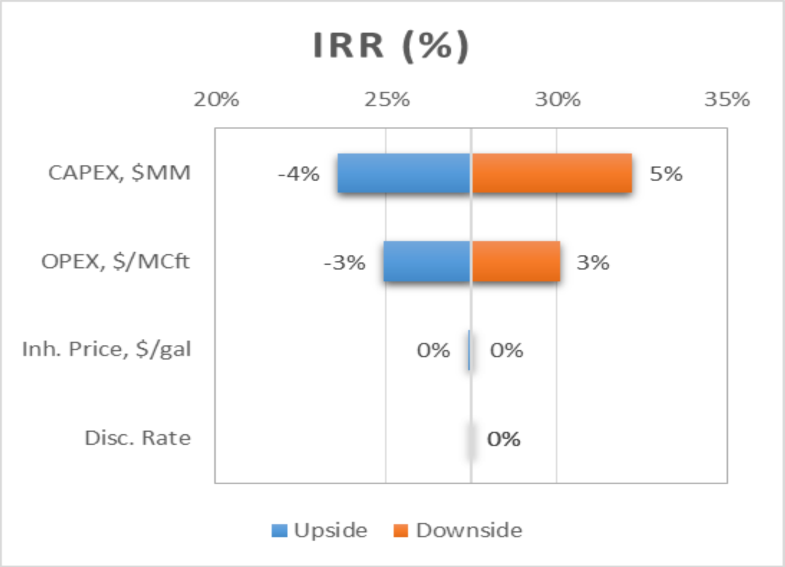

Figure 8b: Sensitivity chart for IRR of MEG

DEG

From the analysis in Figure 9a below, CAPEX contributes the largest value to the uncertainty then the OPEX and discount rate have a significant effect on the uncertainty lastly, the price of the inhibitors have the lowest effect on the uncertainty of the NPV. In Figure 9b below, CAPEX still have the most effect on the uncertainty of the IRR then, the OPEX have a significant effect too. But the discount rate and price of inhibitors shows they both have no effect on the uncertainty

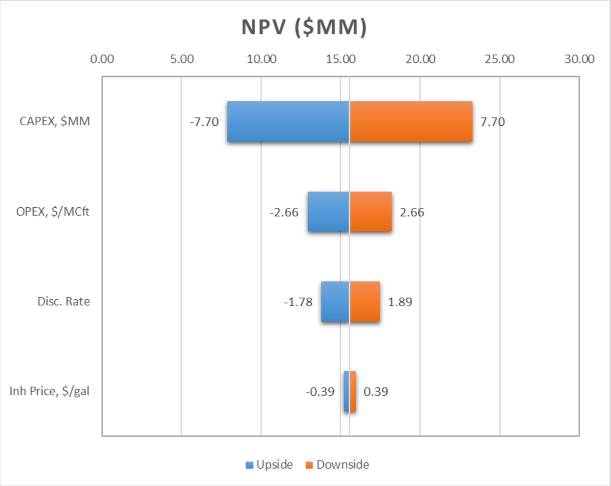

Figure 9a: Sensitivity chart for NPV of DEG.

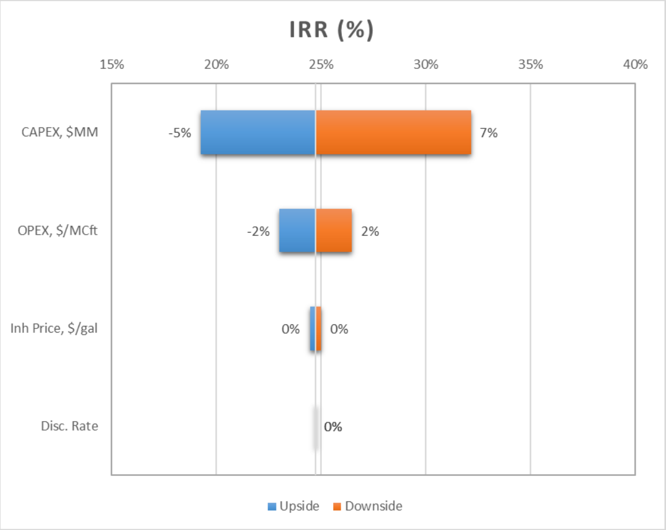

Figure 9b: Sensitivity chart for IRR of DEG

KHI

From the analysis in Figure 10a below, CAPEX represents the highest of the parameters although it can be seen that the OPEX, discount rate and price of inhibitors has a significant contribution to the uncertainty of the NPV model.

In Figure 10b below, CAPEX still have the most effect on the uncertainty of the IRR then, the OPEX have a significant effect too. But the discount rate and price of inhibitors show they both have no effect on the uncertainty.

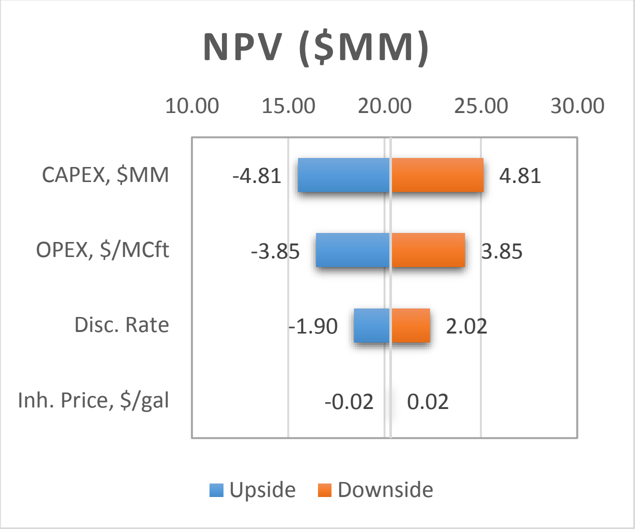

Figure 10a: Sensitivity chart for NPV of KHI

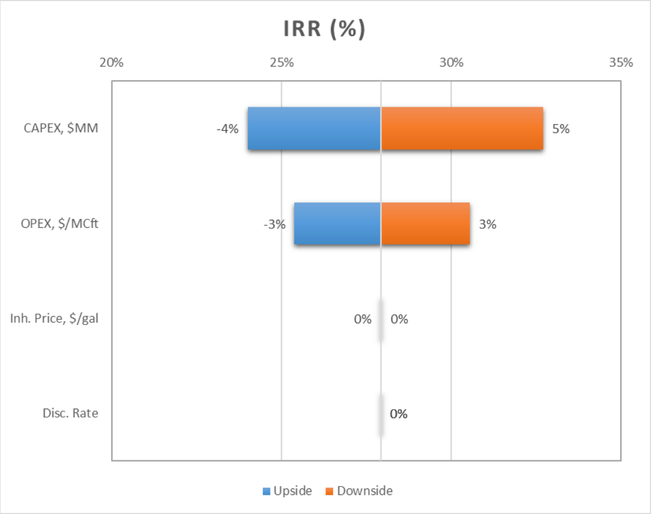

Figure 4.9b: Sensitivity chart for IRR of KHI

ANTI AGGLOMERATE

From the analysis in Figure 11a below, CAPEX contributes the largest value to the uncertainty then the OPEX and discount rate have a significant effect on the uncertainty lastly, the price of the inhibitors have the lowest effect on the uncertainty of the NPV.

In Figure 11b below, CAPEX still have the most effect on the uncertainty of the IRR, the OPEX have a significant effect too. But the price of inhibitors and discount rate show they both have no effect on the uncertainty.

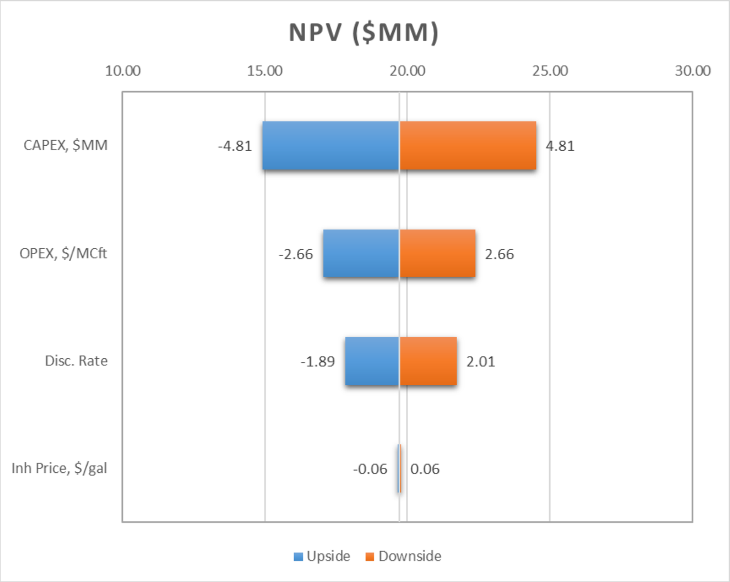

Figure 11a: Sensitivity chart for NPV of AA

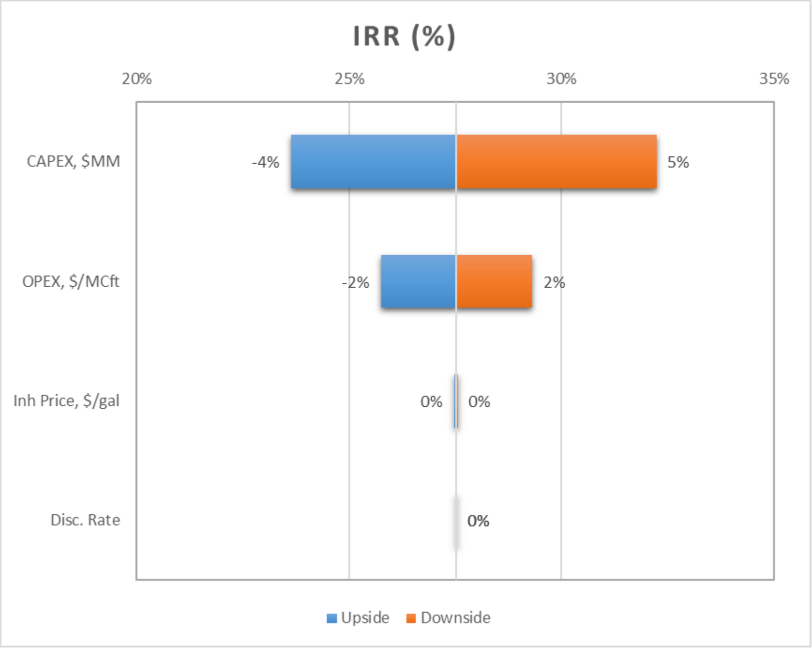

Figure 11b: Sensitivity chart for IRR of AA

V. CONCLUSION

In conclusion, an essential advantage of the probability approach to profitability decision is its ability to provide a better view of the real uncertainties involved in the decision. The MCS, in particular may provide insights into the parameters with the highest effect on the NPV and IRR by carrying out a sensitivity analysis. Results showed that CAPEX has the highest effect on the NPV and IRR although other uncertainty variables showed a significant effect too. Due to the uncertainty gotten mainly from the CAPEX, if the time for the project is delayed or inflation affects the CAPEX or OPEX of the project during the time of the project, the CAPEX and OPEX will increase which will lead to NPV reduction and the project becomes unprofitable. Therefore, higher CAPEX results to reduction on the NPV as well as reduction on IRR. Only when P (NPV>0) is the project investment feasible by means of probabilistic criterion as shown and all five inhibitors meet this criterion. The use of this information aids in selecting an optimized hydrate inhibitor based on the cost and operating conditions the inhibitor will undergo. With the selection of inhibitor based on cost, the economic analysis aspects have been considered in this study. This study has analyzed the METHANOL, MEG, DEG, KHI (PVP) and AA (TMAC). From the result, Kinetic hydrate inhibitor (PVP) would be the most preferred amongst the other inhibitor used considering it is more economical and more profitable due to its higher NPV and IRR and it has the lowest uncertainty hence, the certainty for getting the mean is very high. METHANOL can be used as a second choice because it is the inhibitor with a low uncertainty and has the next highest NPV, then AA, MEG and DEG. The inhibitors can be selected by investors depending on their risk attitude and capital constraints.

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