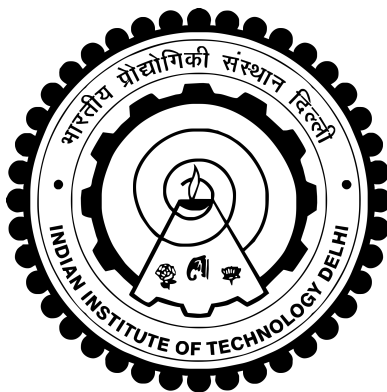


FLOW DYNAMICS IN GAS HYDRATE RESERVOIRS

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DEPARTMENT OF CHEMICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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FLOW DYNAMICS IN GAS HYDRATE RESERVOIRS

by

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Department of Chemical Engineering

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विद्या ददाति विनयं विनयधाति पत्रताम् ।
पात्रत्वाद्धनमाप्नोति धनाद्धर्मं ततः सुखम् ॥

- हितोपदेशः

*Knowledge gives humility; from humility one attains character;
from character, one acquires wealth; from wealth follows good deeds and happiness.*
- Hitopadesha

*To LT. Bhupendra (brother), Papa, Maa,
Shahineer, Bhabhi and Aria ...*

Certificate

This is to certify that the thesis entitled “**Flow Dynamics in Gas Hydrate Reservoirs**”, submitted by **Neelam Choudhary** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** in Chemical Engineering, is a record of the original, bona fide research work carried out by her under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of our knowledge.

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Abstract

The depletion of conventional oil and gas reserves has made unconventional reserves such as gas hydrates a popular choice for growing energy demands. This is also because methane is less polluting than other carbon rich fossil fuels. The large amount of energy stored in the methane hydrate reservoirs can be used to meet the energy demands by extracting methane gas present in these reservoirs which are distributed in deep oceanic sediments and the permafrost regions. The feasibility of the gas production from methane hydrate reservoirs is evident from several short-term field tests in the last decade; however, some crucial issues still exist challenging long-term production. Therefore, the production analysis requires the grasp of geological, technical, and economical factors controlling the methane production potential of these reservoirs. The objective of this work is to understand these reservoir complexities through numerical simulations using an in-house, 3-D finite volume, multi-phase, compositional, and thermal simulator.

In this work, the reservoir porosity, heterogeneity, confinement and hydrate availability have been considered to strategize the gas production methodology. Different well placement and configurations have been explored for class-2 gas hydrate reservoirs which are the most common type of the hydrate reservoirs. For class-2 reservoirs, the size of the aquifer below the hydrate bearing layer governs the hydrate dissociation methodology. Large aquifers make depressurization ineffective and constrain the effectiveness of the injected warm water. However, horizontal wells improve the effectiveness of the warm water injection. It is found that the injection well proximity to the aquifer improves the initial warm water circulation, hence improving the gas production in initial years.

The porosity and permeability in the reservoirs are correlated, therefore, porosity in the hydrate bearing layer and the aquifer layer has different effect on the gas production potential from the hydrate reservoirs. In homogeneous reservoirs the higher porosity leads to higher

gas production. The simulations in this work show that the porosity distribution in the hydrate bearing layer should be considered while predicting the gas recovery from the unconfined hydrate reservoirs with large aquifers.

In moderately confined reservoirs, with lower porosity of the aquifer layer, the gas recovery potential is increased by 6-8 times when injector was placed away from the aquifer layer. The layers in the hydrate zone does not significantly impact the overall gas recovery in a highly unconfined reservoir. However, the injector placed in the high porosity hydrate layer in a moderately unconfined reservoir leads to more gas recovery. The injector location in both the unconfined and moderately unconfined reservoir needs to be selected carefully, however, the producer location does not significantly impact the overall gas recovery.

From above results, it can be seen that the uncertainty in reservoir properties will lead to different gas production outcomes. Therefore, the uncertainty quantification is necessary for these reservoir simulations. Using Monte-Carlo method for uncertainty quantification of gas recovery, it is found that porosity has huge effect on the gas production. A critical porosity point is found beyond which the gas production does not increase regardless of the increase in the reservoir porosity in a confined reservoir. This suggests that the hydrate dissociation is dependent on the heat availability in the reservoir for dissociation. The heat available does not change significantly with the porosity, therefore, after a critical porosity the gas production does not increase. The uncertainty in hydrate saturation leads to the less variations in the gas production.

Overall, this thesis contribute towards understanding the flow dynamic and the efficiently increasing the gas production along with the water handling during the methane gas production from gas hydrate reservoirs .

सारांश

पारंपरिक तेल और गैस भंडार की कमी ने बढ़ती ऊर्जा मांगों के लिए अपरंपरागत भंडार जैसे गैस हाइड्रेट को एक लोकप्रिय विकल्प बना दिया है। ऐसा इसलिए भी है क्योंकि मीथेन कम प्रदूषणकारी है अन्य कार्बन समृद्ध जीवाश्म ईंधन की तुलना में। मीथेन हाइड्रेट जलाशयों में बड़ी मात्रा संग्रहित ऊर्जा का उपयोग इनमें मौजूद मीथेन गैस को निकालकर ऊर्जा की मांग को पूरा करने के लिए किया जा सकता है। मीथेन हाइड्रेट जलाशय गहरे समुद्री तलछट और पर्माफ्रॉस्ट क्षेत्रों में वितरित होते हैं। मीथेन हाइड्रेट जलाशयों से गैस के उत्पादन की संभावना पिछले दशक में हुए कई अल्पकालिक क्षेत्र परीक्षणों से स्पष्ट होता है हालांकि, दीर्घकालिक उत्पादन को चुनौती देने वाले कुछ महत्वपूर्ण मुद्दे अभी भी मौजूद हैं। इसलिए, उत्पादन विश्लेषण के लिए भूवैज्ञानिक, तकनीकी और आर्थिक कारकों की समझ की आवश्यकता होती है जो इन जलाशयों की मीथेन उत्पादन क्षमता का नियंत्रण करते हैं। इस कार्य का उद्देश्य है इन-हाउस, 3-डी सीमित वॉल्यूम, मल्टी-फेज, कंपोजिशन और थर्मल सिम्युलेटर का उपयोग करके इन जलाशय की जटिलताओं को समझें।

इस कार्य में गैस उत्पादन पद्धति को रणनीतिक को समझने के लिए जलाशय की संरचना, विषमता, परिरोध और हाइड्रेट की उपलब्धता का प्रयोग किया गया है। अलग कुंआ प्लेसमेंट और विन्यास के लिए वर्ग -2 गैस हाइड्रेट जलाशयों का प्रयोग किया गया है जो सबसे आम प्रकार हैं हाइड्रेट जलाशयों के। वर्ग -2 जलाशयों के लिए, हाइड्रेट परत के नीचे जलभृत का आकार हाइड्रेट पृथक्करण पद्धति को नियंत्रित करता है। बड़े जलभृत दबाव अवसादन को अप्रभावी बनाते हैं और इंजेक्ट किए गए गर्म पानी की प्रभावशीलता को बाधित करें। हालांकि, क्षैतिज कुओं के प्रयोग से गर्म पानी के इंजेक्शन की प्रभावशीलता में सुधार होता है। यह पाया गया है कि इंजेक्शन जलभृत के निकट है तो प्रारंभिक गर्म पानी परिसंचरण में सुधार करता है, इसलिए प्रारंभिक वर्षों में गैस उत्पादन में सुधार होता है।

जलाशयों में संरचना और पारगम्यता सहसंबद्ध हैं, इसलिए, हाइड्रेट परत और एक्वीफर परत में संरचना का गैस उत्पादन क्षमता पर अलग प्रभाव पड़ता है। सजातीय जलाशयों में उच्च संरचना उच्च गैस उत्पादन की ओर ले जाती है। इस काम में सिमुलेशन से पता चलता है कि हाइड्रेट परत में संरचना वितरण पर विचार करना चाहिए बड़े पैमाने पर अपुष्ट हाइड्रेट जलाशयों से गैस की वसूली की भविष्यवाणी करते समय।

मध्यम रूप से सीमित जलाशयों में, जलभृत परत के कम संरचना के साथ, गैस पुनर्प्राप्ति क्षमता इंजेक्टर को एक्वीफर लेयर से दूर रखने पर 6-8 गुना बढ़ जाता है। परतों में हाइड्रेट ज़ोन अत्यधिक अपुष्ट जलाशय में समग्र गैस वसूली को महत्वपूर्ण रूप से प्रभावित नहीं करता है। हालांकि, इंजेक्टर को उच्च संरचना हाइड्रेट परत में एक मामूली अपुष्ट जलाशय में रखा गया है तो अधिक गैस वसूली की ओर जाता है। अपुष्ट और मध्यम रूप से अपुष्ट दोनों जलाशय में इंजेक्टर का स्थान का चयन सावधानी से करने की आवश्यकता है, हालांकि, उत्पादक स्थान कुल गैस वसूली को महत्वपूर्ण रूप से प्रभावित नहीं करता है।

उपरोक्त परिणामों से, यह देखा जा सकता है कि जलाशय की संपत्तियों में अनिश्चितता होने से गैस उत्पादन में अनिश्चितता आती है, इसलिए, इन जलाशयों के लिए अनिश्चितता की मात्रा का परिमाणीकरण आवश्यक है। अनुकरण गैस वसूली की अनिश्चितता परिमाणीकरण के लिए मॉटे-कालों पद्धति का उपयोग करते हुए, यह पाया जाता है कि गैस उत्पादन पर संरचना का बहुत अधिक प्रभाव पड़ता है। एक महत्वपूर्ण संरचना बिंदु पाया जाता है जिसके आगे गैस में जलाशय संरचना में वृद्धि करने के बाद भी उत्पादन में वृद्धि नहीं होती है। इससे पता

चलता है कि हाइड्रेट पृथक्करण गर्मी की उपलब्धता पर निर्भर है। उपलब्ध गर्मी सरंध्रता के साथ महत्वपूर्ण रूप से नहीं बदलती है, इसलिए, एक महत्वपूर्ण सरंध्रता के बाद गैस का उत्पादन नहीं बढ़ता है। हाइड्रेट संतृप्ति में अनिश्चितता गैस उत्पादन में कम बदलाव की ओर जाता है।

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Abbreviations

Abbreviation/Symbol	Description
Inj.	Injector
Prd.	Producer
OGIP	Original gas in place
GWR	Gas water ratio
HL	Hydrate layer
STP	Standard temperature pressure
CDF	Cumulative density function
SD	Standard deviation
PDF	Probability density function
STP	Standard temperature and pressure

Nomenclature

Symbol	Symbol Description
ρ_j	density of phase j Kg/m^3
S_j	saturation of phase j
W_j^i	weight fraction of component i in phase j
F^i	flux of component i
U_j	internal energy of phase j J/m^3
ρ_R	rock density Kg/m^3
v_j	velocity of phase j
ρ_R	sand internal energy J/Kg
q	source or sink term
J_j^i	molecular diffusion of component i in phase j
λ	effective thermal conductivity $W/m/K$
H_j	specific heat of phase j J/Kg
K	absolute permeability mD
k_{rj}	phase relative permeability
μ_j	viscosity of fluid phase j
P_j	pressure of phase j
g	gravitational force
K_{rj}^o	end point relative permeability mD
P_c	capillary pressure MPa
k_o	reference permeability mD
ϕ_o	reference porosity
ϕ^e	effective porosity of fluid phases
n_j	exponential parameter of phase j

Symbol	Symbol Description	
k	permeability of the phase	mD
ϕ	absolute porosity	
S_G	gas saturation	
S_A	water saturation	
P_{ce}	entry capillary pressure	
S_j^{e*}	normalized saturation of the gas or aqueous phase	
S_j^e	saturation of mobile phase	
S_{Ar}^e	Aqueous residual saturation	
S_{Gr}^e	Gas residual saturation	
$IP - X$	IP-initial pressure of reservoir X-value of initial pressure	
$InJP - Y$	InJP-pressure at injection well Y-value of injection pressure	
