



Rapid Evaluation of Thermodynamic Hydrate Inhibitor Requirement and Impact of Pressure/Temperature Uncertainties Using Curve Fitting

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Abstract

Hydrate inhibitor requirements are often calculated during FEED studies with margins added to account for uncertainties in operating pressures, operating temperatures and/or hydrate dissociation temperature. The addition of margins may lead to over-design of injection and regeneration (where applicable) units, but also limit the operability of the system. A simple methodology is presented to rapidly calculate thermodynamic hydrate inhibitor requirements and evaluate the impacts of margins and uncertainties considered during FEED.

Keywords

Thermodynamic Hydrate Inhibitors; Hammerschmidt Equation, Curve Fitting; Uncertainty.

Introduction

Continuous or batch injection of hydrate inhibitor is regularly performed during production of natural gas and commonly recommended as a hydrate management strategy during FEED studies. Thermodynamic inhibitors such as Mono-Ethylene Glycol (MEG) or Methanol are typically selected when injection of hydrate inhibitor is recommended, and PVT packages used by Process and Flow Assurance engineers can easily predict hydrate dissociation temperatures for different inhibitors [1].

Flow Assurance engineers regularly recommend injection volumes and rates of hydrate inhibitor during FEED studies based on simulated operating conditions (pressure and temperature). However, several modelling parameters and uncertainties can lead to over-design and limit operability if not carefully assessed [2].

A methodology is presented herein to rapidly calculate the hydrate inhibitor requirements and evaluate the impact of margins and uncertainties in operating pressure, operating temperature and hydrate dissociation temperature.

Methodology

The methodology presented herein relies on approximating known hydrate dissociation temperatures mathematically for different concentration of hydrate inhibitor. Therefore, a few hydrate dissociation curves with and without the selected hydrate inhibitor need to be obtained first from the PVT package used for Flow Assurance studies. Then, the hydrate dissociation curves are fitted with a mathematical approximation that describes the shape of the curve suitably.

The uninhibited hydrate dissociation curve should be mathematically fitted as follows:

$$T_{Hyd,0} = a + b.p + c.\ln(p) + d.p^2 \quad (1)$$

where, a , b , c and d , represent fitting coefficients, $T_{Hyd,0}$, uninhibited hydrate dissociation temperature, and p , operating pressure. Note that pressures and temperatures are herein presented using bara and °C, respectively. However, the mathematical functions remain valid with different units for pressure and temperature. Although PVT packages provide hydrate dissociation curves over large ranges of pressures, it is recommended to limit the range of pressure for a better fit and increased accuracy.

Each inhibited hydrate dissociation curve should then be fitted as follows:

$$T_{Hyd,\alpha} = a + b.p + c.\ln(p) + d.p^2 - e \frac{\alpha}{1.8(100 MW - \alpha MW)} - f \alpha p \quad (2)$$

where, a , b , c , and d , are the fitting coefficients calculated at the previous stage, $T_{Hyd,\alpha}$, inhibited hydrate dissociation temperature, e and f , fitting coefficients for pressure correction, MW , molecular weight of the hydrate inhibitor in g/mol, and α , weight percent of the hydrate inhibitor. Note that the last two terms of Eq.(2) correspond to a modified Hammerschmidt's equation [1] to include pressure correction weighted by the .

It is recommended to use a minimum of three inhibited hydrate dissociation curves covering a wide range of operating temperatures.

Once the fitting coefficients have been individually calculated for each of the inhibited hydrate

dissociation curves, the e and f coefficients should be averaged into coefficients K_1 and K_2 , respectively to establish a general hydrate dissociation temperature function Eq.(3).

$$T_{Hyd,\alpha} = a + b.p + c.\ln(p) + d.p^2 - K_1 \frac{\alpha}{1.8(100 MW - \alpha MW)} - K_2 \alpha p \quad (3)$$

The weight percent α of hydrate inhibitor required for any operating pressure p and temperature T can then be approximated quickly for any operating pressure and temperature conditions by solving the second order polynomial function in α :

$$A \alpha^2 + B \alpha + C = 0 \quad (4)$$

with:

$$\begin{cases} A = -1.8 MW K_2 p. \\ B = K_1 + 180 K_2 p MW + 1.8 MW (T_{Hyd,0} - T) \\ C = -180 MW (T_{Hyd,0} - T) \end{cases}$$

Uncertainties in pressure and temperature can be accounted for directly when solving Eq.(4) by replacing p and T with $p+p_{margin}$ and $T+T_{margin}$, respectively, whereas uncertainty in hydrate dissociation temperatures can be considered by replacing $T_{Hyd,0}$ by $T_{Hyd,0} - T_{margin}$.

Example

A typical natural gas composition (Ref.[1]) is presented in Tab.1 on a dry basis. The composition is modelled in Multiflash 7.1 using the Peng-Robinson equation of state. For this example, the dry composition is saturated at 200bara and 75°C. The corresponding hydrate dissociation curves obtained using Multiflash for MEG concentrations between 0wt% and 70wt% are shown in Fig.1.

Table 1. Typical Natural Gas Molar Composition (Dry Composition) [3]

Component	Mole %
N ₂	0.3
CO ₂	1.1
C ₁	90.0
C ₂	4.9
C ₃	1.9
C ₄ (i+n)	1.1
C ₅ (i+n)	0.4
C ₆ (i+n)	0.3

The nine hydrate dissociation curves are fitted as described above and the fitting coefficients are listed in Tab.2, with individual e and f coefficients listed in Tab.3. Note that the fitting is limited to pressures between 10bara and 200bara for increased accuracy.

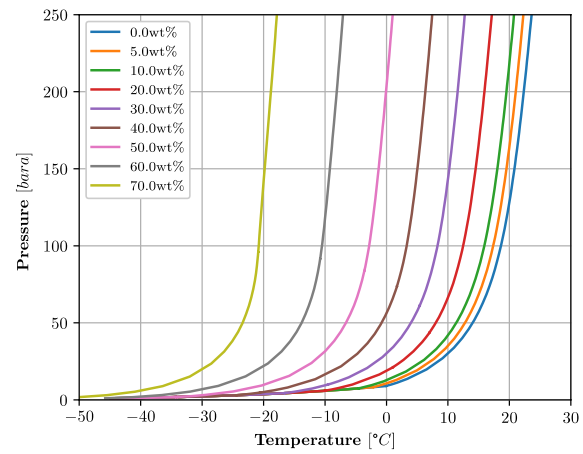


Figure 1. Hydrate dissociation curves with MEG

Table 2. Fitting Coefficients Eq.(3)

Coefficient	Value
a	-20.216
b	-0.045
c	9.285
d	5.848
K ₁ (Tab.3)	2385.090
K ₂ (Tab 3)	1.873 10 ⁻⁴

Table 3: e and f Fitting Coefficients Eq.(2)

α [wt%]	e	f
5	2670.156	4.017E-05
10	2697.927	5.740E-05
20	2694.868	8.278E-05
30	2593.333	1.323E-04
40	2428.900	2.041E-04
50	2245.568	2.539E-04
60	2013.893	3.222E-04
70	1736.079	4.053E-04
	K ₁ =2385.090	K ₂ =1.873 10 ⁻⁴

MEG requirements can then be calculated for any operating pressure and temperature using Eq.(4) with the fitting coefficients in Tab.2. For instance, an operating pressure and temperature condition of 75bara and +4°C requires a minimum of 36.6wt% of MEG in water to depreciate the hydrate dissociation temperature sufficiently to prevent the formation of hydrates (Fig.2). This corresponds to a 0.61 ratio of MEG per water volume when considering a lean MEG concentration in water of 90wt%.

The MEG requirement calculated above is shown against margins on pressure and temperatures in Fig.3. Results show that an uncertainty in operating pressure of ± 10 bar leads to less than ± 2 wt% change in MEG requirement. However, a ± 5 °C uncertainty in operating temperature leads to a ± 9 wt% change in MEG requirement. Similarly, adding an uncertainty of 3°C on the hydrate dissociation temperatures as is commonly done at FEED stage to account for the uncertainty in fluid composition in general and water content in particular, leads to an increase in MEG requirement by 6wt%.

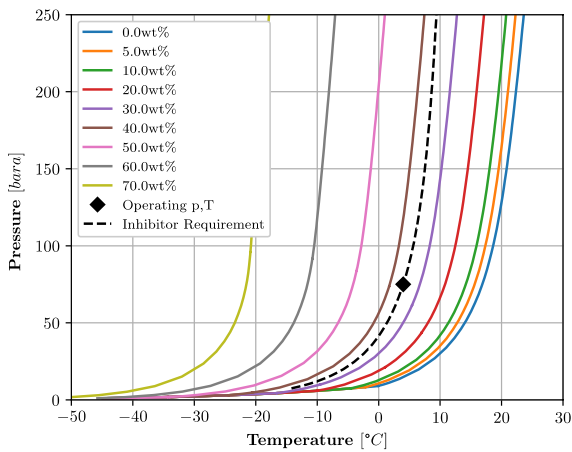


Figure 2. MEG Requirement at 75bara, +4°C

Uncertainties and margins added on operating conditions and/or fluid properties may lead to over-dosing of hydrate inhibitor of the associated injection unit. However, over-dosing may also lead to restrictions in operational conditions. For the case presented above, the MEG freezing temperatures are shown in Fig.4 for the margins on HDT considered. Results show that adding a 3°C margin on the HDT leads to increasing the MEG freezing temperature from -29.8°C to -13.7°C when considering a lean MEG concentration in water of 90wt%. Therefore, even though over-dosing of MEG may be perceived as preventing the formation of hydrates at low temperature, it is important to note that over-dosing limits the range of operable temperatures.

Note that for the example presented above, the difference between the calculated hydrate dissociation temperatures using Eq.(3) and Tab.(2) for 36.6wt% of MEG in water are between 0.4°C and 0.8°C higher than the values obtained with Multiflash. Therefore, even though margins may lead to over-design of equipment, it is important to understand their impact and where they should be considered.

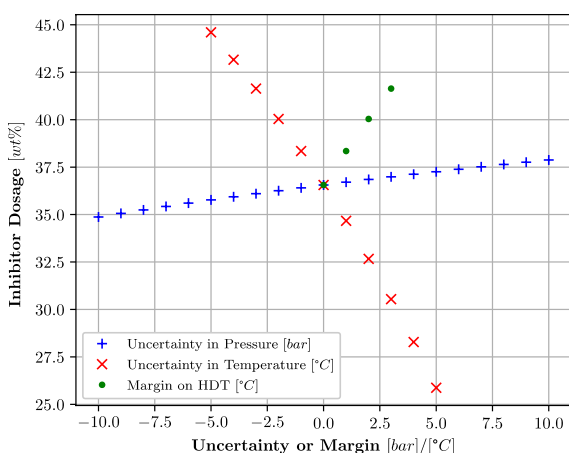


Figure 3. MEG requirement against uncertainty in pressure and temperatures

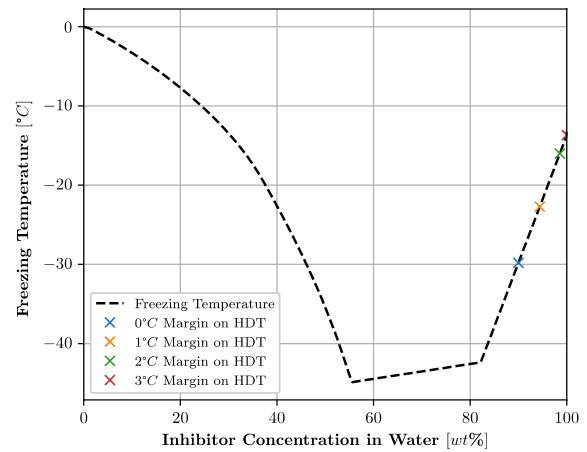


Figure 4. MEG freezing temperature against uncertainty in pressure and temperatures

Discussion

The methodology presented herein allows for rapid evaluation of thermodynamic hydrate inhibitor requirements based on a limited number of hydrate dissociation curves. The methodology relies on a simple mathematical expression and can be automated easily and included in Flow Assurance studies.

Margins on operating conditions and/or hydrate dissociation temperatures are often added during FEED to account for uncertainties in modelling and/or input data. While these margins are often considered 'safe' during FEED, they may lead to over-design of hydrate inhibition injection units, regeneration units (where applicable), and possibly limit the operability of a system.

Therefore, analysing the impact of uncertainties and margins is important to understand the risks and consequences associated with injection of hydrate inhibitor. In addition, a rapid evaluation of the impact of uncertainty on requirements of hydrate inhibitor may help in understanding what parameters will have the greatest impact on the design.

Conclusions

A methodology has been presented to rapidly calculate hydrate inhibition requirements, and to analyse the impacts of uncertainty in pressure and/or temperatures. This methodology relies on a simple mathematical expression that can be automated and included in Flow Assurance studies.

Responsibility Notice

The author is the only responsible for the paper content.

Abbreviations, Symbols

Abbreviation Symbol	Definition
FEED	Front End Engineering Design
HDT	Hydrate Dissociation Temperature
MEG	Mono-Ethylene Glycol
p	Pressure
PVT	Pressure, Volume and Temperature
T	Temperature
wt	Weight

References

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