



# Modeling and simulation of hydrate thermal dissociation around gas production pipe from suboceanic sediment



M. Omid <sup>a,\*</sup>, A. Shahsavand <sup>a</sup>, H. Share Mohammadi <sup>b</sup>

<sup>a</sup> Chemical Engineering Department, Engineering Faculty, Ferdowsi University of Mashhad, Mashhad, Iran

<sup>b</sup> School of Chemical, Gas and Petroleum Engineering, Semnan University, Semnan, Iran

## ARTICLE INFO

### Article history:

Received 14 February 2016

Received in revised form

20 March 2016

Accepted 6 April 2016

Available online 8 April 2016

### Keywords:

Hydrate decomposition

Methane hydrate

Orthogonal collocation

Finite element method

Modeling and simulation

## ABSTRACT

Uncontrolled and spontaneous decomposition of methane hydrates in ocean floors can pose risks and potential problems, including damage to equipment that extracts fuel from underwater tanks. Since one of the main factors in hydrate decompositions is their heat up by oil and gas extraction and transportation pipes, this heating and decomposition of it are examined in this paper. After introduction to control volume and mathematical modeling, the developed equations of math model were solved via orthogonal collocation and finite element method and the results were compared. The results concluded to decomposed hydrate volume, released gas volume and its relevant pressure on sediment layer. In this research, the effect of gas flow velocity in pipes, porosity of sediment layers and thermal conductivity constant in pipes on two important parameter of volume of hydrate and its decomposition pattern were studied and it was realized that rising gas velocity in pipe could increase the volume of decomposed hydrate. A side of this enhancing the porosity leads to reduce the radius and volume of decomposed hydrate. Furthermore enhancing the porosity could increase conduction coefficient of heat transfer in gas media, as the increased velocity of gas shows similar effect on heat transfer rate and hydrate decomposition.

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## 1. Introduction

Methane hydrates (MH) are crystalline solids composed of water and methane gas that exist as vast reserves in marine sediment. Naturally occurring gas hydrates in the permafrost and beneath the ocean floor represent a future source of natural gas (Milkov, 2004; Makogon et al., 2007). Methane hydrates are presently viewed as a potential energy resource for the 21<sup>st</sup> century, because a large amount of methane gas is trapped in hydrate reservoirs (Tsuji et al., 2004). It is estimated that the total amount of gas stored in this form may surpass the energy content of the total fossil fuel reserves by as much as a factor of two. In addition, natural changes in bottom water temperature and/or in pressure can destabilize hydrate layers and potentially result in large landslides and soil failures. Human activity on the seafloor (drilling, laying pipe lines) related to the petroleum exploration and development in deep water is another source of hydrate dissociation. To prevent the risk related to the occurrence of the

gas, it is essential to identify the dynamic of the hydrate system and the consequence of its dissociation on the sediment failures and slope instability. On the other hand, gas hydrates can constitute a geo-hazard to the stability of marine and continental oil and gas platforms due to the adverse effect of environmental warming on their stability. Gas hydrate may at sufficient concentrations cement sediment and significantly modify the sediment strength; its formation and breakdown may influence the occurrence and location of submarine landslides.

In present article, modeling and simulation of hydrate thermal dissociation zone around the vertical buried pipe which considerably employed for natural gas exploitation were investigated. The resulting differential equations were obtained using orthogonal collocation method, and since there were no empirical results in this regard, finite element method was also used for solving equations, and their results were compared.

### 1.1. Literature review of hydrate dissociation

Production of methane from hydrate was modeled by different researchers (Ahmadi et al., 2007; Castaldi et al., 2007; Sun et al.,

\* Corresponding author.

E-mail address: [omidi\\_mostafa@gmail.com](mailto:omidi_mostafa@gmail.com) (M. Omid).

**Nomenclature**

$\dot{m}$	production rate in term of mas ( $\text{kg}/\text{m}^3 \cdot \text{s}$ )
$\dot{n}$	production rate in term of mole ( $\text{mol}/\text{m}^3 \cdot \text{s}$ )
A	constant coefficient ( $\text{K}^{-1}$ )
$A_{\text{dec}}$	specific surface area per unit of bulk volume ( $\text{m}^{-1}$ )
$A_{\text{HS}}$	specific surface area per unit hydrate volume ( $\text{m}^{-1}$ )
B	constant coefficient ( $\text{K}^{-2}$ )
C	constant coefficient
c	constant coefficient ( $\text{J}/\text{mol}$ )
$C_p$	heat capacity of the gas in the pipe ( $\text{kJ}/\text{kg} \cdot \text{K}$ )
E	activation energy of hydrate decomposition ( $\text{J}/\text{mol}$ )
f	fugacity (Pa)
k	thermal conductivity ( $\text{W}/\text{m} \cdot \text{K}$ )
$K^0_d$	intrinsic rate constant for hydrate dissociation ( $\text{mol}/\text{Pa} \cdot \text{s} \cdot \text{m}^2$ )
$K_B$	dissociation constant for methane hydrate ( $\text{mol}/\text{Pa} \cdot \text{s} \cdot \text{m}^2$ )
M	molecular weight ( $\text{g}/\text{mol}$ )
N	molecular number around another molecule (dimensionless)
P	pressure (Pa)
Q	energy consumption in the decomposition ( $\text{J}/\text{m}^3 \cdot \text{s}$ )
R	universal gas constant ( $\text{J}/\text{mol} \cdot \text{K}$ )
S	hydrate saturation in the pore spaces (dimensionless)

T	temperature in hydrate layer (K)
t	time (s)
T	temperature in hydrate zone (K)
$T'$	temperature in pipe (K)
V	velocity of gas in pipe (m/s)
Z	compressibility factor for gas in reservoir (dimensionless)

*Greek symbols*

$\Delta$	Parameter difference
$\alpha$	the thermal diffusivity of gas in the pipe ( $\text{m}^2/\text{s}$ )
$\rho$	density, $\text{kg}/\text{m}^3$
$\varphi$	porosity of sediment (dimensionless)

*Subscripts*

0	base
e	effective (for entire of sediment)
eq	equilibrium
g	methane gas in sediments
h	methane hydrate in sediment
i	Initial
inp	entrance in pipe
s	sediment
w	water in sediments

2005). These recent models work with dissociation thermodynamics, kinetics, multiphase flow and heat transfer, associated with the hydrate depressurization above the quadruple point. Ahmadi et al. neglected conduction heat transfer in gas zone and conduction heat transfer has been considered just for hydrate zone. Furthermore no heat of dissociation has been considered. They added heat loss to the surrounding burden to their models, which was overlooked in the earlier models. While Castaldi et al. considered the conduction heat transfer just for dissociation zone behind the decomposition front.

Yousif et al. (1991) used a Kim–Bishnoi model (Kim et al., 1987) to describe a dissociation process of methane hydrate in Berea sandstone by depressurization. They used a one-dimensional model and assumed that the hydrate dissociation process is isothermal. They used the finite difference method to solve the mass and the momentum equations of the gas and the water phase flow and hydrate dissociation. The numerical results of this research work confirmed by experimental data very well.

Experimental investigations of hydrate dissociation behaviours under thermal stimulation in sediment have been reported extensively. Kamata et al. (2005) carried out a decomposition experiment of methane hydrate sediments by the thermal stimulation. They found that the temperature and pressure in the sample fluctuated between stability and the decomposition region of methane hydrate when the hot water was at a high temperature.

Moridis and Reagan (2007) investigated the production potential of Class 2 hydrate accumulations under depressurization. In their studies, the thermal and hydraulic behavior of hydrate-bearing geologic media was considered. They determined that volumes of gas can be readily produced at high rates for long times from Class1 gas-hydrate accumulations by means of depressurization-induced dissociation using conventional technology.

Liang et al. (2010) developed a 2-D axisymmetric simulator to model methane hydrate dissociation and gas production in

laboratory-scale porous media by depressurization. They considered mass transport, intrinsic kinetic reaction and energy conservation in the governing equations, which were discretized by the finite difference method. A series of simulations are performed to study the effect of several parameters, including initial gas saturation, outlet pressure, surrounding temperature, and absolute permeability, on the behavior of hydrate dissociation in the laboratory-scale system. The results showed that a fast hydrate dissociation rate can be induced by the factors including high initial gas saturation, low outlet pressure, high surrounding temperature and high absolute permeability.

Kurihara et al. (2011) conducted examinations of the methane hydrate dissociation and production using depressurization and thermal methods. With low initial temperatures, they found that the gas production rate by the hot water huff and puff is higher than that by depressurization at early stages of production, while the hot water huff and puff gas production rate is much lower at latter stages of production. In reservoirs with medium and high initial temperatures, the hot water huff and puff is adverse to increases in the gas production.

Falser et al. (2012) conducted experiments to increase gas production from hydrate by combining depressurization with heating of the wellbore. He found that if the heat influx from the outer boundary is limited, the specific heat of the formation is rapidly used up when the wellbore is only depressurized and not heated.

Although in most of research the decomposition of hydrates was considered as a source of energy, in this work the risks of hydrate decomposition was the main goal. In addition, the same studies have only investigated the temperature changes versus time and radius. While in this study the effect of other parameters such as the velocity, thermal conductivity of passing gas in the tube, the porosity of precipitate layers on the amount and form of hydrate decomposition was mentioned, too.

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