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In situ hydrate dissociation using microwave heating: Preliminary study

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Abstract

In this work, we investigate the dissociation behavior of natural gas hydrate in a closed system with microwave (MW) heating and hot water heating. The hydrate was formed at temperatures of 1–4 °C and pressures of 4.5–5.5 MPa. It was found that the gas hydrate dissociated more rapidly with microwave than with hot water heating. The rate of hydrate dissociation increased with increasing microwave power, and it was a function of microwave power. Furthermore, the temperature of the hydrate increased linearly with time during the microwave radiation.

Keywords: Microwave heating; Natural gas hydrate; Methane; Dissociation

1. Introduction

The gas hydrate is an ice like substance composed of small molecules (e.g. CH_4, C_2H_6, CO_2) trapped inside cages of water molecules. It often forms under higher pressure and lower temperature, with deposits found underneath permafrost in Arctic regions and beneath deep ocean floors. Because only 10% of the recovered energy is required for dissociation, hydrate reservoirs have been considered as a substantial future energy resource [1]. 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. With the recognized reservoirs of natural gas hydrates in continental margins and in permafrost regions, a question arises about the feasibility and economics of recovery of gas from these reservoirs. Many methods have been proposed for gas recovery from in situ hydrates, and one of them is the thermal stimulation method. The typical method is to inject hot water or vapor into the reservoirs. Saeger et al. [2] suggested another approach by placing an electromagnetic heater inside the dissociation zone. Some other methods of heat transfer are considered in detail in the monograph of Sloan [3], where flame flows of microwave effects was offered.

Microwaves belong to the portion of the electromagnetic spectrum with wavelengths ranging from 1 mm to 1 m, corresponding to frequencies between 300 MHz and 300 GHz. The two most commonly used frequencies are 0.915 and 2.45 GHz for industry purposes. Conventionally, in heat transfer processes, energy is transferred to the material through convection, conduction and radiation due to thermal gradients. However, microwave energy is delivered directly to materials through their molecular interaction with the electromagnetic field. Microwave heating is the transfer of electromagnetic energy to thermal energy. This difference can result in a great many potential advantages in using microwaves for processing materials. Because microwaves can penetrate materials and deposit energy, heat can be generated throughout the volume of the material. So, it can reduce processing times and prove to be energy saving [4]. In the past, microwave irradiation has

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been successfully used in many areas of the petroleum industry [5–7].

The decomposition of hydrates with microwaves was investigated by Rogers [8] firstly and also studied by Zhang [9]. The results indicated that microwave heating was very effective for hydrate dissociation. Another experimental investigation was reported by Fatykhov and Bagautdinov [10]. Nevertheless, few experimental data obtained by this method are available in the literatures.

This study aims at identifying the features of the decomposition of gas hydrate under conditions of volumetric heating by MW electromagnetic radiation and discussing the possibility of gas recovery from in situ hydrate using microwave heating.

2. Experimental

2.1. Apparatus

Fig. 1 shows a schematic drawing of the experimental set up. The cell consists of a stainless shell and cylindrical quartz tube with a volume of 100 dm^3, in which the microwave is introduced. The stainless shell has two windows, on the front and the back. Hydrate formation and dissociation temperatures are measured trough a Pt100 RTD probe inserted in the cell from the bottom. The uncertainty of the RTD is ±0.1 K. The pressure sensor used in the pipe is a SPTA CZ-3 with an active range from 0 MPa to 10 MPa. The repeatability of the sensor is ±0.028%, and the accuracy is 0.115%. The pressure and temperature of the system are continuously recorded on the computer during the experiments. The cell is immersed in the water bath, which has a working temperature range of 263–368 K.

Table 1
Experimental materials in this work

Materials	Purity/composition	Supplier
Methane	99.99%	Fushan Kede Gas Co.
SDS	>98 wt%	Guangzhou Chemical Agent Co.
Distilled water		Distilled

The microwave generator and transmission system was made in Guangzhou Huayuan Co. Ltd. The output power of the microwave source with the frequency of 2.45 GHz can be adjusted linearly from 0 W to 750 W. Power measurement is accomplished through the directional couplers, which are designed so that a small amount of forward and reflected waves are separated and measured by power meters. In the three port circulator, one port is connected to the microwave source, another is connected to the directional couplers and the third port is connected to a water load. The power that is reflected back to the magnetron is diverted, and the water load absorbs the reflected power.

2.2. Materials

In order to reduce free water and quicken the test process [11,12], 300 ppm of SDS was used in the following tests. The materials used in this work are described in Table 1.

Before the test, the SDS-water solution was pumped into the cell. When the system was cooled to about 4 °C, the cell was vacuum pumped and the hydrate forming gas was pressed in the cell. In order to reduce the effect of free water, the dissociation test started after the hydrates had grown slowly for about four days.

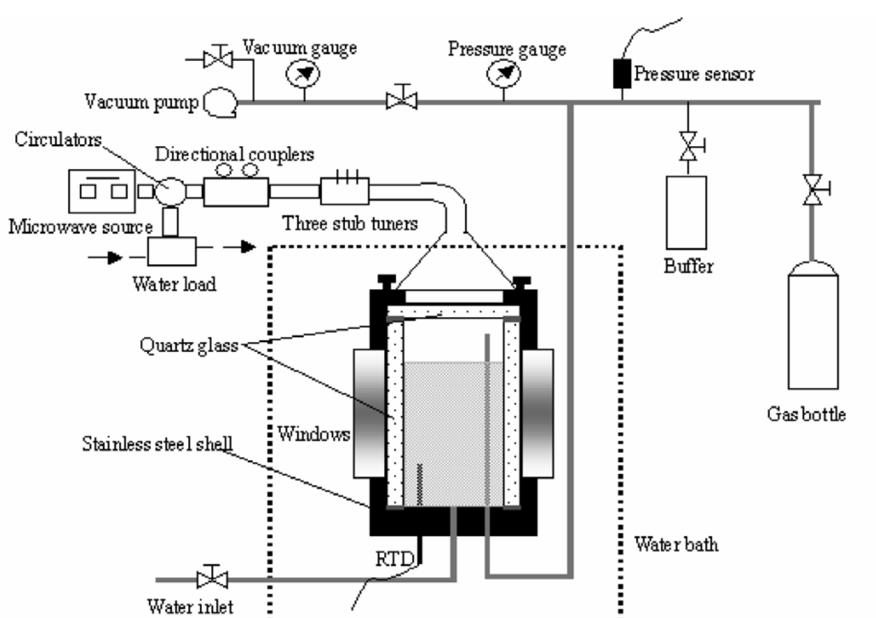

Fig. 1. Schematic diagram of the experimental set up.