Final Year Project 2
Dissertation

Modelling of Effects of Porosity on Methane Hydrates Dissociation via Thermal Stimulation Method

by

Nor Azwan Bin Azahari (13537)

Supervisor: Puan Mazlin Binti Idress

Dissertation submitted in partial fulfilment of
The requirements for the
Bachelor of Engineering (Hons)
(Petroleum)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
(PETROLEUM)

Approved by,

_____

Puan Mazlin Binti Idress

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NOR AZWAN BIN AZAHARI

ABSTRACT

Methane hydrate has a high potential to be an alternative energy resource of the future as it exists in enormous quantities in permafrost regions worldwide. There were various models have been developed to simulate the production of methane gas from the methane hydrates by using different kind of extraction methods. In this study, the Clarke-Kim-Bishnoi model has been selected as it is much more simplified compared to other models and its flexibility to study the formation as well as decomposition of the methane hydrate. The model is used to simulate the effect of changing porosity, different constant pressure at various temperature to the methane hydrate dissociation rate. The temperature is varied as to represent the thermal stimulation method process. The graph of temperature vs. dissociation rate is used to analyze the results. The result shows that as the temperature increases, the dissociation rate will also increases until the methane hydrate completely dissociated. Besides that, higher porosity will results in slightly faster dissociation rate. It has also been found that the dissociation rate for methane hydrate is higher than ethane hydrate. This study has a high potential to be extended for detailed research as it would provide more information on the modelling of gas production from hydrates in porous media.

ACKNOWLEDGEMENT

My utmost gratitude goes to my Final Year Project supervisor, Puan Mazlin Binti Idress, who has guide me to the success of the project throughout this two semesters. The guidance from her were really important for me to get clear understanding of the whole project which enables myself to complete the project effectively. Special thanks to all coordinators of Final Year Project 1 and 2 course for structuring the course and all planning for the students. Special appreciation goes to Dr. Sia Chee Wee for his assistance in the understanding of the Clarke-Kim-Bishnoi model which has been applied in this study. I am very fortunate to have him as the reference of this project for his expertise in methane hydrate researches. In fact, the developer of the Clarke-Kim-Bishnoi model was his Ph.D. supervisor in University of Calgary, Canada. In addition, my thanks also dedicated to my university colleagues who have supported each other in completing the Final Year Project since the beginning of the first phase until the end of the second phase. We did share our thoughts and discussing any matter to added our knowledge and strengthen the understanding for our learning process. Special appreciation also credited for everyone who has contributed directly or indirectly in making my Final Year Project a success. The helps, supports and encouragements from the people mentioned above will always be a pleasant memory throughout my life. I hope that all knowledge that I obtained during the Final Year Project would be very beneficial for me as well as the others.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

As the world population and economy is growing rapidly, the demand of energy is getting higher and this would be a concern to the current hydrocarbon reserves. It is predicted that, by next 20 years, the current reserve would not be able to meet the energy demand which means the dependent on petroleum as the single source of energy should be reduced and the research on its substitution should be expanded.

There are a type of unconventional hydrocarbon energy, known as methane hydrate, which is scattered at various places in the globe and have not been explored widely just because of the petroleum reserves are still available and more economical to develop. Ayhan (2010) states that methane hydrates or clathrates are like ice of crystalline lattice formed from the consolidation of water and high concentration of methane at high pressure and low temperature condition. Methane hydrates appear as ice but the methane gas molecules are surrounded by the crystals.

Every $1m^3$ of hydrate contains approximately 170 Sm^3 of methane gas at standard temperature and pressure (John, 2009). This shows that methane hydrates could appear to be an unconventional energy resource which would benefit the future world. Nevertheless, methane gas is a potent greenhouse gas in which could increase the temperature of the Earth when the gas is released to the atmosphere.

According to John (2009), methane is able to trap heat 20 times greater than carbon dioxide. The combustion of methane could release up to less than 25% carbon dioxide than the combustion of coal with controlled mass. Additionally, the combustion is also free from nitrogen and sulfur oxides which are harmful to the environment.

Methane hydrate would dissociate when the pressure decrease and temperature increase at the condition which the hydrate is unstable and causing the methane molecule to separate with the water molecule thus producing the methane gas. There are 4 main method to dissociate the methane hydrate which are i) depressurization, ii) inhibitor stimulation, and iii) thermal stimulation

1.2 PROBLEM STATEMENT

There are a lot of models have been developed to understand the in-situ decomposition phenomena of methane hydrates and its recovery process from the hydrate reservoirs. However, not every model is representative for simulating the effects of porosity and permeability on methane hydrate dissociation by thermal stimulation method.

1.3 OBJECTIVE

i. To identify various models that have been developed to simulate gas production from the hydrates reservoirs by using different kind of extraction methods and select the best model.
ii. To simulate the effect of changing porosity at various temperature to the dissociation rate of methane hydrate
iii. To simulate the effect of changing the constant pressure at various temperature to the dissociation rate of methane hydrate.
iii. To compare the dissociation rate of methane hydrate and ethane hydrate.

1.4 SCOPE OF STUDY

In the context of this project, the dissociation behavior is studied on the thermal stimulation method only. By using this method, heat will be introduced in the reservoir by injecting hot water or electrifying the reservoir. This process will cause the hydrates particles to destabilize to allow the production of methane gas.

The variables that will be tested in the model are porosity, permeability, and temperature while the pressure rate and other rock properties are kept constant throughout the project.

1.5 RELEVANCY OF THE PROJECT

As not every model that has been developed is representative for simulating the effects of porosity on methane hydrate dissociation by thermal stimulation method, this project would be very beneficial for providing new discoveries and more information in this topic of interest.

Furthermore, the best model, to simulate the dissociation of methane hydrates in the porous media by using the thermal method, could be selected after being compared with various other models. In this way, future researchers could refer to the outcome of this project for their study in applying thermal stimulation method for dissociating methane hydrates in the reservoir. Thus, improvised results could be expected from their study and advanced knowledge about this study could be discovered.

This project is also would be very beneficial for the author as it encourages the author to explore the future technology for the oil and gas industry. It also helps the author to broaden his knowledge about this topic and allowing him to contribute in discovering a lot more information related to the production of methane gas from hydrates, specifically, by using the thermal stimulation method.

CHAPTER 2
LITERATURE REVIEW AND THEORY

Hou et al (2006) states that methane hydrate will steadily exist under low temperature and high pressure condition in the hydrate formation zone as shown in Figure 1. Theoretically, methane hydrate would be dissociated when the temperature and pressure condition is moved to the hydrate free zone either by reducing the pressure below the phase critical decomposition pressure or increasing the temperature. This process happens as the methane gas is separated with the free water phase by using appropriate mechanical methods. The chemical reaction for the methane hydrate decomposition is represented as follows:

$$(CH_4 \bullet 6H_2O)_{solid} \leftrightarrow (CH_4)_{gas} + 6(H_2O)_{liquid}$$

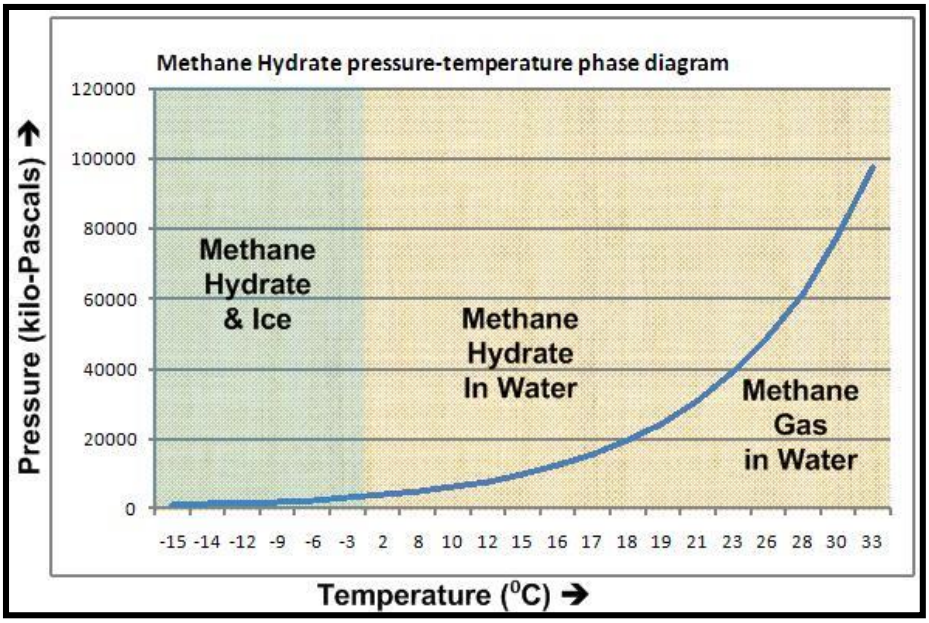


Figure 1: Methane Hydrate Phase Diagram, Williamborg, (2010), Methane Hydrate Phase Diagram [ONLINE]. Available at: http://upload.wikimedia.org/wikipedia/commons/b/b4/Methane_Hydrate_phase_diagram.jpg [Accessed 03 February 14].

According to Sloan (1998), the process begins at the vapor-solid state, when the hydrate has formed by excessive gas and all free water phase have transformed as solid. The system will converted into the three-phase equilibrium state through the sensible heat input where no changes of phase occur during the transition. At this stage, energy is used on the hydrate dissociation process at controlled pressure and temperature. As the hydrate is completely dissociated, the gas could be produced by removing the free water phase.

Thermal stimulation method is used to promote the dissociation process of the methane hydrate by introducing heat into the reservoir. According to Kurihara et al (2011), this method can be conducted by hot water circulation method, wellbore heating method and hot water huff n' puff method. The overview of these methods have been illustrated in Figure 2. The temperature of the reservoir could also be increased by hot water flooding method in which hot water will be injected into the reservoir from an injecting well and is flooded toward the production well to heat up the methane hydrate between the wells.

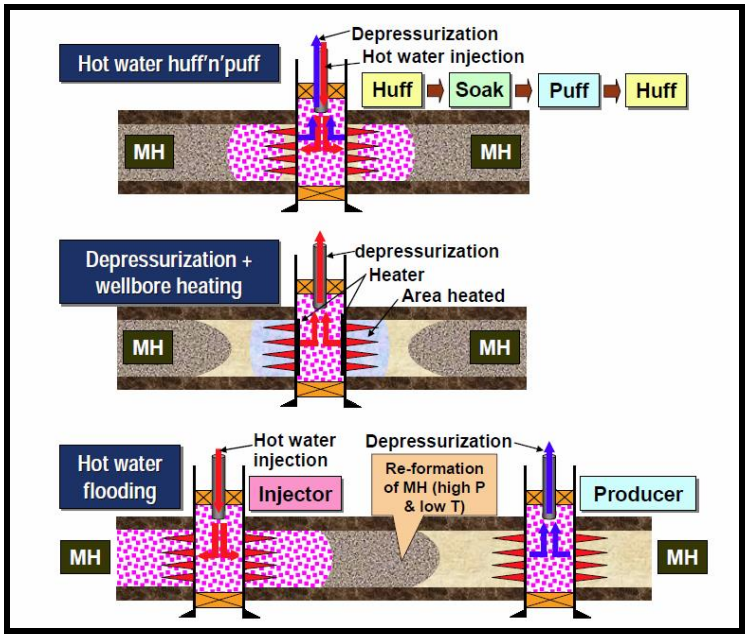


Figure 2: Overview of a variety of thermal methods
From: Kurihara et al. (2011) Gas Production from Methane Hydrate Reservoirs.

Yong Liu (2008) has concluded that thermal stimulation method has trivial to the gas production for single vertical well in cylindrical coordinate system because the production well has small radius while the radius expands at far from the production well. This condition will require high heat flux at the well to avoid from the trivial effect of the flow rate of the gas far from the well which has resulted from the radius increase of the system. On the other hand, in multiple well system, gas production would be higher resulted from the thermal stimulation.

Previously, various models have been developed to investigate the feasibility of commercial gas production from hydrate reservoirs. Hong et. al. (2003) states that there are two categories of model which are analytical and numerical. Analytical models are suitable for mechanistic studies for improved understanding of the process whereas numerical models are more comprehensive and have smaller number of assumptions. The comparison between the models is presented in Table 1.

Models	Heat transfer		Fluid flow		Kinetics	Solution method
	Conduction	Convection	Gas	Water		
Holder & Anger[1]	x		x			Numerical
Burshears et al.[2]	x		x	x		Numerical
Jamaludin et al.[9]	x				x	Numerical
Selim & Sloan[3]	x	x	x			Analytical
Yousif et al.[10]			x	x	x	Numerical
Makogon[6]	x	x	x	x		Analytical
Masuda et al.[12]	x	x	x	x	x	Numerical
Tsypkin[4]	x	x	x	x		Analytical
Moridis[13]	x	x	x	x	x	Numerical

Table 1.1: Comparison of different models.
From: Hong, H., Pooladi-Darvish, M. & Bishnoi, P.R. (2003) Analytical Modelling of Gas Production From Hydrates in Porous Media

A study to model the heating curve for gas hydrate dissociation in porous media at isochronic condition has been presented by Cristophe et al. (2007) which has applied an equation of state of the gas, cumulative volume distribution of the porous medium and a Van Der Waals-Platteeuw-type thermodynamic model. The relation between the equilibrium pressure and temperature of the hydrate dissociation can be written as follows:

$$\frac{\Delta\mu_W^0}{RT} - \int_{T_0}^{T} \frac{\Delta H_W(T)}{RT^2}\,dT + \int_0^P \frac{\Delta V_W}{RT}\,dP - \sum_i v_i \ln(1 + C_i f) - \ln(\gamma_W x_W) = 0$$

However, as the methane hydrates are formed in a porous medium, all phases are located in the pores so that the capillary forces contribute to the mechanical balance and pressure is not uniformly distributed between the phases. Therefore, the chemical potentials of the components for the different phases should include a capillary contribution. Because of that, a correction term should be introduced to the model to account for the capillary effect.

In present, most of the thermodynamic models to predict the methane hydrate equilibrium in porous media are based on the Van Der Waals-Platteeuw model which is combined with Gibbs-Thomson relationship that can determine the interfacial tension between methane hydrate and water from the experimental data. Besides the Van Der Waals-Platteeuw-type thermodynamic model, there were also other models has been developed by Wilder et al. (2001), Klauda and Sandler (2001) and Smith et al. (2002) which proposed the calculation method with included the distributions of pore-size.

CHAPTER 3
METHODOLOGY

3.1 Project Activities

3.1.1 Final Year Project 1

3.1.1.1 Selection of the project title

All final year students was allowed to choose the best 3 desired Final Year Project title from a given list and then propose them to the course coordinator. The course coordinator will assign the Final Year Project title based on the CGPA of the students and announce it with the list of supervisors a week later.

3.1.1.2 Identifying the problem statement and objective

During the first meeting with the supervisor, the author was given a clear briefing on the Final Year Project overview. The supervisor assisted the author to identify the problem statement and objective of the project.

3.1.1.3 Exploring resources from various medium

The author had explore various reading materials from the library as well as the internet in order to get clear understanding about the project. The author managed to know the importance of this study and acknowledged some studies that had been conducted previously.

3.1.1.4 Gathering all data and information

A lot of useful data have been obtained throughout the research and they were gathered systematically by the author in his database. The data was stored according to the topic whether it is about the methane hydrate background, research papers, or calculation method.

3.1.1.5 Analyze all data and information

All data that have been gathered were then analyzed to identify the best model which suits the study. The models were compared and reviewed by the supervisor for further clarification.

3.1.1.6 Selection of the base model

The author desires the simplest model for the project as for limiting the knowledge in the Final Year Project level. Thus, Clarke-Kim-Bishnoi model has been applied to calculate the dissociation rate of methane hydrate (Kim et al., 1987). The dissociation rate is a function of temperature, the specific surface area of MH and fugacity difference as expressed by the following equations:

$$R_d = \emptyset \cdot S_h \cdot k_d^0 \exp\left(-\frac{E}{RT}\right) \cdot A_{HS} \cdot \left[f_e(T) - f_g\right]$$

Where,

R_d : Dissociation rate of Methane Hydrate, mol/(m³·s)

$\emptyset$: Porosity

S_h : Methane hydrate saturation

k_d^0 : Intrinsic dissociation rate constant, mol/(m²·MPa·s)

E : Activation energy, J/mol

R : Gas constant, J/(K·mol)

T : Temperature, K

A_{HS} : Surface area of spherical Methane Hydrate grain, 1/μm

$f_e(T)$: Fugacity of methane under equilibrium condition, MPa

f_g : Gas fugacity in pore space, MPa

3.1.2 Final Year Project 2

3.1.2.1 Design computer program

A computer program is used for easily repetitive calculation using the model. In this case, the most compatible computer software that can be applied is Microsoft Excel. There were 2 programs generated by using the software which are to calculate the fugacity of methane gas and to calculate the methane hydrate dissociation rate. The fugacity is calculated by using Peng-Robinson Equation of State while Clarke-Kim-Bishnoi model is used to compute the methane hydrate dissociation rate.

3.1.2.2 Setting appropriate input for the program

<u>Calculating fugacity of methane gas</u>

Peng-Robinson Equation of State (PR-EOS) has been implemented to calculate the gas fugacity in pore space, $f_g$and fugacity of methane under equilibrium condition, $f_e(T)$. The Peng-Robinson Equation of State is expressed as:

$$\ln\frac{f^g}{P} = \left(Z^g - 1\right) - \ln\left(Z^g - B\right) - \frac{A}{2\sqrt{2}B}\ln\frac{Z^g + \left(1+\sqrt{2}\right)B}{Z^g + \left(1-\sqrt{2}\right)B}$$

The transition of the gas, water and hydrate phases can be determined through the driving force $f_g - f_e(T)$. The hydrate will dissociate if $P_G < P_e$ in which the driving force $f_g - f_e(T) < 0$. Since the fugacity term is evaluated based

on free gas PR-EOS, the kinetic model is only applicable to system where free gas phase is involved in hydrate dissociation.

In order to compute the equilibrium hydrate dissociation temperature at a given pressure in the system, firstly, determine the pressure and make an initial guess for the temperature. Next, enter the input into the computer program to compute the fugacity of methane gas by using PR-EOS.

The following is the procedure to calculate the gas fugacity, f_g by using PR-EOS:

1) Obtain Critical Temperature (T_C), Critical Pressure (P_C) and Acentric Factor (ω) for the gas.

2) Find b in PR-EOS

$$b = 0.07779\frac{RT_c}{P_c}$$

3) 3. Find *a* in PR EOS

i. Determine κ.

$$\kappa = 0.37464 + 1.5422\omega - 0.26992\omega^2$$

ii. Determine α.

$$\sqrt{\alpha(T)} = 1 + \kappa\left(1 - \sqrt{\frac{T}{T_c}}\right)$$

iii. Determine $a(T)$.

$$a(T) = 0.45724\,\frac{(RT_c)^2}{P_c}\alpha(T)$$

4) Determine reduced parameters *A* and *B*.

$$A = \frac{aP}{(RT)^2}$$

$$B = \frac{bP}{RT}$$

5) Evaluate the cubic constants in the Z expression.

$$Z^3 + (-1 + B)Z^2 + (A - 2B - 3B^2)Z + (-AB + B^2 + B^3) = 0$$

6) Solve the cubic for the roots and determine if they fall in the subcooled liquid, superheated vapor or the two phase coexistence region.

Calculating methane hydrate dissociation rate

The formulation for the equilibrium condition of methane hydrate in porous media has been adapted from the data presented by Sloan (1998) based on a series of experiments which has been conducted. It can be defined as the following expression:

$$P_e = exp[0.1102 \cdot (T + 273.15) - 29.173]$$

Nevertheless, Kim-Bishnoi model was originally developed for bulk phase system. Thus, its applicability for the hydrate system in porous media has been an important concern. It has been justified that the hydrate transition will always be the same as any other normal chemical reactions despite the environment surrounds the hydrate. The different performance of mass, heat transport and the reaction sites that the system can provide are the factors for the difference of the hydrate formation and dissociation property in the bulk phase system and the porous media system (Sun et al., 2006).

The parameters used to test the Clarke-Kim-Bishnoi model has been adapted from a study conducted by Sakamoto et al (2007). However, the variables such as porosity and fugacity of methane gas in the pore space is changed to satisfy the objectives. The dissociation rate of methane hydrate is then calculated and the plot of temperature versus dissociation rate is plotted.

3.1.2.3 Test the model

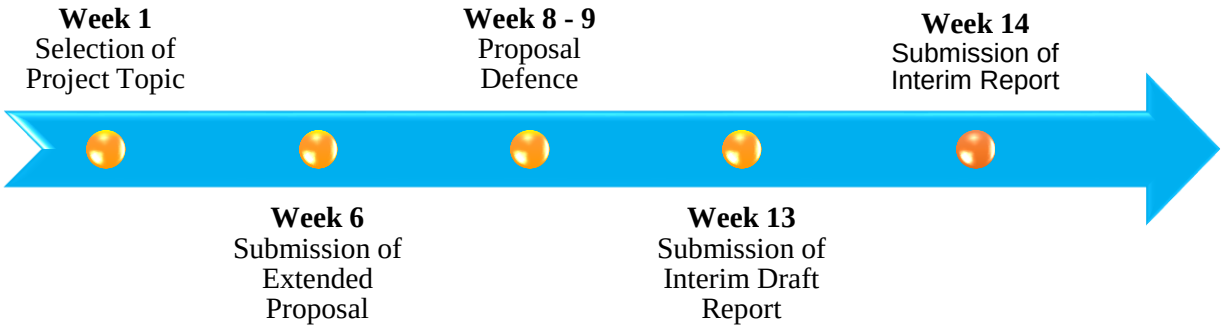
The model is tested by varying the temperature at a constant pressure and porosity. The value of temperature that is applied in the model is ranged from 4˚C to 43˚C. The constant pressures of 200 Bar, 75 Bar and 50 Bar are tested for all temperature. At constant pressure of 75 Bar, the value of porosity is varied at 39.7%, 39.3% and 40.3%.

3.1.2.4 Analyzing the result

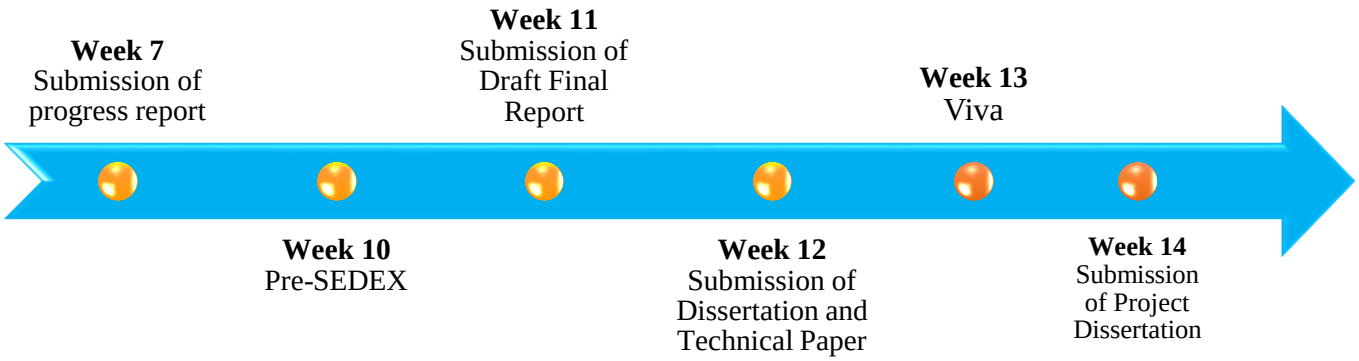
The results that would be produced should obey the theory of hydrate dissociation. The results produced for each constant pressure and the changes of porosity are compared to justify the theory. Once the result satisfies the theory, the model have managed to be validated and the conclusions are made.

3.2 Project Key Milestones

3.2.1 Final Year Project 1



3.2.2 Final Year Project 2



3.3 Gantt Chart

3.3.1 Final Year Project 1

No.	Project Activity / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project topic														
2	First meeting with supervisor														
3	Identify the problem statement														
4	Identify the objective														
5	Conducting research from various resources														
6	Extended Proposal														
7	Proposal Defense														
8	Propose several models														
9	Finalizing the model														
9	Interim Draft Report														

3.3.2 Final Year Project 2

No.	Project Activity / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Design computer program														
2	Identifying method to compute several parameters														
3	Test the model using computer program generated														
4	Submission of Progress Report														
5	Analyze the results														
6	Justifying the results														
7	Pre-Sedex														
8	Final Report														
9	Project Dissertation														
10	Technical Paper														
11	Viva														
12	Submission of Project Dissertation (Hard Bound)														

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

Table 4.1: Value of the known parameters in the model.

Reservoir pressure, MPa	7.50
Initial reservoir temperature, ˚C	3.70
Initial MH saturation	0.289
Intrinsic rate of decomposition, (kmolCH_4/m^2kPa s)	1.24 x 10^3
Surface area of spherical MH grain, 1/μm	0.375
Activation energy, J/mol	9400
Gas constant	8.314

Table 4.2: The properties of methane gas.

Critical Temperature, Tc	190.4 K
Critical Pressure, Pc	46 Bar
Acentric Factor, ω	0.011
b	2.677
κ	0.3916

4.1.1 Comparison between the dissociation rate of methane hydrate at different constant pressure.

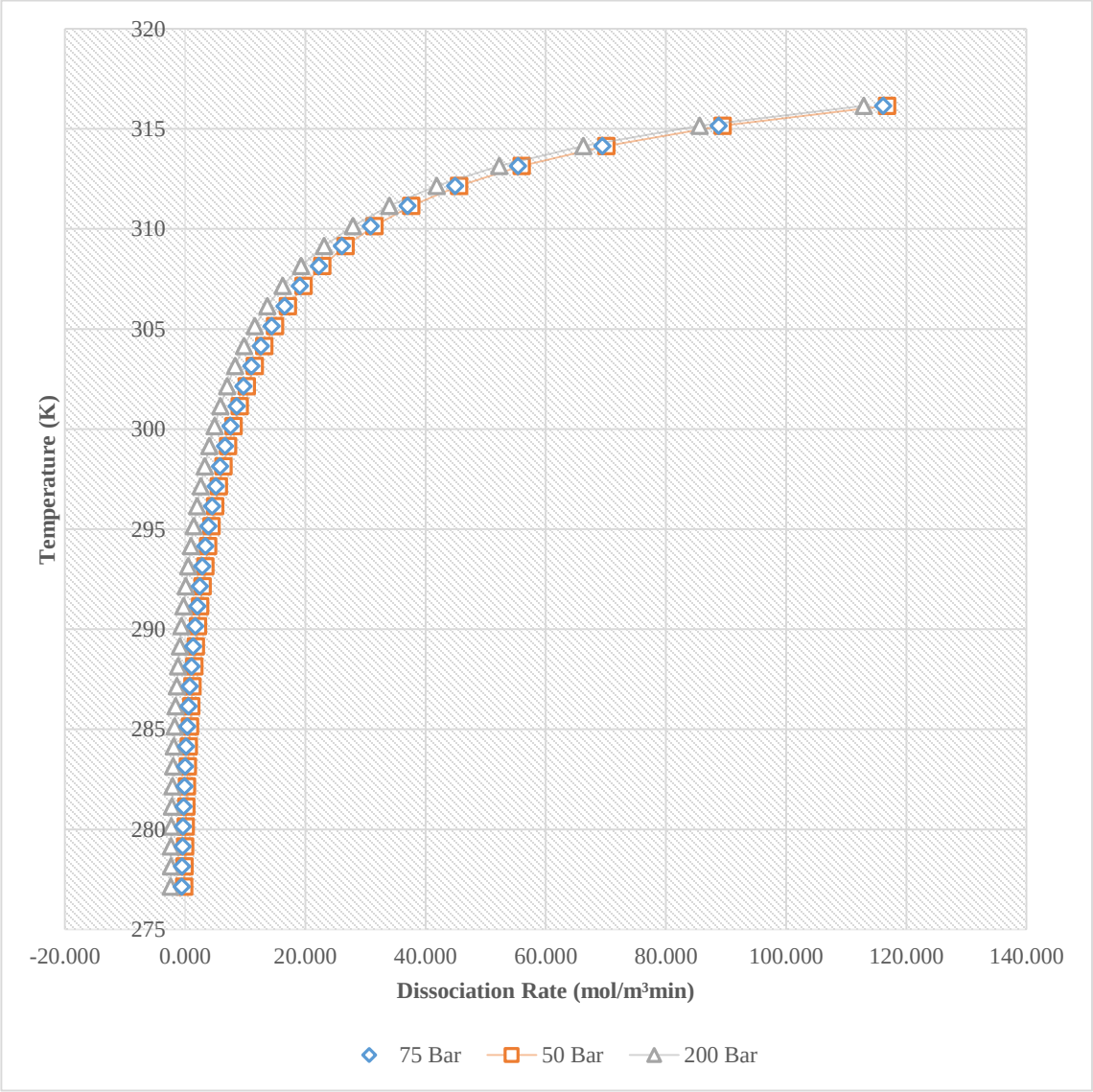


Figure 4a: Temperature vs. Dissociation Rate at 50 Bar, 75 Bar and 200 Bar

4.1.2 Comparison between the dissociation rate of methane hydrate at 75 Bar and various porosity

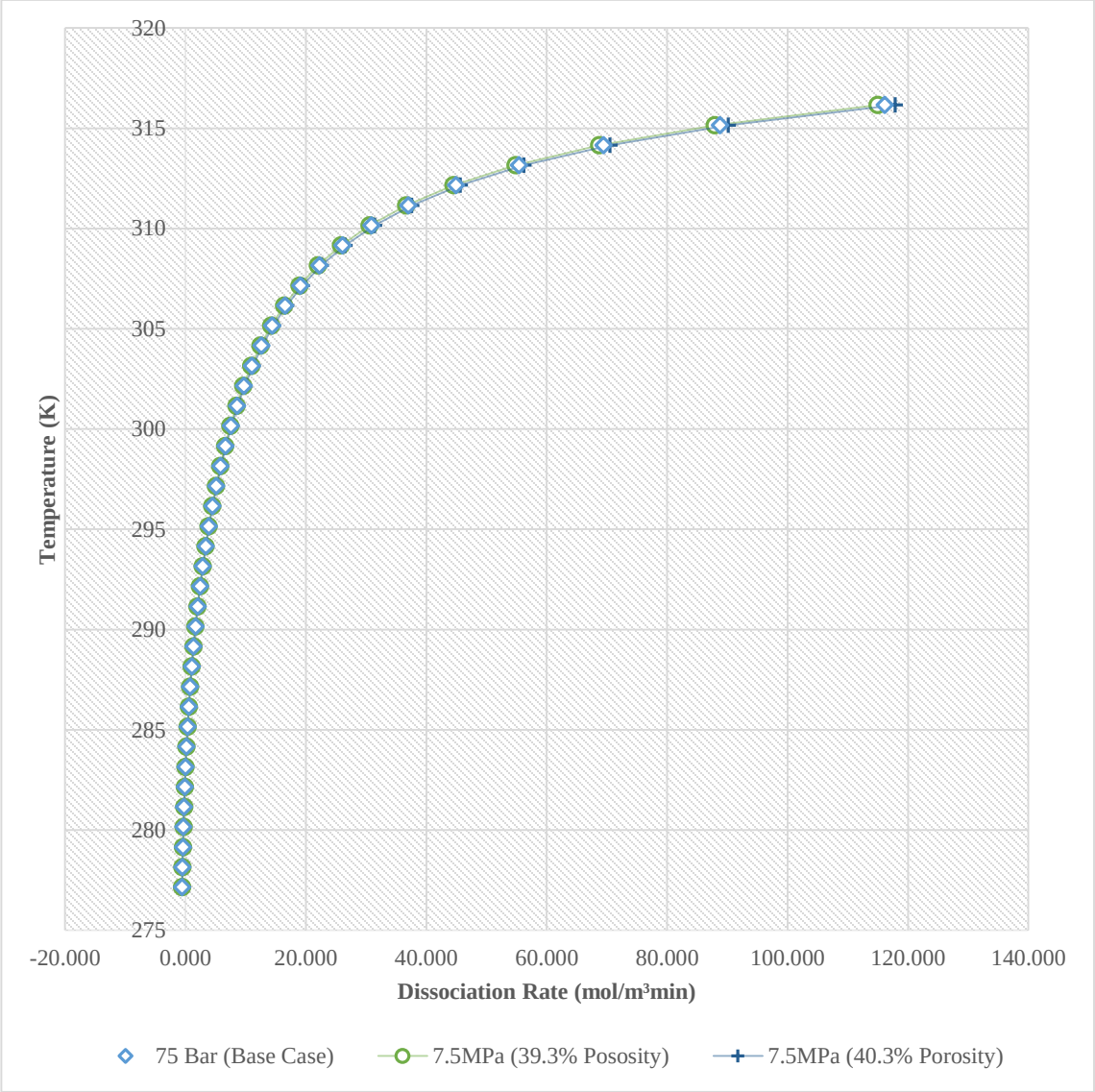


Figure 4b: Temperature vs. Dissociation Rate at 75 Bar and different porosity.

4.1.3 Comparison between the dissociation rate of different gases at 75 Bar and Φ = 39.7%.

Table 4.3: The properties of ethane gas.

Critical Temperature, Tc	305 K
Critical Pressure, Pc	48.8 Bar
Acentric Factor, ω	0.1
b	4.05
κ	0.53

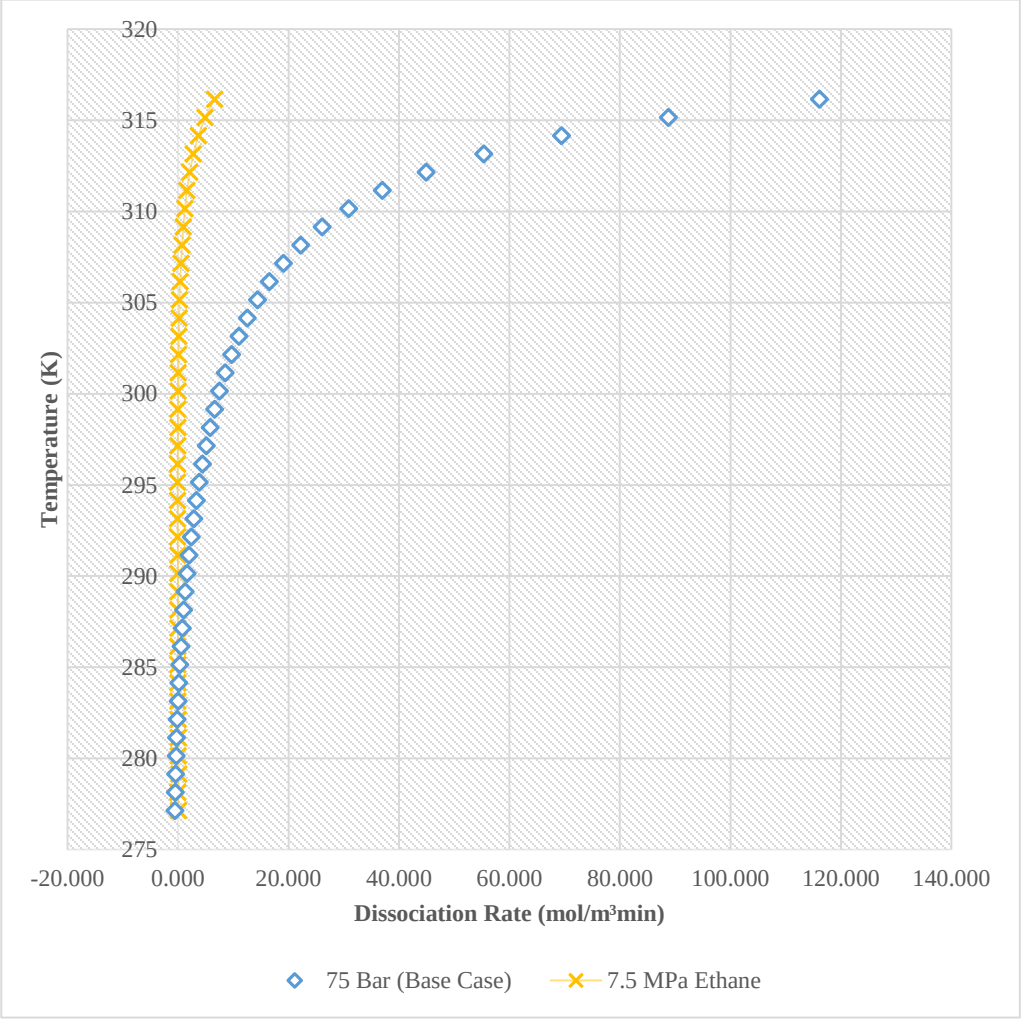


Figure 4c: Temperature vs. Dissociation Rate for different gases.

4.2 Discussion

Based on all tabulations as presented in the Appendix, the results of the computations seems sensible especially the value obtained for the gas compressibility factor, z, which follow the standard trend of z-chart. Besides that, the calculated gas fugacity in pore space, f_g, and fugacity of methane under equilibrium condition, $f_e(T)$, can also be acceptable as the result shows that the hydrate will only dissociated when $f_g < f_e(T)$ in which the driving force $f_g - f_e(T) < 0$. The negative value obtained for the dissociation rate shows that the methane hydrate is still in its stability zone and remains in the hydrate form. The methane hydrate will only begin to dissociate once the temperature exceeds the equilibrium temperature. Based on Figure 1, the value of dissociation rate obtained shows that the principle of methane hydrate dissociation is obeyed. For example, at pressure of 50 bar and temperature of 279.15 K, methane hydrate is still exist in the hydrate stability zone and negative value of dissociation rate is obtained. However, as the temperature increases to 288.15 K at the same pressure, the phase has transisted into the hydrate dissociation zone and positive value will be obtained for the dissociation rate.

Based on Figure 4a-c, as the temperature increases, the dissociation rate will also increase. However, the rate of increase will slightly reduced towards the end of the process as the saturation of methane hydrate is decreasing. The dissociation rate will remain constant once the methane hydrate is completely dissociated. The same trend is shown at all constant pressure, different porosities as well as different gas.

The comparison between the dissociation rate of methane hydrate at different constant pressure in Figure 4a shows that the dissociation rate will be lower for higher pressure. As an example, at temperature of 296.15 K, the dissociation rate at pressure of

50 bar, 75 bar and 200 bar are 4.984 mol/m³min, 4.471 mol/m³min and 1.992 mol/m³min. This is because, at lower pressure, the driving force that influences the dissociation process is higher thus enhancing the rate of dissociation.

As the methane hydrate dissociates, the porosity of the sediment should be increasing due to the change of the solid phase that coverd the porous spaces into gas and water. Thus, the study for the effect of porosity is included in this study. The values of porosity are varied to 39.7%, 39.3% and 40.3% which can be categorized as low, medium and high. Based on Figure 4b, the rate of methane hydrate dissociation is higher at higher reservoir porosity. This is because, in high porosity sediment, the saturation of methane hydrate is higher and more heat will be absorbed by methane gas. The percolation of the heat is easy because of large porosity for gas to percolate. Therefore, the dissociation rate of methane hydrate is higher in larger reservoir porosity.

The comparison between the dissociation rate of methane hydrate and ethane hydrate is presented in Figure 4c which shows that the dissociation rate would be lower for longer carbon chain molecule. This is due to higher energy that is required to separate the ethane gas from the water molecule compared to the methane gas. Therefore, the dissociation process will takes place at higher temperature.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study presents the usefulness Clarke-Kim-Bishnoi model which has been selected from various models that can be applied to simulate the dissociation of hydrates for gas production from gas hydrate reservoirs. The effects of porosity on methane hydrate dissociation via thermal stimulation method is investigated by varying the temperature at constant pressures and porosity. Besides that, the model is also applied for comparing the dissociation rate for methane hydrate and ethane hydrate. The conclusions can be summarized as follows.

1. The dissociation rate of methane hydrate increases as the temperature increases. The dissociation rate will remain constant once the methane hydrate is completely dissociated.
2. The methane hydrate dissociation rate will be lower at higher pressure as the driving force that influences the dissociation process is higher.
3. At larger reservoir porosity, methane hydrate dissociation rate is higher as the percolation of the heat by the gas is easier in large reservoir porosity.
4. The dissociation rate of methane hydrate is higher than ethane hydrate because higher energy is required to separate the ethane gas from the water molecule.

5.2 Recommendation

As stated in the scope of the study, this study is only limited to investigate certain parameters for the final year project. Nevertheless, this study is highly recommended to be extended further to investigate more information on simulating the methane hydrate dissociation via thermal stimulation method. Some recommendations for further studies on this research are presented below.

1. Investigating the effect of rock permeability which is important in the production of the free gas;
2. Detailed study on the thermal conductivity to dissociate the hydrate in the hydrate zone;
3. Applying realistic value for the porosity percentage that based on the Malay Basin properties;
4. Conducting appropriate experiments to validate the theoretical data by computing the percentage difference.

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APPENDIX

Table 4.4: Calculation of dissociation rate of methane hydrate, R_d for the base case (P = 75 Bar and Φ = 39.7%).

T	A	B	Z	ln Φ	Fg	Pe	A	B	Z	ln Φ	Fe	R_d
277.15	0.297	0.087	0.817	0.034	77.619	39.311	0.156	0.046	0.896	0.023	40.214	-0.563
278.15	0.295	0.087	0.819	0.034	77.616	43.891	0.172	0.051	0.887	0.024	44.974	-0.498
279.15	0.292	0.087	0.823	0.034	77.586	49.005	0.191	0.057	0.875	0.026	50.317	-0.422
280.15	0.289	0.086	0.824	0.034	77.606	54.714	0.211	0.063	0.865	0.028	56.289	-0.335
281.15	0.287	0.086	0.826	0.034	77.607	61.088	0.234	0.070	0.853	0.030	62.970	-0.233
282.15	0.284	0.086	0.830	0.034	77.588	68.205	0.258	0.078	0.842	0.032	70.444	-0.116
283.15	0.282	0.085	0.830	0.034	77.616	76.151	0.286	0.087	0.830	0.034	78.797	0.019
284.15	0.279	0.085	0.833	0.034	77.612	85.022	0.316	0.096	0.817	0.036	88.166	0.176
285.15	0.277	0.085	0.835	0.034	77.614	94.928	0.350	0.107	0.805	0.038	98.588	0.354
286.15	0.274	0.084	0.837	0.034	77.615	105.987	0.388	0.119	0.795	0.039	110.181	0.557
287.15	0.272	0.084	0.839	0.034	77.616	118.334	0.429	0.133	0.787	0.039	123.037	0.788
288.15	0.269	0.084	0.841	0.034	77.618	132.121	0.475	0.148	0.781	0.038	137.231	1.048
289.15	0.267	0.084	0.843	0.034	77.619	147.513	0.525	0.164	0.778	0.035	152.826	1.340
290.15	0.265	0.083	0.845	0.034	77.620	164.698	0.581	0.183	0.780	0.031	169.872	1.666
291.15	0.262	0.083	0.847	0.034	77.622	183.886	0.644	0.203	0.786	0.024	188.414	2.028
292.15	0.260	0.083	0.849	0.034	77.623	205.309	0.712	0.226	0.797	0.015	208.500	2.427
293.15	0.258	0.082	0.851	0.034	77.625	229.228	0.788	0.252	0.813	0.004	230.201	2.867
294.15	0.256	0.082	0.854	0.034	77.609	255.933	0.873	0.280	0.835	-0.009	253.623	3.352
295.15	0.254	0.082	0.856	0.034	77.612	285.749	0.966	0.312	0.863	-0.024	278.922	3.883
296.15	0.251	0.082	0.858	0.034	77.615	319.040	1.069	0.347	0.896	-0.040	306.400	4.471
297.15	0.249	0.081	0.860	0.034	77.619	356.208	1.184	0.386	0.937	-0.058	336.129	5.117
298.15	0.247	0.081	0.860	0.035	77.635	397.707	1.310	0.430	0.984	-0.076	368.624	5.834
299.15	0.245	0.081	0.862	0.035	77.639	444.040	1.451	0.478	1.037	-0.094	404.402	6.635
300.15	0.243	0.080	0.865	0.035	77.633	495.771	1.606	0.532	1.097	-0.110	444.018	7.534
301.15	0.241	0.080	0.866	0.035	77.644	553.530	1.778	0.592	1.165	-0.125	488.249	8.549
302.15	0.239	0.080	0.868	0.035	77.637	618.016	1.968	0.659	1.240	-0.138	538.123	9.708

303.15	0.237	0.080	0.869	0.035	77.652	690.016	2.179	0.733	1.325	-0.148	594.825	11.038
304.15	0.235	0.079	0.871	0.035	77.650	770.404	2.413	0.816	1.418	-0.155	659.986	12.582
305.15	0.233	0.079	0.872	0.035	77.660	860.157	2.671	0.908	1.522	-0.156	735.695	14.392
306.15	0.231	0.079	0.874	0.035	77.662	960.367	2.958	1.010	1.637	-0.152	824.691	16.537
307.15	0.229	0.079	0.876	0.035	77.662	1072.251	3.275	1.124	1.764	-0.142	930.617	19.111
308.15	0.227	0.078	0.878	0.035	77.658	1197.169	3.626	1.251	1.904	-0.123	1058.377	22.237
309.15	0.225	0.078	0.878	0.035	77.675	1336.641	4.015	1.392	2.059	-0.096	1214.668	26.088
310.15	0.223	0.078	0.880	0.035	77.678	1492.362	4.446	1.549	2.230	-0.058	1408.783	30.905
311.15	0.222	0.078	0.882	0.035	77.679	1666.224	4.923	1.724	2.419	-0.007	1653.841	37.025
312.15	0.220	0.077	0.884	0.035	77.678	1860.341	5.452	1.919	2.628	0.057	1968.709	44.942
313.15	0.218	0.077	0.884	0.035	77.692	2077.073	6.037	2.136	2.860	0.137	2381.080	55.379
314.15	0.216	0.077	0.886	0.035	77.696	2319.055	6.686	2.377	3.115	0.235	2932.518	69.430
315.15	0.214	0.077	0.887	0.035	77.699	2589.228	7.404	2.645	3.398	0.353	3686.946	88.786
316.15	0.213	0.076	0.889	0.035	77.701	2890.877	8.200	2.944	3.711	0.496	4745.336	116.132

Table 4.5: Calculation of dissociation rate of methane hydrate, R_d at P = 50 Bar and Φ = 39.7%.

T	A	B	Z	ln Φ	Fg	Pe	A	B	Z	ln Φ	Fe	R_d
277.15	0.198	0.058	0.869	0.027	51.366	39.311	0.156	0.046	0.896	0.023	40.214	-0.168
278.15	0.196	0.058	0.871	0.027	51.365	43.891	0.172	0.051	0.887	0.024	44.974	-0.098
279.15	0.195	0.058	0.872	0.027	51.364	49.005	0.191	0.057	0.875	0.026	50.317	-0.016
280.15	0.193	0.057	0.874	0.027	51.364	54.714	0.211	0.063	0.865	0.028	56.289	0.077
281.15	0.191	0.057	0.876	0.027	51.364	61.088	0.234	0.070	0.853	0.030	62.970	0.185
282.15	0.189	0.057	0.877	0.027	51.364	68.205	0.258	0.078	0.842	0.032	70.444	0.309
283.15	0.188	0.057	0.879	0.027	51.364	76.151	0.286	0.087	0.830	0.034	78.797	0.450
284.15	0.186	0.057	0.880	0.027	51.364	85.022	0.316	0.096	0.817	0.036	88.166	0.612
285.15	0.184	0.056	0.882	0.027	51.364	94.928	0.350	0.107	0.805	0.038	98.588	0.796
286.15	0.183	0.056	0.883	0.027	51.365	105.987	0.388	0.119	0.795	0.039	110.181	1.006
287.15	0.181	0.056	0.885	0.027	51.365	118.334	0.429	0.133	0.787	0.039	123.037	1.243
288.15	0.180	0.056	0.886	0.027	51.365	132.121	0.475	0.148	0.781	0.038	137.231	1.509
289.15	0.178	0.056	0.888	0.027	51.366	147.513	0.525	0.164	0.778	0.035	152.826	1.808
290.15	0.177	0.055	0.889	0.027	51.366	164.698	0.581	0.183	0.780	0.031	169.872	2.140
291.15	0.175	0.055	0.890	0.027	51.367	183.886	0.644	0.203	0.786	0.024	188.414	2.508
292.15	0.173	0.055	0.892	0.027	51.368	205.309	0.712	0.226	0.797	0.015	208.500	2.914
293.15	0.172	0.055	0.893	0.027	51.368	229.228	0.788	0.252	0.813	0.004	230.201	3.361
294.15	0.170	0.055	0.895	0.027	51.369	255.933	0.873	0.280	0.835	-0.009	253.623	3.851
295.15	0.169	0.055	0.896	0.027	51.370	285.749	0.966	0.312	0.863	-0.024	278.922	4.390

296.15	0.168	0.054	0.897	0.027	51.370	319.040	1.069	0.347	0.896	-0.040	306.400	4.984
297.15	0.166	0.054	0.898	0.027	51.371	356.208	1.184	0.386	0.937	-0.058	336.129	5.637
298.15	0.165	0.054	0.900	0.027	51.372	397.707	1.310	0.430	0.984	-0.076	368.624	6.361
299.15	0.163	0.054	0.901	0.027	51.373	444.040	1.451	0.478	1.037	-0.094	404.402	7.168
300.15	0.162	0.054	0.902	0.027	51.374	495.771	1.606	0.532	1.097	-0.110	444.018	8.074
301.15	0.161	0.053	0.903	0.027	51.375	553.530	1.778	0.592	1.165	-0.125	488.249	9.096
302.15	0.159	0.053	0.904	0.027	51.375	618.016	1.968	0.659	1.240	-0.138	538.123	10.261
303.15	0.158	0.053	0.906	0.027	51.376	690.016	2.179	0.733	1.325	-0.148	594.825	11.599
304.15	0.157	0.053	0.907	0.027	51.377	770.404	2.413	0.816	1.418	-0.155	659.986	13.150
305.15	0.155	0.053	0.908	0.027	51.378	860.157	2.671	0.908	1.522	-0.156	735.695	14.967
306.15	0.154	0.053	0.909	0.027	51.379	960.367	2.958	1.010	1.637	-0.152	824.691	17.119
307.15	0.153	0.052	0.910	0.027	51.380	1072.251	3.275	1.124	1.764	-0.142	930.617	19.699
308.15	0.151	0.052	0.911	0.027	51.381	1197.169	3.626	1.251	1.904	-0.123	1058.377	22.833
309.15	0.150	0.052	0.912	0.027	51.382	1336.641	4.015	1.392	2.059	-0.096	1214.668	26.692
310.15	0.149	0.052	0.913	0.027	51.383	1492.362	4.446	1.549	2.230	-0.058	1408.783	31.515
311.15	0.148	0.052	0.914	0.027	51.384	1666.224	4.923	1.724	2.419	-0.007	1653.841	37.643
312.15	0.147	0.052	0.915	0.027	51.384	1860.341	5.452	1.919	2.628	0.057	1968.709	45.567
313.15	0.145	0.051	0.916	0.027	51.385	2077.073	6.037	2.136	2.860	0.137	2381.080	56.011
314.15	0.144	0.051	0.917	0.027	51.386	2319.055	6.686	2.377	3.115	0.235	2932.518	70.070
315.15	0.143	0.051	0.918	0.027	51.387	2589.228	7.404	2.645	3.398	0.353	3686.946	89.433
316.15	0.142	0.051	0.919	0.027	51.388	2890.877	8.200	2.944	3.711	0.496	4745.336	116.787

Table 4.6: Calculation of dissociation rate of methane hydrate, R_d at P = 200 Bar and Φ = 39.7%.

T	A	B	Z	ln Φ	Fg	Pe	A	B	Z	ln Φ	Fe	R_d
277.15	0.793	0.232	0.755	0.002	200.359	39.311	0.156	0.046	0.896	0.023	40.214	-2.409
278.15	0.786	0.232	0.757	0.003	200.605	43.891	0.172	0.051	0.887	0.024	44.974	-2.376
279.15	0.778	0.231	0.760	0.004	200.846	49.005	0.191	0.057	0.875	0.026	50.317	-2.331
280.15	0.771	0.230	0.763	0.005	201.084	54.714	0.211	0.063	0.865	0.028	56.289	-2.275
281.15	0.765	0.229	0.765	0.007	201.319	61.088	0.234	0.070	0.853	0.030	62.970	-2.205
282.15	0.758	0.228	0.768	0.008	201.550	68.205	0.258	0.078	0.842	0.032	70.444	-2.120
283.15	0.751	0.227	0.770	0.009	201.778	76.151	0.286	0.087	0.830	0.034	78.797	-2.017
284.15	0.744	0.227	0.773	0.010	202.003	85.022	0.316	0.096	0.817	0.036	88.166	-1.893
285.15	0.738	0.226	0.776	0.011	202.224	94.928	0.350	0.107	0.805	0.038	98.588	-1.748
286.15	0.731	0.225	0.778	0.012	202.443	105.987	0.388	0.119	0.795	0.039	110.181	-1.578
287.15	0.725	0.224	0.781	0.013	202.658	118.334	0.429	0.133	0.787	0.039	123.037	-1.380
288.15	0.719	0.223	0.783	0.014	202.871	132.121	0.475	0.148	0.781	0.038	137.231	-1.154

289.15	0.712	0.223	0.786	0.015	203.080	147.513	0.525	0.164	0.778	0.035	152.826	-0.895
290.15	0.706	0.222	0.788	0.016	203.287	164.698	0.581	0.183	0.780	0.031	169.872	-0.603
291.15	0.700	0.221	0.791	0.017	203.491	183.886	0.644	0.203	0.786	0.024	188.414	-0.276
292.15	0.694	0.220	0.793	0.018	203.692	205.309	0.712	0.226	0.797	0.015	208.500	0.089
293.15	0.688	0.220	0.796	0.019	203.890	229.228	0.788	0.252	0.813	0.004	230.201	0.494
294.15	0.682	0.219	0.798	0.020	204.086	255.933	0.873	0.280	0.835	-0.009	253.623	0.943
295.15	0.676	0.218	0.800	0.021	204.280	285.749	0.966	0.312	0.863	-0.024	278.922	1.440
296.15	0.670	0.217	0.803	0.022	204.471	319.040	1.069	0.347	0.896	-0.040	306.400	1.992
297.15	0.665	0.217	0.805	0.023	204.659	356.208	1.184	0.386	0.937	-0.058	336.129	2.602
298.15	0.659	0.216	0.808	0.024	204.845	397.707	1.310	0.430	0.984	-0.076	368.624	3.284
299.15	0.653	0.215	0.810	0.025	205.028	444.040	1.451	0.478	1.037	-0.094	404.402	4.048
300.15	0.648	0.215	0.812	0.026	205.210	495.771	1.606	0.532	1.097	-0.110	444.018	4.910
301.15	0.642	0.214	0.814	0.027	205.388	553.530	1.778	0.592	1.165	-0.125	488.249	5.889
302.15	0.637	0.213	0.817	0.027	205.565	618.016	1.968	0.659	1.240	-0.138	538.123	7.011
303.15	0.632	0.212	0.819	0.028	205.739	690.016	2.179	0.733	1.325	-0.148	594.825	8.304
304.15	0.626	0.212	0.821	0.029	205.911	770.404	2.413	0.816	1.418	-0.155	659.986	9.811
305.15	0.621	0.211	0.823	0.030	206.081	860.157	2.671	0.908	1.522	-0.156	735.695	11.583
306.15	0.616	0.210	0.825	0.031	206.249	960.367	2.958	1.010	1.637	-0.152	824.691	13.691
307.15	0.611	0.210	0.828	0.032	206.415	1072.251	3.275	1.124	1.764	-0.142	930.617	16.226
308.15	0.606	0.209	0.830	0.032	206.578	1197.169	3.626	1.251	1.904	-0.123	1058.377	19.314
309.15	0.601	0.208	0.832	0.033	206.740	1336.641	4.015	1.392	2.059	-0.096	1214.668	23.127
310.15	0.596	0.208	0.834	0.034	206.899	1492.362	4.446	1.549	2.230	-0.058	1408.783	27.904
311.15	0.591	0.207	0.837	0.034	206.979	1666.224	4.923	1.724	2.419	-0.007	1653.841	33.988
312.15	0.586	0.206	0.839	0.035	207.138	1860.341	5.452	1.919	2.628	0.057	1968.709	41.865
313.15	0.581	0.206	0.841	0.036	207.296	2077.073	6.037	2.136	2.860	0.137	2381.080	52.263
314.15	0.577	0.205	0.843	0.037	207.451	2319.055	6.686	2.377	3.115	0.235	2932.518	66.274
315.15	0.572	0.204	0.845	0.037	207.604	2589.228	7.404	2.645	3.398	0.353	3686.946	85.590
316.15	0.567	0.204	0.847	0.038	207.755	2890.877	8.200	2.944	3.711	0.496	4745.336	112.896

Table 4.7: Calculation of dissociation rate of methane hydrate, R_d at P = 75 Bar and Φ = 39.3%.

T	A	B	Z	ln Φ	Fg	Pe	A	B	Z	ln Φ	Fe	R_d
277.15	0.297	0.087	0.817	0.034	77.619	39.311	0.156	0.046	0.896	0.023	40.214	-0.557
278.15	0.295	0.087	0.819	0.034	77.616	43.891	0.172	0.051	0.887	0.024	44.974	-0.493
279.15	0.292	0.087	0.823	0.034	77.586	49.005	0.191	0.057	0.875	0.026	50.317	-0.418
280.15	0.289	0.086	0.824	0.034	77.606	54.714	0.211	0.063	0.865	0.028	56.289	-0.332
281.15	0.287	0.086	0.826	0.034	77.607	61.088	0.234	0.070	0.853	0.030	62.970	-0.231
282.15	0.284	0.086	0.830	0.034	77.588	68.205	0.258	0.078	0.842	0.032	70.444	-0.114
283.15	0.282	0.085	0.830	0.034	77.616	76.151	0.286	0.087	0.830	0.034	78.797	0.019
284.15	0.279	0.085	0.833	0.034	77.612	85.022	0.316	0.096	0.817	0.036	88.166	0.174
285.15	0.277	0.085	0.835	0.034	77.614	94.928	0.350	0.107	0.805	0.038	98.588	0.350
286.15	0.274	0.084	0.837	0.034	77.615	105.987	0.388	0.119	0.795	0.039	110.181	0.551
287.15	0.272	0.084	0.839	0.034	77.616	118.334	0.429	0.133	0.787	0.039	123.037	0.780
288.15	0.269	0.084	0.841	0.034	77.618	132.121	0.475	0.148	0.781	0.038	137.231	1.037
289.15	0.267	0.084	0.843	0.034	77.619	147.513	0.525	0.164	0.778	0.035	152.826	1.326
290.15	0.265	0.083	0.845	0.034	77.620	164.698	0.581	0.183	0.780	0.031	169.872	1.649
291.15	0.262	0.083	0.847	0.034	77.622	183.886	0.644	0.203	0.786	0.024	188.414	2.007
292.15	0.260	0.083	0.849	0.034	77.623	205.309	0.712	0.226	0.797	0.015	208.500	2.403
293.15	0.258	0.082	0.851	0.034	77.625	229.228	0.788	0.252	0.813	0.004	230.201	2.838
294.15	0.256	0.082	0.854	0.034	77.609	255.933	0.873	0.280	0.835	-0.009	253.623	3.318
295.15	0.254	0.082	0.856	0.034	77.612	285.749	0.966	0.312	0.863	-0.024	278.922	3.844
296.15	0.251	0.082	0.858	0.034	77.615	319.040	1.069	0.347	0.896	-0.040	306.400	4.426
297.15	0.249	0.081	0.860	0.034	77.619	356.208	1.184	0.386	0.937	-0.058	336.129	5.066
298.15	0.247	0.081	0.860	0.035	77.635	397.707	1.310	0.430	0.984	-0.076	368.624	5.775
299.15	0.245	0.081	0.862	0.035	77.639	444.040	1.451	0.478	1.037	-0.094	404.402	6.568
300.15	0.243	0.080	0.865	0.035	77.633	495.771	1.606	0.532	1.097	-0.110	444.018	7.458
301.15	0.241	0.080	0.866	0.035	77.644	553.530	1.778	0.592	1.165	-0.125	488.249	8.463
302.15	0.239	0.080	0.868	0.035	77.637	618.016	1.968	0.659	1.240	-0.138	538.123	9.610
303.15	0.237	0.080	0.869	0.035	77.652	690.016	2.179	0.733	1.325	-0.148	594.825	10.927
304.15	0.235	0.079	0.871	0.035	77.650	770.404	2.413	0.816	1.418	-0.155	659.986	12.455
305.15	0.233	0.079	0.872	0.035	77.660	860.157	2.671	0.908	1.522	-0.156	735.695	14.247
306.15	0.231	0.079	0.874	0.035	77.662	960.367	2.958	1.010	1.637	-0.152	824.691	16.371
307.15	0.229	0.079	0.876	0.035	77.662	1072.251	3.275	1.124	1.764	-0.142	930.617	18.918
308.15	0.227	0.078	0.878	0.035	77.658	1197.169	3.626	1.251	1.904	-0.123	1058.377	22.013
309.15	0.225	0.078	0.878	0.035	77.675	1336.641	4.015	1.392	2.059	-0.096	1214.668	25.825
310.15	0.223	0.078	0.880	0.035	77.678	1492.362	4.446	1.549	2.230	-0.058	1408.783	30.593
311.15	0.222	0.078	0.882	0.035	77.679	1666.224	4.923	1.724	2.419	-0.007	1653.841	36.652
312.15	0.220	0.077	0.884	0.035	77.678	1860.341	5.452	1.919	2.628	0.057	1968.709	44.489

313.15	0.218	0.077	0.884	0.035	77.692	2077.073	6.037	2.136	2.860	0.137	2381.080	54.821
314.15	0.216	0.077	0.886	0.035	77.696	2319.055	6.686	2.377	3.115	0.235	2932.518	68.730
315.15	0.214	0.077	0.887	0.035	77.699	2589.228	7.404	2.645	3.398	0.353	3686.946	87.891
316.15	0.213	0.076	0.889	0.035	77.701	2890.877	8.200	2.944	3.711	0.496	4745.336	114.962

Table 4.8: Calculation of dissociation rate of methane hydrate, R_d at P = 75 Bar and Φ = 40.3%.

T	A	B	Z	ln Φ	Fg	Pe	A	B	Z	ln Φ	Fe	R_d
277.15	0.297	0.087	0.817	0.034	77.619	39.311	0.156	0.046	0.896	0.023	40.214	-0.571
278.15	0.295	0.087	0.819	0.034	77.616	43.891	0.172	0.051	0.887	0.024	44.974	-0.506
279.15	0.292	0.087	0.823	0.034	77.586	49.005	0.191	0.057	0.875	0.026	50.317	-0.429
280.15	0.289	0.086	0.824	0.034	77.606	54.714	0.211	0.063	0.865	0.028	56.289	-0.340
281.15	0.287	0.086	0.826	0.034	77.607	61.088	0.234	0.070	0.853	0.030	62.970	-0.237
282.15	0.284	0.086	0.830	0.034	77.588	68.205	0.258	0.078	0.842	0.032	70.444	-0.117
283.15	0.282	0.085	0.830	0.034	77.616	76.151	0.286	0.087	0.830	0.034	78.797	0.020
284.15	0.279	0.085	0.833	0.034	77.612	85.022	0.316	0.096	0.817	0.036	88.166	0.178
285.15	0.277	0.085	0.835	0.034	77.614	94.928	0.350	0.107	0.805	0.038	98.588	0.359
286.15	0.274	0.084	0.837	0.034	77.615	105.987	0.388	0.119	0.795	0.039	110.181	0.565
287.15	0.272	0.084	0.839	0.034	77.616	118.334	0.429	0.133	0.787	0.039	123.037	0.799
288.15	0.269	0.084	0.841	0.034	77.618	132.121	0.475	0.148	0.781	0.038	137.231	1.064
289.15	0.267	0.084	0.843	0.034	77.619	147.513	0.525	0.164	0.778	0.035	152.826	1.360
290.15	0.265	0.083	0.845	0.034	77.620	164.698	0.581	0.183	0.780	0.031	169.872	1.691
291.15	0.262	0.083	0.847	0.034	77.622	183.886	0.644	0.203	0.786	0.024	188.414	2.058
292.15	0.260	0.083	0.849	0.034	77.623	205.309	0.712	0.226	0.797	0.015	208.500	2.464
293.15	0.258	0.082	0.851	0.034	77.625	229.228	0.788	0.252	0.813	0.004	230.201	2.911
294.15	0.256	0.082	0.854	0.034	77.609	255.933	0.873	0.280	0.835	-0.009	253.623	3.402
295.15	0.254	0.082	0.856	0.034	77.612	285.749	0.966	0.312	0.863	-0.024	278.922	3.942
296.15	0.251	0.082	0.858	0.034	77.615	319.040	1.069	0.347	0.896	-0.040	306.400	4.538
297.15	0.249	0.081	0.860	0.034	77.619	356.208	1.184	0.386	0.937	-0.058	336.129	5.194
298.15	0.247	0.081	0.860	0.035	77.635	397.707	1.310	0.430	0.984	-0.076	368.624	5.922
299.15	0.245	0.081	0.862	0.035	77.639	444.040	1.451	0.478	1.037	-0.094	404.402	6.735
300.15	0.243	0.080	0.865	0.035	77.633	495.771	1.606	0.532	1.097	-0.110	444.018	7.647
301.15	0.241	0.080	0.866	0.035	77.644	553.530	1.778	0.592	1.165	-0.125	488.249	8.678
302.15	0.239	0.080	0.868	0.035	77.637	618.016	1.968	0.659	1.240	-0.138	538.123	9.854
303.15	0.237	0.080	0.869	0.035	77.652	690.016	2.179	0.733	1.325	-0.148	594.825	11.205
304.15	0.235	0.079	0.871	0.035	77.650	770.404	2.413	0.816	1.418	-0.155	659.986	12.772
305.15	0.233	0.079	0.872	0.035	77.660	860.157	2.671	0.908	1.522	-0.156	735.695	14.609

306.15	0.231	0.079	0.874	0.035	77.662	960.367	2.958	1.010	1.637	-0.152	824.691	16.787
307.15	0.229	0.079	0.876	0.035	77.662	1072.251	3.275	1.124	1.764	-0.142	930.617	19.399
308.15	0.227	0.078	0.878	0.035	77.658	1197.169	3.626	1.251	1.904	-0.123	1058.377	22.573
309.15	0.225	0.078	0.878	0.035	77.675	1336.641	4.015	1.392	2.059	-0.096	1214.668	26.483
310.15	0.223	0.078	0.880	0.035	77.678	1492.362	4.446	1.549	2.230	-0.058	1408.783	31.372
311.15	0.222	0.078	0.882	0.035	77.679	1666.224	4.923	1.724	2.419	-0.007	1653.841	37.585
312.15	0.220	0.077	0.884	0.035	77.678	1860.341	5.452	1.919	2.628	0.057	1968.709	45.621
313.15	0.218	0.077	0.884	0.035	77.692	2077.073	6.037	2.136	2.860	0.137	2381.080	56.216
314.15	0.216	0.077	0.886	0.035	77.696	2319.055	6.686	2.377	3.115	0.235	2932.518	70.479
315.15	0.214	0.077	0.887	0.035	77.699	2589.228	7.404	2.645	3.398	0.353	3686.946	90.128
316.15	0.213	0.076	0.889	0.035	77.701	2890.877	8.200	2.944	3.711	0.496	4745.336	117.887

Table 4.9: Calculation of dissociation rate of ethane hydrate, R_d at P = 75 Bar and Φ = 40.3%.

T	A	B	Z	ln Φ	Fg	Pe	A	B	Z	ln Φ	Fe	R_d
277.15	0.896	0.132	0.226	0.580	133.913	39.311	0.470	0.069	0.129	1.262	138.830	0.074
278.15	0.888	0.131	0.227	0.580	133.995	43.891	0.520	0.077	0.147	1.103	132.274	-0.026
279.15	0.880	0.131	0.228	0.580	134.014	49.005	0.575	0.085	0.152	1.079	144.111	0.156
280.15	0.872	0.130	0.228	0.581	134.030	54.714	0.636	0.095	0.174	0.911	136.005	0.031
281.15	0.864	0.130	0.229	0.580	133.987	61.088	0.704	0.106	0.191	0.801	136.109	0.034
282.15	0.857	0.129	0.230	0.579	133.872	68.205	0.779	0.118	0.212	0.680	134.683	0.013
283.15	0.849	0.129	0.231	0.579	133.770	76.151	0.862	0.131	0.234	0.562	133.636	-0.002
284.15	0.842	0.128	0.232	0.577	133.580	85.022	0.954	0.146	0.258	0.448	133.018	-0.009
285.15	0.835	0.128	0.233	0.575	133.347	94.928	1.056	0.162	0.284	0.334	132.567	-0.013
286.15	0.827	0.128	0.235	0.573	133.063	105.987	1.169	0.180	0.312	0.221	132.181	-0.015
287.15	0.820	0.127	0.236	0.571	132.728	118.334	1.294	0.201	0.343	0.108	131.810	-0.016
288.15	0.813	0.127	0.237	0.568	132.340	132.121	1.432	0.223	0.377	-0.005	131.444	-0.016
289.15	0.806	0.126	0.239	0.565	131.898	147.513	1.585	0.248	0.415	-0.118	131.088	-0.014
290.15	0.799	0.126	0.241	0.561	131.402	164.698	1.755	0.276	0.456	-0.233	130.489	-0.016
291.15	0.792	0.125	0.242	0.557	130.851	183.886	1.942	0.307	0.500	-0.344	130.391	-0.008
292.15	0.785	0.125	0.239	0.575	133.299	205.309	2.150	0.342	0.548	-0.456	130.150	-0.058
293.15	0.779	0.125	0.241	0.573	133.009	229.228	2.380	0.381	0.602	-0.568	129.927	-0.058
294.15	0.772	0.124	0.242	0.570	132.684	255.933	2.635	0.424	0.660	-0.679	129.742	-0.056
295.15	0.765	0.124	0.243	0.568	132.321	285.749	2.917	0.471	0.723	-0.791	129.597	-0.053
296.15	0.759	0.123	0.245	0.565	131.921	319.040	3.229	0.524	0.793	-0.901	129.565	-0.046
297.15	0.753	0.123	0.247	0.561	131.481	356.208	3.575	0.584	0.869	-1.011	129.611	-0.037
298.15	0.746	0.122	0.248	0.558	130.999	397.707	3.957	0.649	0.953	-1.120	129.809	-0.024

299.15	0.740	0.122	0.250	0.554	130.476	444.040	4.381	0.723	1.044	-1.227	130.174	-0.006
300.15	0.734	0.122	0.252	0.549	129.908	495.771	4.851	0.804	1.144	-1.333	130.762	0.018
301.15	0.728	0.121	0.254	0.545	129.294	553.530	5.371	0.895	1.254	-1.436	131.637	0.049
302.15	0.722	0.121	0.256	0.539	128.630	618.016	5.947	0.996	1.375	-1.537	132.875	0.089
303.15	0.716	0.120	0.258	0.534	127.918	690.016	6.584	1.108	1.508	-1.635	134.569	0.142
304.15	0.710	0.120	0.261	0.528	127.150	770.404	7.291	1.233	1.654	-1.728	136.843	0.209
305.15	0.704	0.120	0.263	0.521	126.330	860.157	8.073	1.372	1.814	-1.817	139.842	0.296
306.15	0.698	0.119	0.266	0.514	125.449	960.367	8.939	1.527	1.990	-1.899	143.758	0.405
307.15	0.692	0.119	0.269	0.507	124.508	1072.251	9.899	1.699	2.184	-1.975	148.843	0.545
308.15	0.687	0.118	0.272	0.499	123.502	1197.169	10.961	1.891	2.397	-2.042	155.415	0.724
309.15	0.681	0.118	0.275	0.490	122.451	1336.641	12.138	2.105	2.633	-2.099	163.913	0.951
310.15	0.676	0.118	0.279	0.481	121.327	1492.362	13.442	2.342	2.892	-2.144	174.927	1.244
311.15	0.670	0.117	0.283	0.471	120.139	1666.224	14.887	2.607	3.178	-2.175	189.284	1.624
312.15	0.665	0.117	0.287	0.461	118.889	1860.341	16.486	2.901	3.495	-2.190	208.159	2.122
313.15	0.659	0.117	0.292	0.450	117.601	2077.073	18.258	3.229	3.844	-2.187	233.262	2.781
314.15	0.654	0.116	0.296	0.438	116.248	2319.055	20.221	3.593	4.230	-2.161	267.162	3.670
315.15	0.649	0.116	0.302	0.426	114.846	2589.228	22.396	3.999	4.656	-2.110	313.804	4.894
316.15	0.644	0.115	0.307	0.413	113.402	2890.877	24.805	4.451	5.129	-2.031	379.466	6.620