MICROMECHANICAL ADHESION FORCE MEASUREMENTS BETWEEN CYCLOPENTANE HYDRATE PARTICLES IN WATER

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ABSTRACT
One of the variables influencing the mechanism of hydrate plug formation in oil pipelines producing high water cuts is the interaction between hydrate particles suspended in water. In this work, we measured the adhesion force between cyclopentane hydrate particles in water using a micromechanical force apparatus (MMF). The cyclopentane hydrate particles were formed externally on glass fiber cantilevers, and then transferred to the MMF cell containing water saturated with cyclopentane in equilibrium with cyclopentane hydrates. We measured an average adhesion force of 1.4 mN/m over the temperature range of 274.16 K to 278.16 K, contact force range of 1.5 to 5 mN/m, and contact time range of 5 to 20 seconds. The average adhesion force between cyclopentane hydrates suspended in water (1.4 mN/m) was less than half the force measured between cyc5 hydrates suspended in cyclopentane (3.6 mN/m). We found no effect of temperature and contact force (1 to 5 mN) on the measured force suggesting the absence of liquid capillary bridge. The adhesion force between hydrate particles suspended in water was explained by solid-solid adhesion theory. Using this theory a force of 150 mN/m was predicted. The model over prediction of the adhesion force may be attributed to the lower contact area between particles, due to uneven contact surface.

Keywords: gas hydrate, adhesion force, surface energy, cyclopentane

NOMENCLATURE

\begin{itemize}
  \item $F$ \quad Force [Pa]
  \item $k$ \quad Spring Constant [kg/s^2]
  \item $d$ \quad Displacement [m]
  \item $R_1$, $R_2$, $R^*$ \quad Particle Radius [m]
  \item $W$ \quad Surface energy [J/m^2]
  \item $\gamma_{LL}$ \quad Interfacial Tension [N/m]
  \item $\theta$ \quad Contact Angle [radian]
  \item $D$ \quad Separation Distance [m]
  \item $d$ \quad Liquid Layer Height [m]
\end{itemize}

INTRODUCTION
As oil fields mature, more water is produced, which leads to the formation of a free water phase in pipeline flow. An increase in the water cut (volume fraction of water in liquid) increases the hydrate formation and plugging risk. It is essential to understand the transport properties of a hydrate – water slurry, such as apparent viscosity, in order to model hydrate slurry systems. Particle-particle interaction is an important factor in understanding the rheological behavior of a solid-liquid slurry. Darbouret [1] studied the rheology of a tert-butylammonium bromide hydrate – water slurry and suggested agglomeration occurs between hydrate particles. In order to understand the nature of interaction between particles, various authors have measured the adhesion forces between hydrate particles. Yang [2] measured the adhesion force between ice-ice and hydrate-hydrate particles by using a micromechanical force apparatus, and found that the forces increased with increasing temperature. Similarly Taylor [3] performed adhesion force measurements between THF hydrate particles in different surrounding media and explained the forces by capillary bridge theory. Dieker [4] studied the effect of different additives (different crude oils added to