EA Methane Hydrate Surface Morphology in a Dynamic Water Dominant Flowloop*

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Abstract

Methane hydrates are the world's largest unexploited hydrocarbon resource, with the capacity to support the world's current demand for energy and, in particular, LNG. Methane hydrates are solid crystalline compounds, composed of a molecular cage of water molecules that trap methane under low-temperature and high-pressure conditions (Sloan, 1998). The world's first successful offshore production of methane hydrate occurred in the Eastern Nankai Trough of Japan in March 2013. The production process employed depressurisation of methane hydrates, followed by downhole separation of methane and water; independent methane- and water-continuous production lines connected subsea infrastructure to the surface (Yamamoto et al., 2014). In favourable temperature and pressure conditions, the potential for hydrate reformation during this production process introduces a flow assurance risk to the operation; severe hydrate reformation may result in blockage of subsea equipment, which can be costly and dangerous to rectify. Most of the flow assurance research on hydrates has focused on oil-dominant systems, while this investigation focuses on hydrate blockage formation in water-dominant systems. This work has been part of "Research Consortium for Methane Hydrate Resources in Japan" (MH21) in accordance with "Japan's Methane Hydrate R&D Program".

The flowloop consisted of 16.7 m of stainless-steel tubing (10 mm diameter) with two high-resolution differential pressure transducers, absolute pressure transducer, two Platinum Resistance Thermometers, a thermistor, Coriolis mass flow meter, circulation pump, and in-line camera (Figure 1). An in-line camera provided a 7000 by 9300 μm images at four frames per second. Images of three-phase flow (water/gas/hydrate) were captured for a range of hydrate volume fractions in the liquid slurry (1.5 to 20 %), as well as hydrate growth rates, under both laminar and turbulent flow conditions.

The flowloop was filled under vacuum (14 torr) with distilled water and an initial 25 - 40 mL of methane gas was added by the removal of equal volume of water. The system was then allowed to equilibrate with the dissolution of methane into water overnight at constant pressure by the addition of methane gas. This allowed the volume of free gas to be constant while the gas/water mixture underwent dynamic circulation at a turbulent velocity of 1.3 m/s. Initially the flowloop is outside the methane hydrate stability condition (16°C and 100 bar) and is cooled at a constant rate of three degrees per hour until the temperature reaches three degrees to represent the conditions of the seafloor, where methane hydrate is stable at pressure above 35 bar.

Hydrate formation is identified by observing changes in pressure and temperature. The conversion of compressible gas bubbles forming into hydrate-encrusted bubbles, results in an overall decrease in flowloop pressure (red dotted line in Figure 2). The utilisation of our in-line camera allowed us to capture unique images of surface morphology during hydrate growth. This study focused on morphological observations during hydrate growth, where the results illustrate that the hydrate crystal morphology depends on the degree of shear and degree of sub-cooling in the system. Hydrates preferentially form at the methane/water interface, where the behaviour of the resultant hydrate particles size on a gas bubble depends on the shear conditions of the system.

Figure 3 shows typical water and gas bubble images before the start of hydrate formation. Figure 4 shows an image of the flow a few seconds after the beginning of hydrate formation; velocity 1.3 m/s, temperature 10°C and pressure ~85 bar. The red highlighted box shows a gas bubble with fine hydrate nodules on the surface and the blue highlighted boxes shows a rough surface morphology. This is a distinct image for a dynamic system as static (quiescent) systems have shown fine/smooth surface morphology for high degrees of subcooling and large/rough surface morphology for low degrees of subcooling (Li, et al., 2013; Li, et al., 2014).

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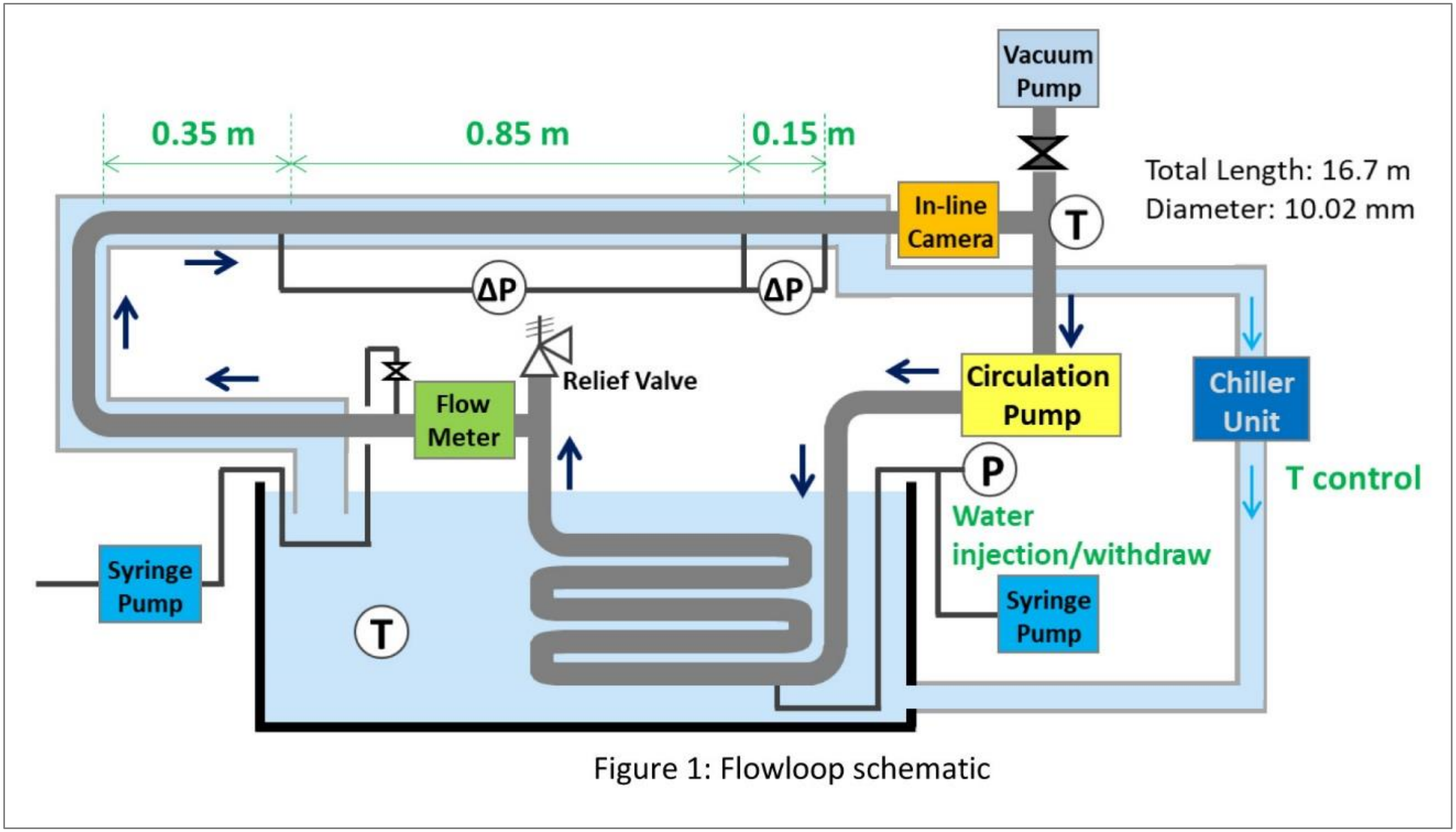

Figure 1. Flowloop schematic.

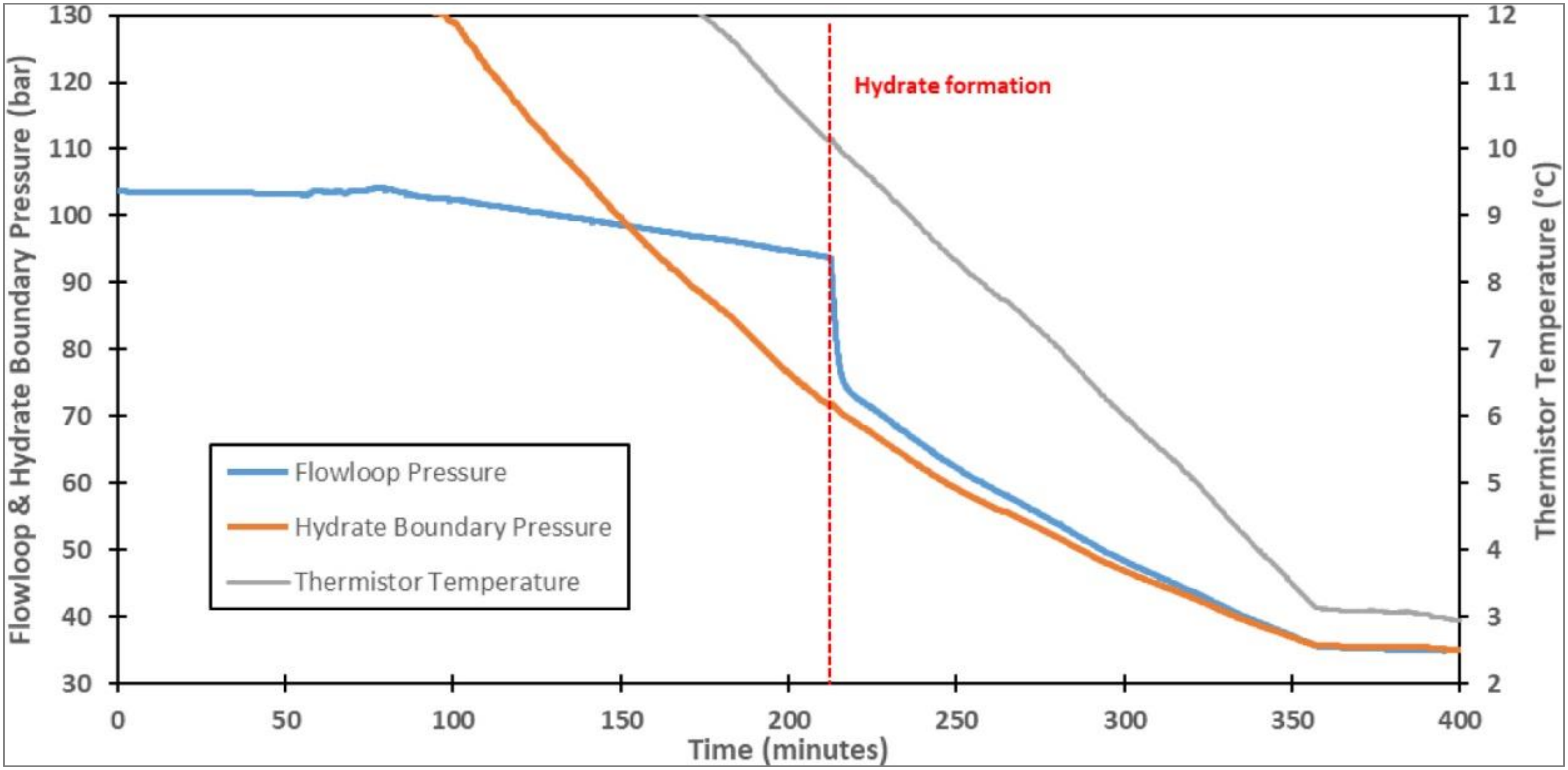

Figure 2. Typical pressure profile for beginning of initial hydrate formation.

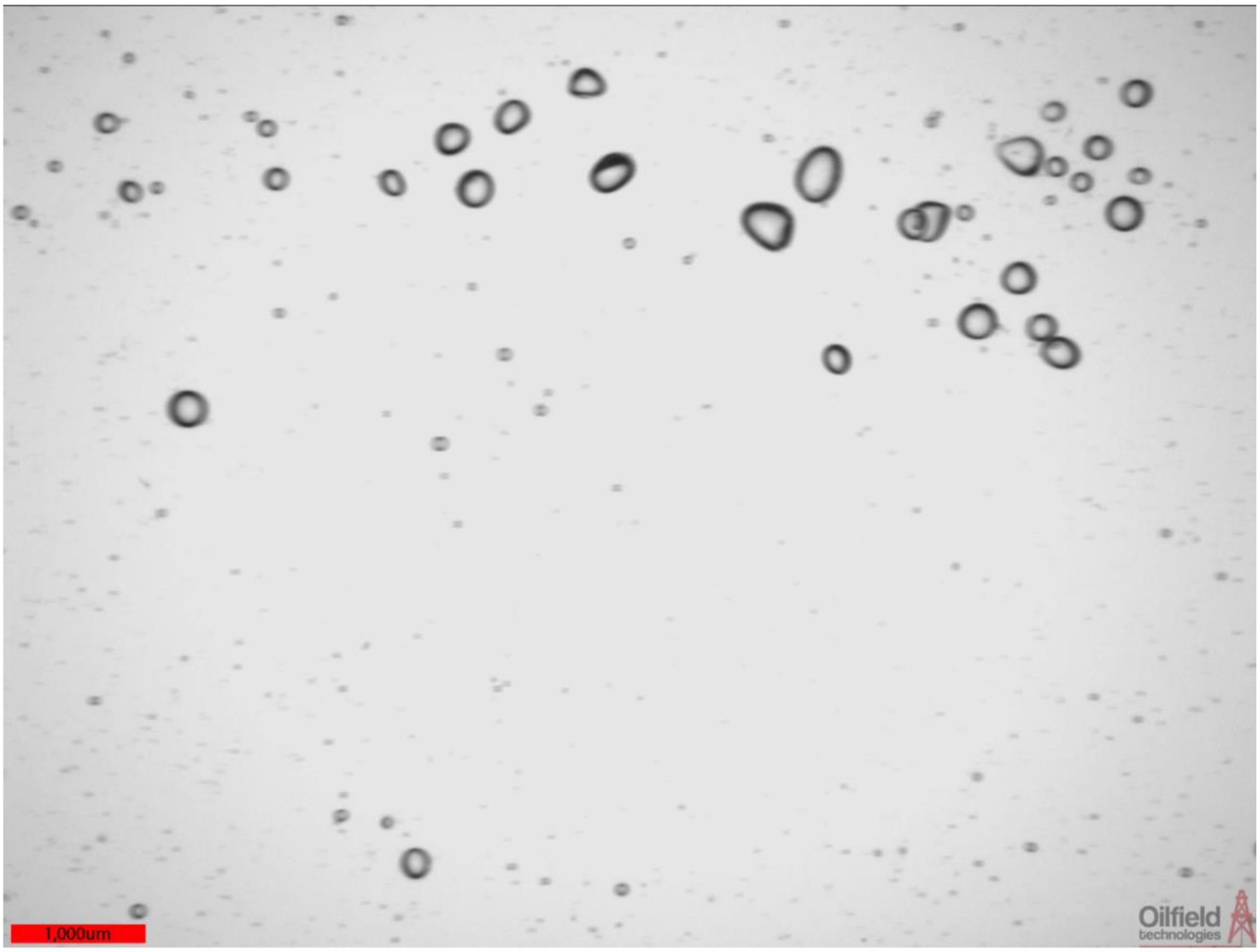

Figure 3. Water and gas bubble flow. Before hydrate formation.

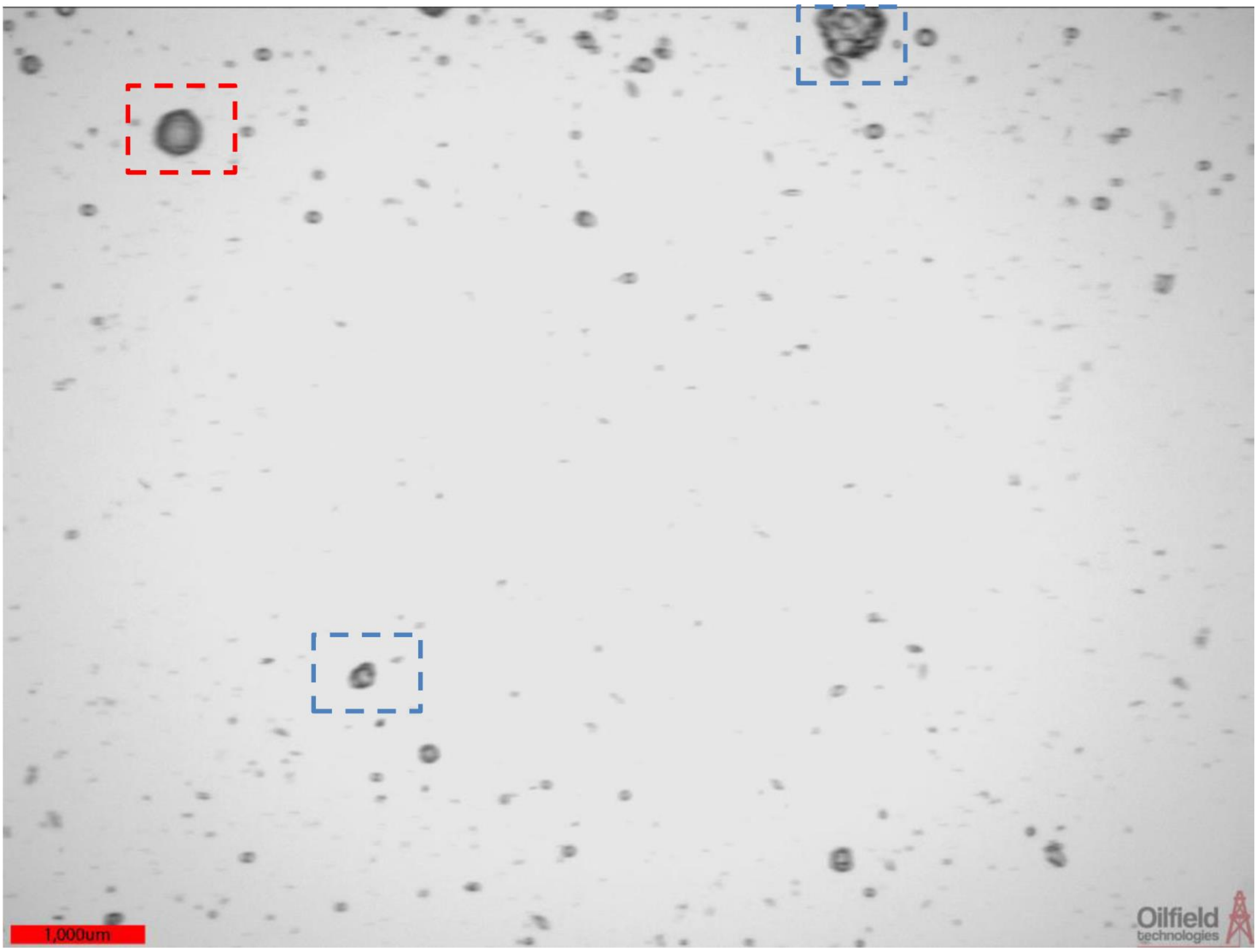

Figure 4. Water, hydrate, and gas bubble flow. Beginning of hydrate formation.