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Application of Artificial Neural Networks on Measurement of Gas Hydrates in Pipelines

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Abstract

In Transportation or transmission of Deep water hydrocarbon transportation pipeline, the hydrocarbon flow can decrease due to the growth of gas hydrates which lead to additional operational cost and time constraints. The monitoring of Deepwater transmission pipelines is quite crucial as they are operated at high pressures and low temperatures. So, the risk of Gas hydrate formation conditions is highly prevalent and poses a major operational and safety challenge. In recent times, Artificial Neural Network (ANN) is very critically used over the research of hydrates because of its pros of high data simulation capacity and accurate curve fitting nature. Therefore, the aim of this work is to provide the latest review on application of Artificial Neural Network (ANN) in the prediction of gas hydrate formation in Deepwater gas pipelines. Moreover, this study potentially paves the way for the knowledge of latest research carrying out in the prediction of gas hydrates which also helps in the development of advanced algorithms with respect to the work mentioned or discussed here.

Keywords: *Hydrate formation, ANN, Hydrate prediction, Gas Pipelines.*

1. Introduction

Gas hydrates or “clathrates” are often referred to as solid inclusion compounds. Basically, the hydrates possess a network of water molecule cages which acted as "host" that could be trapped by smaller paraffin as "guest" molecule. The common gas hydrate guest molecules are methane (CH4), Ethane (C2H6), Carbon dioxide (CO2) and propane (C3H8). Gas Hydrates are more likely to form at the interface of water (H2O) and the above-mentioned gases. [1] The lower solubility nature of CH4 in water (H2O) leads to insufficient CH4 molecules availability. [2] Due to this, the small amounts of hydrate cages in the liquid body are formed. Similarly, the small amount of vaporized water (H2O) in the presence of gas provides only a few hydrate cages forming in the body of the gas; there are very few water molecules to make a significant amount of the host crystal structures in the bulk gas. When the water droplet is emulsified in the oil phase, hydrates are formed at the oil-water interface.

One conceptual formation picture for hydrate formation is shown in Figure 1.

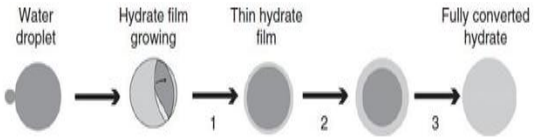

Figure 1: Formation of Hydrate on an Emulsified Water Droplet [1]

Gas Hydrate are formed mostly during transient flow conditions. Also, start-up or restart of the system during an emergency or may be a shutdown situation effects in the formation of hydrates. Such conditions are uncommon operational situations. These Gas hydrates are formed in the presence of water (H2O). Due to the considerations at designing, the gas hydrates are not so often found during general flow operations. Gas dominant systems are more prone for Hydrate formation when compared to Oil dominant system as the oil systems possess high reservoir

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temperatures due to its heat capacity nature Whereas Gas dominant systems has a rapid cooling nature when compared with Oil systems. Many oil production flow lines are insulated to maintain high temperatures in the flow stream.

Throughout the 19th century, an intellectual nosiness was developed towards the Gas hydrates. Earlier, the focus was more on components that tend to form gas hydrates and at which conditions are more prone for the formation. Research on Gas hydrates and discovery of elements that form hydrates was made during this time. Later, in 20th century the industrial importance of Gas hydrates increased.

The major challenge during study of Gas hydrates was to predict the hydrate formation temperature and Pressure. This is carried out as its important to evaluate the optimal conditions to reduce the effect of hydrates on the flow. Initially, Manual calculation methods were highly followed to estimate the formation of hydrate conditions. Unfortunately, these hand calculation methods are not reliable often as they accuracy of them is low. [3] As universally accepted, the accuracy of the results depends on the information given as input.

The emergence of high-speed simulation computers and huge data processing software's has brought a great change in engineering. The dependence on the rough manual calculations for estimation of gas hydrate formation is greatly reduced.

Moreover, there is a broader range of further calculations is in existence for the well-known manual calculation methods. Thus, the improvement and development of new software's are highly important. Although these simulation models are mostly thermodynamic models that are recommended by researchers.

As stated earlier, one of the major problems concerning the study of gas hydrates is they are nonstoichiometric by nature. Any modelling technique for prediction of Gas hydrate formation had to handle this as uncommon nature. Further, the discussion about the formation of different types of Gas hydrates is needed. Several types of Gas hydrates would have been differentiated using rigorous models.

2. Base for development of modelling techniques:

Gibbs has developed the principal for phase equilibrium more than 100 years ago. It states that:

- The Pressure and Temperature of the phases are equal
- The chemical potential of every components in each phase is equal
- A minimal Global Gibbs free energy.

These are applied to phase equilibrium conditions involving Gas hydrates and are highly useful for the formation of the models for performing hydrate equilibrium calculations.

Three major models have been developed or followed as a base for development of any model to estimation formation of hydrates.

1) Statistical Model
2) Multi component statistical model
3) Equilibrium Model

1) Statistical Model

The first model for estimating rate of formation of hydrates was done by Vander Waals and Platteeuw in 1959 and the proposed model was a statistical model. [3] The non H20 species concentration was treated like the process of adsorption of gas onto solid in gas hydrates. The term for a single guest molecule was evaluated as:

Where

$\mu^H - \mu^\beta = RT \sum Vi \ln(1 - Yi)i$

Y = Function of Probability

vi= No. of cavities (I – TYPE),

The Y is the probability function that is occupied by the guest molecules of "I" cavity type.

It can be assumed by:

$Y_i = \frac{ciP}{1 + ciP}$

P = Pressure of Gas

ci=Guest molecule function that occupied the cage

P = Pressure

2) Multi component Statistical Model:

The Original statistical model approach was the basis of formation of gas hydrates calculations but found to be not accurate enough to accept them. Then, a modified statistical model was proposed by Parrish and Prausnitz in 1972 to ease up the accurate calculations for Gas hydrate formation. This model is proposed with two major differences with the existing statistical model. This model included the multi component mixtures that forms gas hydrates and then secondly involved over all components. They are proposed as

$\mu H - \mu\beta = RT \sum Vi_i \ln(1 - \sum Ykj)_k$

$Yki = \frac{ciPk}{1 + \sum jcijPj}$

Where, the second equation represents the probability function

Here the sum function is for the number of components, and the Partial pressure of any given component is represented by P with its subscript. Other than the occupied guest molecules, remaining gas molecules that are present are also considered as they compete with the occupied guest molecule for spacing them in the cage. Due to this, the probability of occupancy of guest molecule in Hydrate lattice is reduced. This helped in accounting the non-ideal nature in gas phase and applications at high pressures. Slight adjustments were made to the model for reflecting the changed that would occur due to pressures and to improve curve fitting nature.

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3) Equilibria Model

Later, a critical advancement was made by the model proposed by Ng and Robinson in 1977. This model can be used to predict the formation of gas hydrates in the presence of hydro carbon liquid at equilibria condition. Volumetric change and change in enthalpy must be evaluated firstly. Also, an equivalent equation of the perms can be used.

In this model, the equation proposed by Peng and Robinson in 1976 was used to calculate the fugacity. This equation can be applied for Non-Aqueous liquids alongside gases. Slight adjustments were recommended again on the parameters to reflect the change from equation proposed by Peng and Robinson in the model. Similarly, the equation proposed by Soave in 1972 or dual applicable equations for both gases and liquids can be used. However, the equations proposed by Soave and Peng-Robinson alongside the modified versions of them have become the pillars of Oil and Gas industry.

Further research proposed various methods for development of prediction models for rate of formation of gas hydrates among which the modified version of Parrish and Prausnitz method was used vividly including systems containing liquid formers.

Table 1: Base for development of modelling techniques

Model	Features	Scientist	Year
Statistical	To estimate rate of formation of hydrates	Vander Waales and Platteeuw	1959
Multi component Statistical	To ease up the accurate calculation calculations for Gas hydrate formation	Parrish and Prausnitz	1972
Equilibria	To predict the formation of gas hydrates in the presence of hydro carbon liquid at equilibria condition	Peng and Robinson	1977

3. Widely Used Commercial Softwares

These models served as a base for the development of accurate software's to estimate hydrate calculations. Two of the most reliable ones are EQUI-PHASE Hydrate developed by D.B. Robinson and his Associates in Edmonton, Alberta, and a program developed by INFOCHEM in London, England. Also, the CSMHYD package plays a major role in the current days. The most general purpose of these simulation programs is to include the capability to prediction of gas hydrate formation. These often helps by including warnings about the possibility of hydrate formation streams. These include HYSYS from HYPROTECH (Calgary, Alberta), ASPEN from Aspen Technology (Cambridge, Massachusetts) and PROSIM from Bryan Research & Engineering (Bryan, Texas).

All these programmes are tested for purity and mixture components at various operational conditions that are tending to happen during real-time operation and are found to be highly reliable. [2]

4. Usage of Artificial Neural Networks (ANN)

Based on the equations suggested by researchers that are presented previously research on Prediction and Control of natural gas hydrates has taken a big turn. Various methods started to evolve for reducing the effect of hydrates in the flow.

Some developments are made recently focusing on the prevention and control of formation of gas hydrates in both offshore wells as well as onshore systems. Major Control procedures commonly used in this area include variations on currently adapted practices such as [3]

1) Lowering the system pressure by Application of heat

2) Dehydrating some amounts of Gas/Liquid phases to reduce availability of components for hydrate formation.

3) Efficient inhibition system

4) Allowing the Hydrate formation to later treat them by discharge of H20, entrapment of hydrates and decomposing them.

Research on inhibition increased as it reduces the potential effect of hydrates on the flow system. Anti Agglomerants are proved to be more effective in recent times and are highly suggestible for the control of hydrate formation especially in oil production systems that are operated at Offshore conditions. During the deep-water applications, major concerns like Gas hydrates, emulsions, foam, water quality issues were not observed during operation. Usage of methanol inhibition was significantly low, but the usage of anti-agglomerates will provide potential advantages like smaller storage facility and smaller pumping requirements alongside less supply and smaller umbilical. The early usage of MULTIFLASH software for hydrate modelling was reported during this research. [4]

Later, the research on phase behaviour and multiphase transient lines came for better interest. Most available transient multiphase models are based either on the Two-Fluid Model (TFM) which includes equation of conservation of one momentum for each phase or on the Drift-Flux Model (DFM) based on one overall momentum conservation equation plus some algebraic slip relations. [5] But a Zero pressure wave model based on one-dimensional approach is developed for better improvement of phase behaviour approach to understanding formation hydrates in multiphase systems. This led as the base for development of models to describe the hydrates evolution processes from nucleation to kinetic growth.

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The application of numerical methods became very important for the understanding of hydrate behaviour over the flow. Also, huge data processing systems alongside high advancements in soft computational techniques like ANN, GA came into applicability and changed the entire analyses picture. Various estimation methods have been reviewed for hydrate formation temperature (HFT) to find which approach is giving more accurate results. A typical ANN model has been developed and compared with results obtained in Engineering Equation Solver (EES) and Statistical Package for the Social Sciences (SPSS) software. Comparison of these results with the estimated ANN model results with 30% of unseen data displays excellent performance by ANN. It was found that ANN is more accurate than traditional methods and even better performance than the models developed by EES & SPSS proposed correlations for HFT estimation. [6]

The risks of Gas hydrate formation were greatly reduced by usage of Thermodynamic inhibitors, such as methanol mostly. Later, to evaluate Phase equilibria in Multiphase transmission Pipelines, CPA (Cubic Plus Association) equation is used considering a Thermodynamic tactic. The determination of hydrate formation conditions is sculpted by the solid solution theory developed by Vander Waals and Platteeuw. Further, for the prediction of dissociation of hydrates of CH4 and natural gases was made by the usage of thermodynamic models that are developed with the presence of methanol aqueous solutions and H20.

[7] A considerable acceptance is found when the comparison between experimental data and data retrieved from developed ANN models is made.

Further, ANN models are developed to meet the novel requirements with industrial collaboration and prototypes are designed for the same work. The research about application of ANN for optimization of hydrate inhibition rate beside detecting safety margins of hydrates, degree of hydrate inhibition, phase equilibrium. ANN models are highly used in industries for initial detection of blockage in pipelines due to hydrate formation. [8] ANN models are useful for detection of changes in the operating system due to the formation of hydrates and helps to react to prevent the blockage. Later, interest about hydrates started to develop towards the usage of hydrates as a potential fuel source for future such as transportation, capture and for industries as storage source. [9] Key application was found as the dissociation of hydrate and extraction of gas for use of alternative fuels has been increased.

Research about the influence of heat transfer and mass transfer upon the decomposition of CH4 Hydrate is made and summarized that constant energy molecular dynamics are used for simulations. It is found that decomposition of CH4 hydrate is affected by rate of heat and mass transfer due to the release of methane gas into the liquid phase occurred because of the dissociation of methane hydrates. Since the dissociation of gas hydrates is an endothermic reaction, temperature gradients are established between the remaining solid hydrate and the solution phases. As the trend of dissociation of CH4 hydrate is observed, the release of large amounts of CH4 near the solid-liquid interface which can form bubbles that affect the rate of mass transfer between the phases. The solving of energy equations is done by developing ANN models. [9]

Artificial neural network (ANN) correlations are widely used to correlate parameters and it is well known that ANN is a useful approach for correlating a limited quantity of experimental data with required variables in some specific cases. It is also claimed that ANN is more powerful for multi- parameter correlations. By means of ANN correlations, the concentrations of thermodynamics inhibitors/KHI/AA and salts can be determined simultaneously using the measured electrical conductivity, acoustic velocity, and temperature. [10] An Artificial neural network (ANN) is trained by trial and error and requires neither an analytical formula nor understanding of the physical relationships behind. This is done for achieving a novel approach for LDHI's. A claim has been made that ANN is especially used for some applications where multi-parameter correlations are needed with the interaction and the relations between the measured parameters are not well known. [11] A comprehensive Artificial neural network (ANN) model for predicting hydrate formation conditions for pure gases and gas mixtures is proposed. The ANN model enables the user to accurately predict hydrate formation conditions for a given gas mixture minimising the cost for experimental evaluation. [12] The novel Artificial neural network (ANN) is developed in optimizing inhibitor injection rates, reducing the impact on the environment and operational costs. The models are useful in improving reliability of the operations and production as they help in observing the safety margin and thus helps in protection or safety of the system in failure cases like pumping defects and change in operational parameters like water cut. These results assisted to conclude that ANN models are greatly feasible with high accuracy for determination of various inhibitor systems such as Methanol (CH3OH), Mono Ethylene Glycol (C2H4O) and kinetic inhibitor salts. [13]

Further, CSMHyk is used in developing Prediction models of hydrate formation in Water, Oil and Gas dominant systems. This model helps to predict temporal and spatial hydrate formation and plugging in flow lines of oil, water and gas-dominated systems, which are used widely and of high importance in flow assurance. [14]

Application of soft computational techniques on the research of hydrates increased vividly. Experimental analysis on Gas hydrates has been made and then soft computational models like GA, ANN, PSA (Particle Swarm Algorithm) and ICA (Imperialist Competitive Algorithm) are modelled for optimization of the experimentally generated data and curve fitting is applied for enhancing the observed correlations accuracy. The

results from this novel correlation are compared to that of the prior works and it indicated that the proposed novel correlation proposed has the higher accuracy and minimum error. [15] A comparison analysis has been carried out on the performance of accuracy in predicting hydrate formation pressure in binary mixtures. This comparison was done between models developed in CSMHYK and ANN. [16] This result was quite interesting as the ANN model displayed greater accuracy when compared to the CSMHYK model.

An Experimental Investigation of Gas-Hydrate Formation and Particle Transportability in Dispersed Multiphase-Flow Systems Using a High-Pressure Flow Loop was carried out and an ANN prediction model has been developed. This model was later tested for many existing field data and found that the model serves as an accurate prediction model. [17]

Interest towards the carbon dioxide hydrates is of high importance as the CO2 hydrates are a critical threat to flow assurance compared to CH4 hydrates. Experimental evaluation has been done and a thermodynamic model alongside Artificial Neural Network (ANN) model has been developed for estimation of CO2 solubility in aqueous sodium salt of L-phenylalanine. This has been carried out for developing technology towards the inhibition process. [18] Further, a novel Artificial Neural Network (ANN) model for estimating Performance of aqueous Tetra Butyl Ammonium Hydroxide (C4H9)4NOH) and Piperazine (C4H10N2. 6H2O) along with their blends for carbon dioxide (CO2) capture. This work helps in improving carbon dioxide capture and hydrate inhibition procedure for achieving better flow assurance. [19]

Many, Artificial Neural Network (ANN) models have been developed for evaluation of kinetics of hydrates and for estimating inhibition rates for prevention of hydrate formation in flow lines. [20]

5. Conclusion

Over the past 3 decades, Research on gas hydrates have made a substantial progress in experimental analysis which led to the development of many models for studying and predicting the behaviour of gas hydrates at various conditions. A number of hydrate growth kinetic models especially soft computational models like GA (Generic Algorithm), ANN (Artificial Neural Networks), PSA (Particle Swarm Algorithm) and ICA (Imperialist Competitive Algorithm) are developed from diverse Engineering perceptions that included Heat and Mass transfer, Surface chemistry, Intrinsic Kinetic Reaction and Multiphase fluids flow. This review study on Gas hydrates summarizes the Semi Empirical Alongside Analytical models that are proposed for various perspectives of formation and growth of hydrates. Farther, a future outlook about the area of interest on Growth and analysis of Gas hydrates is also discussed. Regardless of the proposal of various models, there is no unified model that covers all the observations claimed or studied. Lack of connection among the Physical Behaviours and chemical nature is clearly noted. For development of such unified model, a multi scale physics which groups all is needed. Also, a novel model for estimating the rate of formation of hydrates in three-phase gas – oil-water system is yet to be proposed. For effective industrial applications, an accurate model that covers Semi Empirical parameters is required. This helps in the design of concrete reactors to handle gas Hydrates. Nevertheless, scaling of these Semi Empirical parameters is very critical during application of them on apparatus. Numerical modelling on formation of gas hydrates could be influential especially about Porous media and transmission pipelines. But, it requires a Real time data (either Field or Experimental) for efficient prediction and validation. We accept as true that the expansion about the research on formation of Gas hydrates and its growth will escalate far by the improvement or designing of efficient prediction models together with the experimental analysis. This will help in improving flow assurance in Oil and Gas industry substantially.

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