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FORMATION OF HYDRATE PLUG WITHIN RECTANGULAR NATURAL GAS PASSAGE

Kwanjae Seong*, Myung Ho Song, Jung Hyuk Ahn, Kwang Sung Yoo
Department of Mechanical Engineering
Dong Guk University
26 Pil-dong 3-ka, Joong-ku, Seoul, 100-715
KOREA

ABSTRACT

In order to obtain a better understanding of hydrate plug formation mechanism in natural gas pipelines, formation and growth of hydrate layer within a rectangular channel formed by brass bottom and top surfaces and an insulated inner and an outer surface of transparent polycarbonate tube was studied experimentally. A gas mixture of 90 % methane balanced with propane was supplied at specified flow rates while the humidity and temperature of the supply gas was controlled at desired values using bubble type saturators and heat exchangers placed in series. Hydrate formation occurred along the top and bottom brass surfaces maintained at temperatures below equilibrium hydrate formation temperature, while the transparent tube served as window for visual observation. A series of carefully controlled laboratory experiments were performed to reveal the shape of porous hydrate layer under different combinations of under-cooling and moisture concentrations. The observed transient characteristics of hydrate layer profiles will provide important data that can be used for validation of numerical models to predict hydrate plugging of natural gas pipelines.

Keywords: flow assurance, hydrate layer, hydrate plugging experiment

INTRODUCTION

As oil and gas reservoirs in the near off-shore shallower areas are being depleted, the industry is expanding their production sites into deeper waters resulting in higher pressure and lower temperature and more isolated locations resulting in extended connecting pipelines. These changes of increase in pressure, decrease in temperature and longer distances that gases have to travel provide a more favorable condition for hydrate formation, thus the problem of flow assurance is becoming more critical for safe and economic operations at deep off-shore oil and gas production sites. [1] Another challenge in flow assurance is due to the fact that hydrates can form in gas pipelines where there is no free water phase. Laboratory experiments have produced evidence of hydrate formation without the presence of free water. [2] Therefore, hydrate formation and potential blockage due to hydrate plugs in gas pipelines, where no free water phase is present, pose another flow assurance problem. [3]

For flow assurance, in recent years the focus seems to be changing from that of prevention strategy of total annihilation of hydrates called the “avoidance strategy” to that of living with the hydrates, whereby instead of zero tolerance, management or control of hydrate formation and growth is emphasized to avoid blockage due to hydrate plugs. [4] With the latter strategy of

* Corresponding author: Phone: +822 2260 3703 Fax +822 2263 9379 E-mail: kwanjseong@dongguk.edu

managing the hydrates to a certain level to ensure flow assurance, it is crucial that we understand the mechanism of hydrate formation leading to blockage. However, there are only a few detailed studies dealing with this problem. In this study, an experimental apparatus was designed and fabricated to study the formation and the growth of hydrates from a gas mixture of methane and propane with different moisture concentrations. The hydrates were formed in a rectangular passage cooled to temperatures below equilibrium hydrate formation temperature. Results obtained in this study will provide important data on the mechanism of hydrate formation and the ensuing buildup leading to blockage, which could provide important data to be used for flow assurance in management and control strategy in natural gas pipelines. Additionally, the results from this study could be used in verifying numerical models developed to predict hydrate plugging of natural gas pipelines.

EXPERIMENTAL SET-UP AND PROCEDURE

Hydrate formation and plugging test experimental apparatus

The schematic layout of hydrate formation and plugging test experimental apparatus is presented in Fig. 1. The experimental apparatus is designed to simulate the condition of natural gas with different levels of water saturation exposed to high pressure and low temperature. Main components of the apparatus are comprised of the following;

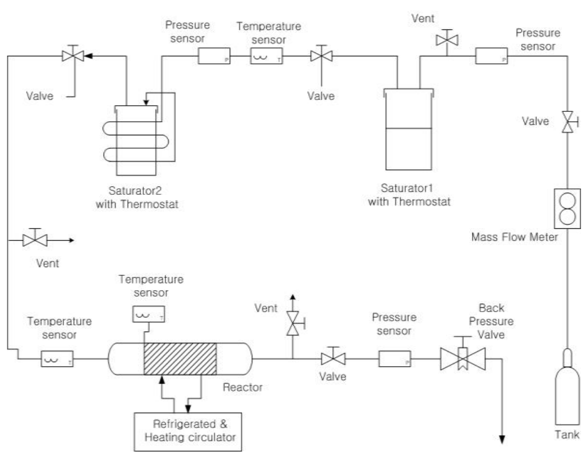
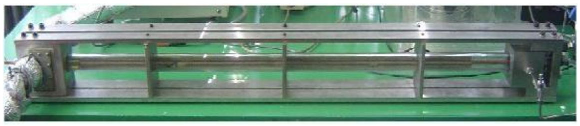


Figure 1. Schematic layout of hydrate formation and plug test experimental apparatus

Reactor where hydrates will be formed, Saturators to control the water saturation level of supplygas, Gas supply tanks with regulator to supply a steady mixture of 90% methane-10% propane to the reactor, Coolant supply unit to ensure that the surfaces in the reactor are exposed to the gas at a temperature below the hydrate formation temperature, Gas booster and circulation network to ensure a constant high pressure supply of gas to the reactor and to recover the exit gas from the reactor.

The reactor (Fig. 2), where gas hydrate formation will occur, has a casing made from transparent polycarbonate material that can withstand a pressure up to 100 bars. In the center of the casing runs a copper tube of 1 mm thickness that will carry the coolant and is held in place by blocks specially designed to withstand high pressure. Between the casing and the copper tube runs a brass annulus with a rectangular passage of height and depth of 5 mm cut out, where gas will flow to form gas hydrates on the top and the bottom surfaces. At the leading end of the reactor cylindrical polyurethane of same cross section as the brass annulus with sloped top surface was fitted onto the copper tube to help guide the flow of gas directly into the rectangular passage. In the entrance and exit blocks are formed 1/8” SS ports for gas supply and exhaust with T-type thermocouples installed. Both ends of the reactor are covered with specially designed blocks with O-rings for sealing.



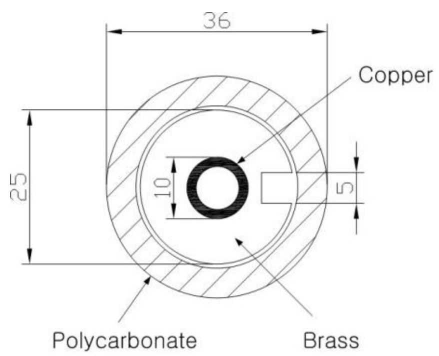


Figure 2. Reactor and its cross section dimensions

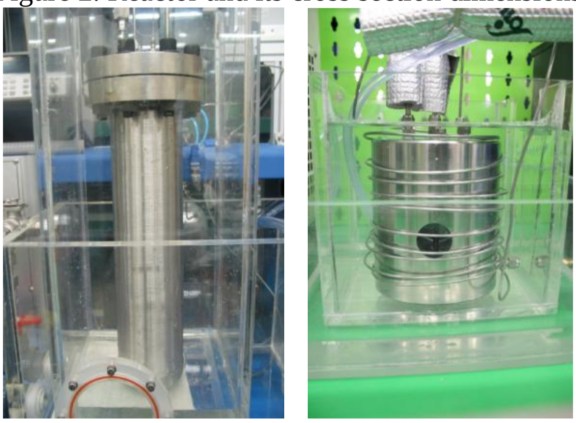
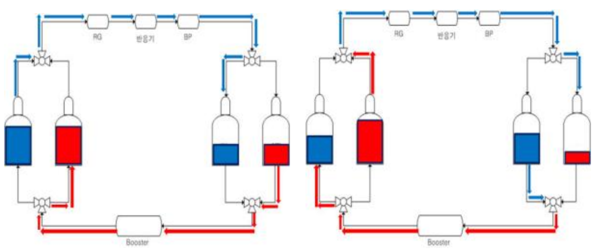


Figure 3. Main and secondary saturators in bath

Saturators (Fig. 3) are high-pressure canisters containing water to add moisture to dry gases while they pass through. The main saturator is a three-liter canister containing 1.5 liter of water and can withstand up to 100 bars. The gas passes through the heated water though a nozzle before going through the secondary saturator. It was found that a saturation of about 80% is achieved in the main saturator. In the second saturator, before blowing into the water through a nozzle fully saturating the gas, the gas passes through a 4 m pipe wound around the canister in the bath obtaining the same temperature as the bath water temperature.

The gas supply of methane and propane mixture to the reactor which is recovered from the reactor exit cannot be exhausted into the environment but has to be captured and re-circulated to the gas supply tank. The re-circulation network, presented in Fig. 4, is composed of 4 gas tanks, a gas booster, 4 three-way-valves with pneumatic actuators and controlled by a PLC circuit.



(a) First half-cycle (b) Latter half-cycle

Figure 4. Gas re-circulation network

Experimental procedure

The preliminary steps before the gas is supplied to the reactor are as follows. First, temperatures are set for the three baths; the main and the secondary saturators, the coolant supply to the copper tube in the reactor. A significant drop in temperature occurred along the supply gas pipeline, almost 10 meters long, and condensation of water was found in the gas pipeline. To prevent condensation in the pipeline, band heater wound around the supply gas pipeline was used to heat the supply gas and the pipeline was covered with insulation. Data logger recorded temperature readings from the saturators and the coolant flowing copper pipe in the reactor. When the operational temperatures are reached, gas is supplied to the pipeline and operational pressure is obtained by controlling the inlet valve to the reactor. After a steady pressure reading is obtained, the temperatures of the saturator baths are adjusted to ensure that the inlet gas temperature at the reactor is below the formation temperature at the operational pressure. The reactor inlet gas temperature can be controlled by varying the saturator water bath temperature and the heating capacity of the band heater. The moisture content of the supply gas can be controlled by varying the saturator temperatures and the gas flow rate is controlled by the mass flow controller installed at the exit of the gas supply tank. The constant pressure in the reactor is maintained by the backpressure valve installed after the reactor exit. After confirming that the pressure and temperature conditions are established as suitable for hydrate formation, pictures at three locations of the reactor (the inlet, 10 and 40 cm downstream) were taken at fixed intervals along with recordings of visual observations.

Experimental Results

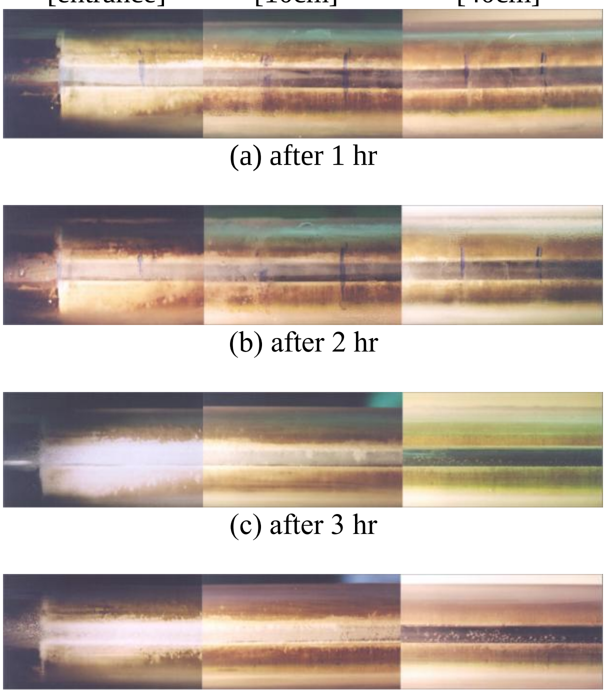
Two sets of experiments were carried out at following conditions.

Reactor Pressure : 40 bars
Coolant Inlet Temperature : -10 °C
Gas Inlet Temperature : 19 °C
Gas Flow Rate : 6.7 lpm / 13.3 lpm

Although the gas inlet temperature of 19 °C is a little above the equilibrium temperature of 17 °C for methane-propane mixture at 40 bars, gas temperature at reactor outlet was measured between 8 and 9 °C. Photographs taken at the entrance region of the reactor, region 10 cm downstream and 40 cm downstream after (a) 1 hr, (b) 2 hrs, (c) 4 hrs and (d) 6 hrs are presented respectively in Fig.s 5 and 6 for gas flow rates of 6.7 and 13.3 lpm. Following results were observed from these experiments that were carried out for six hours.

1. At the very early stage of the experiment, condensation occurred on the inside surface of the transparent polycarbonate casing.
2. The first hydrate formation was observed in both the upper and lower crevices between the brass annulus and the casing from the entrance region to about 40 cm downstream location, at about the same time as 1 above. 3. After about 15 minutes, a thin film of hydrate formed uniformly on both the upper and the lower brass surfaces of the gas passage way.
4. A difference in flow rates does not seem to have any affect on observations 1, 2 and 3.
5. After about 1 hour, hydrate spots began to appear on both the lower and upper surfaces at irregular locations. These particle spots were more densely located in the entrance region becoming sparser downstream. Spots were observed at earlier time for the larger flow rate.

[entrance] [10cm] [40cm]



(a) after 1 hr

(b) after 2 hr

(c) after 3 hr

(d) after 4 hr

Figure 5. Reactor passage way photographs with gas flow rate of 6.7 lpm

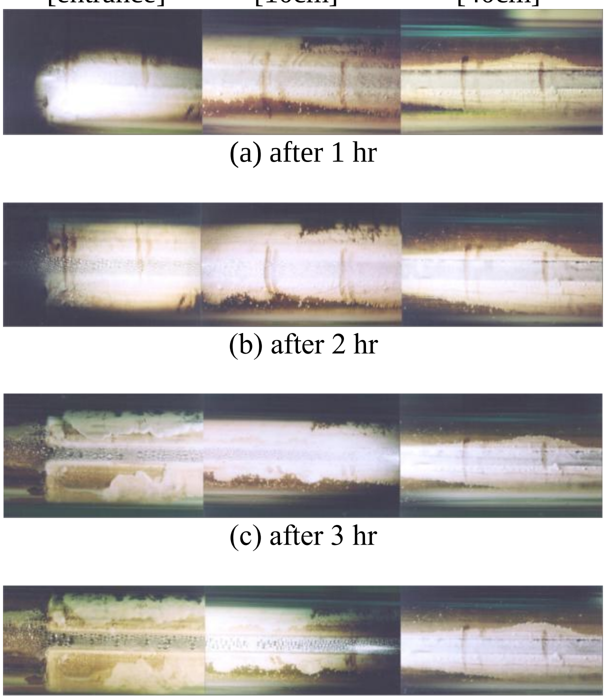
6. After about three hours, water droplets were observed on the inside surface of the casing from the entrance region to about 20 cm downstream. Droplet size was considerably bigger for the larger flow rate.
7. Hydrate films and spots on the upper and lower surfaces continue to grow. The growth rate is faster in the entrance region than downstream and for the larger flow rate.
8. The growth rate of the hydrate film is noticeable during the first two hours becoming slower and almost unnoticeable after 3 hours.
9. In a previous experiment on the current apparatus with different shaped (oblong) passage way, that had a much larger surface to cross sectional area ratio, total hydrate blockage was obtained after about ten hours of continuous operation. The flow rate dropped to almost zero whereas the pressure drop was only around 1 bar.

CONCLUSIONS AND FUTURE WORK

Conclusions

1. With enough moisture content, we were able to demonstrate that hydrates will form without fresh water phase under equilibrium conditions.

[entrance] [10cm] [40cm]



(a) after 1 hr

(b) after 2 hr

(c) after 3 hr

(d) after 4 hr

Figure 6. Reactor passage way photographs

with gas flow rate of 13.3 lpm

2. Judging from the onset of hydrate formation and its subsequent growth, especially comparing the current observations and our previous experience of result 9 above, continual growth of the initial hydrate formation leading to plugging depends on the effective strength between film growth rate and insulation effect from the formed hydrate film.

3. The reason of absence of hydrate formation downstream after 40 cm seems to be from depletion of water moisture due to consumption in hydrate formation and partly due to condensation especially in the entrance region.

Future Work

We were successful with our experimental apparatus in obtaining hydrate formation and growth as explained above. However the current experimental apparatus needs some modifications. The foremost being the inhibition of hydrate formation on the inside surface of the poly carbonate casing, thus allowing a clear view into the reactor passage. This will allow us to obtain quantitative data such as the growth rate of the thickness and length and a transient profile of the hydrate layer along the reactor passage walls. This information can be critical in understanding the hydration growth mechanism after formation and subsequent growth leading to blockage. An important factor that must be taken into consideration in the designing of shape and dimensions of the passage way is that enough surface area should be available to lower the gas temperature well below the equilibrium point so that insulating effect of the hydrate film can be overcome. Lastly, it is imperative that water condensation be limited to the minimum, especially in the entrance region.

ACKNOWLEDGEMENT

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