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PREDICTION OF THE THERMODYNAMIC HYDRATE FORMATION CONDITIONS FOR METHANE GAS

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ABSTRACT

This research work proposes the analysis of predicted data of hydrate formation conditions in an intelligent optimization-based approach. The thermodynamic conditions for hydrate formation were used to assess the plugging risk. Hydrate formation thermodynamic properties and chemical reaction were statistical analyses on developed model results. Thus, the developed algorithm was applied to the experimental data of gas pipeline to validate the results. This research study improves the present models via a novel approach of an empirical model that predicts and suggests parameters for the thermodynamic hydrate formation conditions of methane gas.

Keywords: optimisation algorithm; statistical analysis; temperature; pressure; thermodynamics.

INTRODUCTION

The crucial challenge in deepwater gas transmission pipeline is hydrate by the effect of thermodynamic properties and heat transfer conditions of the compositionsofgas mixtures. That will come in with a very high burden of risks in deepwater hydrocarbon production and transportation system. The clathrate hydrate was firstly introduced by Faraday and Davey later than in 1988 Villard showed the performance of it in the effects of thermodynamics and heat transfer conditions on a mixture of gases [1, 2]. The clogging phenomena of natural gas hydrates due to external and internal effects on gas mixture was determined by Hammerschmidt in 1934 [3, 4]. According to the numbers of statics that hydrocarbon industry spends annually hundred million dollars for flow assurance issues [5]. A model is proposed which is used to predict the vapour, liquid and hydrate at a limit of temperature from 34 to 60 F, pressure and gas gravity were applied in the range from 65 to 1500 and from 0.552 to 0.9, respectively [6]. An empirical correlation for hydrate formation was developed [7, 8], using Statistical Analysis Software (SAS) to correlate hydrate formation temperature with various variables, such as pressure 150 psi to 4300 psi, water vapour pressure 31 to 78, and specific gravity that range from 0.6 to 1. The optimisation algorithm was applied in the prediction yield for developing a sensible model [9, 10]. In the last couple of years, many correlation models have been proposed but unfortunate hydrocarbon industry is facing in a challenge position to overcome hydrate formation due to many parameters are required to re-adjust in existing models [11]. The implementation of complex models is very time consuming and not easily connected with the analysed situation of hydrate formation conditions. Constant coefficients are developed using intelligent optimisation algorithm modelling in this research for hydrate formation prediction. The balanced constant coefficients were found with minimum error in employing intelligent optimisation modelling. In the gas pipeline, the various thermodynamic and heat transfer conditions were predicted were presented in this research work. This research work goal is to develop a prediction model for hydrate formation that is tried to achieve through the proposed model at various gravities on the given sets of thermodynamic conditions of hydrate formation. The fundamental empirical model such as Kobayashi model [6], Hammerschmidt model [3], Ghiasi model [12] and Bahadori model [13]were applied for validation of this developed research model results. Moreover the VdW-P model is applied to validate the developed model results with experimental data of Sloan [2].

METHODOLOGY

This research method is to propose hydrate formation prediction through the intelligent optimization algorithm. The unknown variables of the developed model are optimized by adopting intelligent optimization algorithms [14-16]. The method of this research developed by applying the Gaussian and exponential model equations as shown in Figure-2 and the basic algorithm of this research is shown in Figure-1. The developed model was optimized by GWO, GA and PSO and statistical analysis of results. The algorithm of this research model was introduced for hydrate formation prediction correlation which is based on exponential and Gaussian equations as stated in Figure-1. The developed model equations are given as follows for pressure and temperature correlation models respectively.

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```
Input: ProblemSize, PopulationSize
Output: Pg-best
population←0
Pg-best←0
For(n=1 to Populationsize )
Pvelocity← RandomVelocity()
For (k=1 to problemSize)
Calculate T(n,K)
J(n,k)= (X_exp – X_pre)^2
End
J(n)= developed model
Pp-best←J(n)
Localcost←J(n)
If(Cost(Pp-best) <= Cost(Pg-best))
Pg-best←Pp-best
End
End
```

Figure-1. Research model algorithm.

$$P = ae^{bT_r} \quad (1)$$

$$T = \left\{ \begin{array}{l} a_1 e^{-\left(\frac{P_r - a_2}{a_3}\right)^2} + a_4 e^{-\left(\frac{P_r - a_5}{a_6}\right)^2} + a_7 e^{-\left(\frac{P_r - a_8}{a_9}\right)^2} \\ + a_{10} e^{-\left(\frac{P_r - a_{11}}{a_{12}}\right)^2} + a_{13} e^{-\left(\frac{P_r - a_{14}}{a_{15}}\right)^2} \end{array} \right\} \quad (2)$$

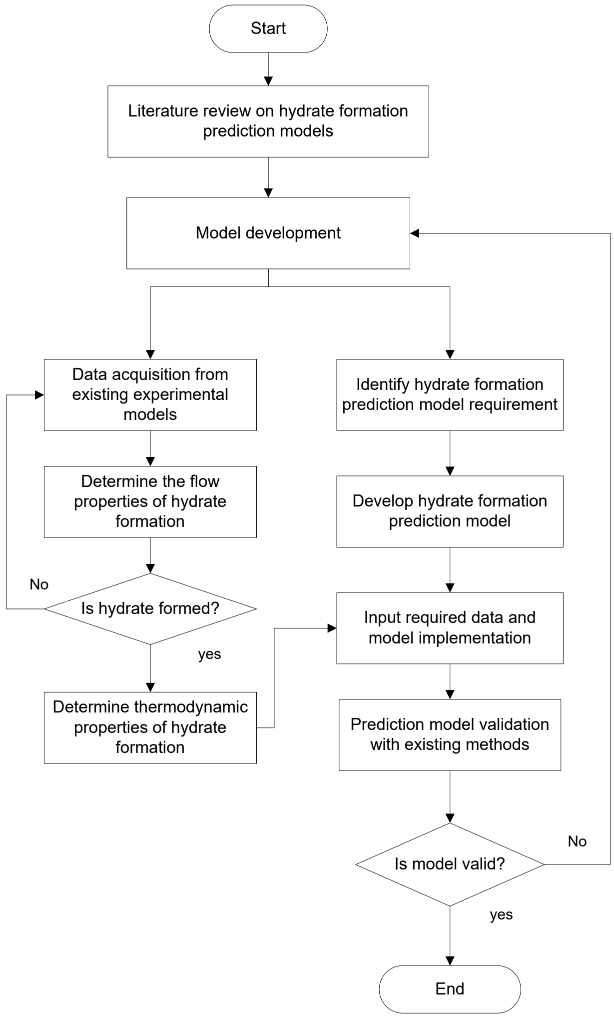

Figure-2. Research methodology.

RESULT AND DISCUSSIONS

Figure-3 and Figure-4 present the thermodynamic properties of methane gas in hydrate formation. The results of this research show reliable trends of agreement among the predicted thermodynamic properties of hydrate formation and adopted experimental data. Results came out on applying Eq. (1) and Eq. (2) and similarly validated with experimental datasets from '1' to '8' with CH_4 gas hydrate formation. This research result shows a lesser difference of error as compared to existing data on fundamental empirical models. The 13-point dataset was used firstly which ranges from 273.7 to 285.9 MPa stated the difference of error 0.162% and0.159% less point recorded as shown in Figure-9. However, the existing model reported pressure of 0.199 and 0.245 MPaon the same datasets of this research. The fundamental empirical model applied to validate this research results that give resemblance with lesser error for pressure and temperature correlation as shown in Figure-5 and Figure-6. The other results developed on 20 points of a dataset that ranges from 15 to 397 MPa which gives the minimum error of 0.158 and 0.159 as compare to existing model error 0.264, 0.694 as shown in Figure-10.

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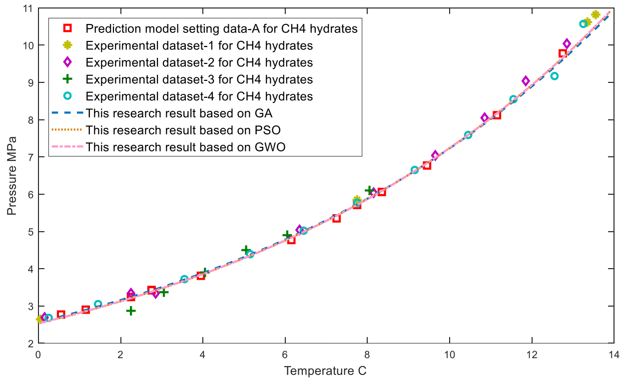

Figure-3. Results of hydrate formation pressure compared with dataset 1 to 4.

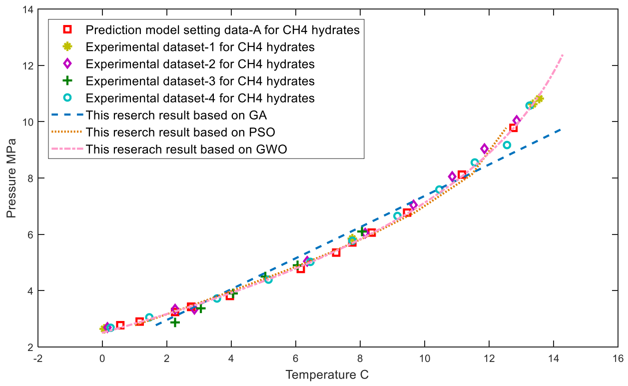

Figure-4. Results of hydrate formation temperature compared with dataset 1 to 4.

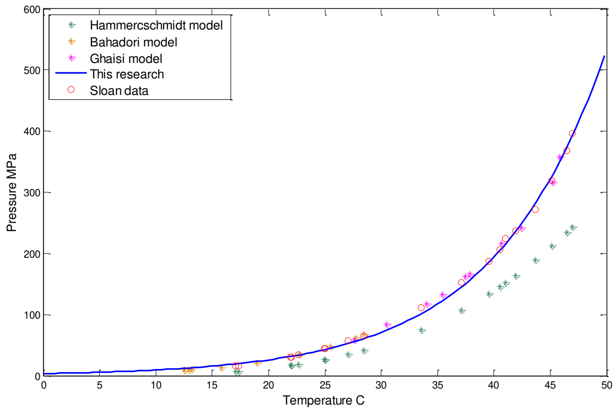

Figure-5. Comparison of HFP results with a previous empirical model.

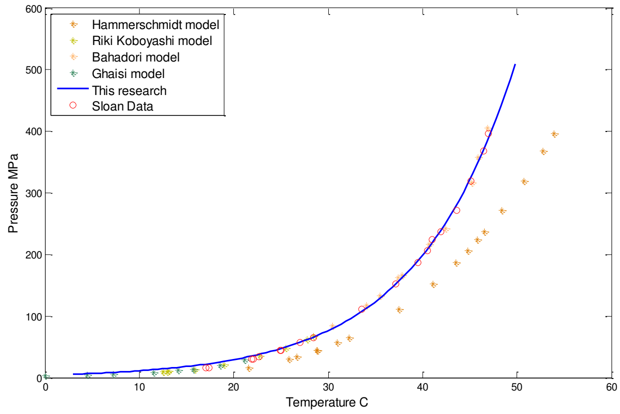

Figure-6. Comparison of HFT results with previous empirical models.

Figure-7 and Figure-8 present an analysis of developed model results by the help of VdW-P model which give ideal condition in light of fundamental models. The oil and gas industry would like to control hydrate formation earlier than the hydrate stability range [14, 17]. The hydrate constancy temperature and pressure range are predictable by thermodynamic models [18, 19]. Moreover, the low temperatures (at seabed 277 K) and the high pressure within the hydrate formation region require inhibitors to overcome hydrate formation. Throughout the last couple of decades, scientists have initiated a new type of flow assurance methods to prevent flow assurance obstructions [20]. Hydrate formation experimental data have been used in this research and compared with the thermodynamic model. The conditions above the ice point temperature lower than 273.1K (-0.05C) forms hydrates in gas transmission pipeline [2, 7, 17]. The conventional control strategy was used to overcome gas hydrates in transmission pipeline by the help of thermodynamic inhibitors. However, thermodynamic inhibitors are uneconomical and environmentally unreliable [15, 21-23]. Consistently this research results approaching the prediction model conditions during the transportation of natural gas and injection of inhibitor quantity.

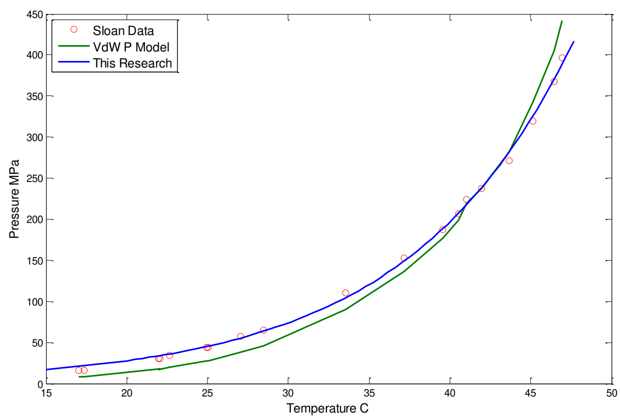

Figure-7. HFP model result compared with VdW-P model.

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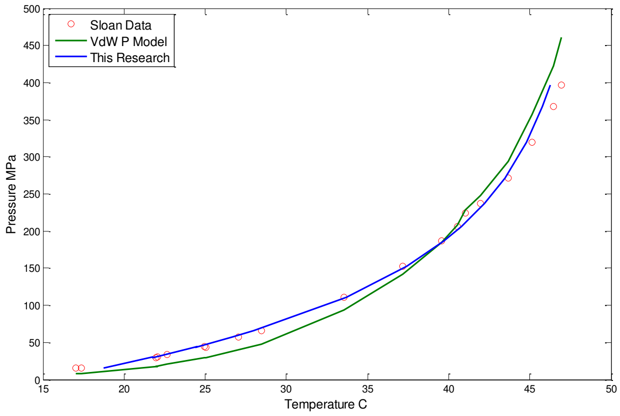

Figure-8. HFT model results compared with VdW P model.

The published datasets of Sloan [2]were applied for validation of developing model results in this research. Figure-9 and Figure-10 presents the analyzed results of the benchmark model. Table-1 is statistically analyzed the prediction data of hydrate formation pressure that shows the optimum and balance results for a binary system of gas mixtures. The regression R^2 is in between of 0.95 to 0.98 that shows the significance of every composition of the gases in this research. Results were indicating that the obtained regression model for methane gas hydrate formation pressure is very well fitted for the observations. Moreover, predicted R^2 0.95 to 0.98 is in a reliable equivalence contract in an adjusted R^2 0.95 to 0.97. Durbin-Watson 0.463 to 1.6 for each component of gases is showing the uniformity and stability of accuracy in developed model results.

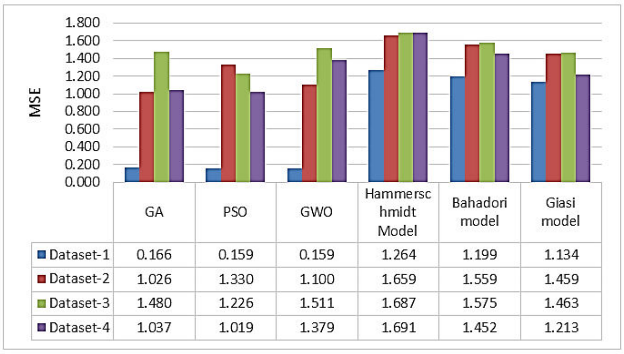

Figure-9. Analysis of pressure correlation model error with existing empirical models.

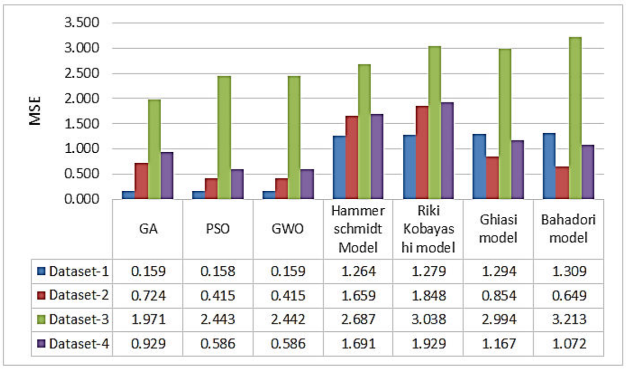

Figure-10. Analysis of temperature correlation model error with existing empirical models.

Table-1. Hydrate formation model error analysis.

Data	R	R^2	Adjusted R^2	Standard Error Estimate	Durbin Watson
Dataset-1	0.979	0.958	0.954	0.464	0.463
Dataset-2	0.958	0.936	0.909	0.3212	0.6653
Dataset-3	0.937	0.89	0.895	0.0748	0.6851
Dataset-4	0.973	0.909	0.938	0.29247	0.8748

Table-2 presents ANOVA statistics analysis results which show F-stat=$F_{critical}$or F(1, 11) = 252.428, 93.036, 89.681 and 68.432 at a significant value less then < 0.00 in binary of all gases. The two-tailed test calculated in the significance of each variable at a minimum of p-value at 95% significantly less than 0.05. Constant coefficients are great significance thus they have an immense contribution to the prediction of hydrate formation statistically. This research has prediction capacity with related experimental data of methane gas hydrates. Moreover, the statistical result supports the prediction model results.

Table-2. Hydrate formation model ANOVA statistics.

Data	Statistical results	Sum of Squares	f	Mean Square	F	Sig.
Dataset-1	Regression	54.378	1	54.378	252.42	0
	Residual	2.37	11	0.215		
	Total	56.748	12			
Dataset-2	Regression	3717.88	1	3717.88	93.036	0
	Residual	239.77	6	39.962		
	Total	3957.65	7			
Dataset-3	Regression	0.503	1	0.503	89.681	0
	Residual	0.056	10	0.006		
	Total	0.559	11			
Dataset-4	Regression	1916.99	1	1916.99	68.432	0
	Residual	140.067	5	28.013		
	Total	2057.06	6			

CONCLUSIONS

This research work analysis the hydrate formation prediction model results and applications for thermodynamic properties. The VdW-P model, statistical analysis and existing published experimental data of Sloan were applied for validation and verification of the developed model results. The validation of this research results with the four fundamental empirical model equations. The minimum error difference was analyzed with existing empirical model results that is the best contribution to this research work. The novel constant coefficients of the developed model have examined on adopted benchmark empirical models, thermodynamic model and experimental data.

NOMENCLATURE

a & b	Coefficient pressure correlation model
T_r	Reduce temperature
P	Pressure of the fluid
a_1 to a_{15}	Coefficients temperature correlation model
e	Exponential function
T	Temperature of flow in the pipeline
P_r	Reduced pressure.

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