Hydrate Slurry Characterization in the Presence of Anti-Agglomerants: Connecting High-Pressure Rheometer Studies with Flowloop Test Results

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Subsea oil and gas operations within hydrate formation conditions require additional control measures, such as electrical heating or injection of thermodynamic inhibitors, in order to assure continuous fluid flow throughout the pipe. Cost reduction and environmental protection are incentives for minimizing the use of traditional thermodynamic inhibitor injection in subsea flowlines. Therefore, low dosage hydrate inhibitors (LDHIs) can present an attractive alternative to traditional additives for preventing gas hydrate plug formation. Through the use of hydrate agglomeration inhibitors or anti-agglomerants (AAs), production lines may be operated within the hydrate stability region. In this strategy, hydrates are allowed to form but with minimal agglomeration of hydrate particles, allowing the successful transportation of small solid particles dispersed in a bulk liquid phase. In order to deploy anti-agglomerants as a hydrate management strategy in oil fields, an advanced understanding of the properties of hydrate slurries and practical limits for successful hydrate transport are required. This paper presents high pressure large-scale flowloop experiments, coupled with high pressure laboratory-scale rheometer studies, in order to understand flowloop experimental results in terms of hydrate slurry properties at different operating conditions. The experimental matrix was designed to investigate the properties of hydrate slurries at different water cuts, as well as systems with anti-agglomerant under-dosing. Additionally, various rheological models for suspensions of

solid particles are considered to describe hydrate slurry viscosity, depending on the system properties (i.e., slurry continuous phase and degree of agglomeration inhibition).

High pressure large-scale flowloop tests using AAs were conducted at University of Tulsa facilities in order to study hydrate particle transportability over a range of operating conditions, with water cuts ranging from 30 to 80 vol. %, different mixture velocities, and different AA concentrations (i.e., under-inhibited systems). High pressure laboratory-scale rheometer experiments were carried out using similar fluids. Rheological studies included experiments at constant and ramping shear rates, as well as cold restart tests to obtain the yield stress of hydrate slurries after varying shut-in periods.

Successful hydrate particle transport was observed for hydrate volume fractions below 40 vol. % regardless of the water cut in the system, providing that AA is sufficiently dosed, however the flowloop tests' limited time-scale may not be sufficient to discard long time-scale hydrate accumulation mechanisms as deposition. Furthermore, higher relative pressure drops were recorded at intermediate water cuts (i.e., 50 vol. %) than in either low (i.e., 30 vol. %) or high (i.e., 80 vol. %) water cut systems, for any given hydrate volume fraction. On the other hand, under-inhibited systems caused hydrate accumulation at the bottom of the flowline (i.e., hydrate bedding), eventually leading to the formation of solid hydrate deposits. The hydrate slurry viscosity obtained from rheometer experiments qualitatively agreed with flowloop test results, providing useful information to advance our understanding of the contribution of hydrate particles to the viscosity of the hydrate slurry in both oil and water continuous systems in the presence of anti-agglomerants, and the correlation between flowloop test results and hydrate slurry viscosity.

The new data and analysis presented in this paper will be helpful in developing advanced predictive models for hydrate slurry behavior in the presence of anti-agglomerants, particularly in terms of hydrate slurry viscosity. Ultimately, this information can lead to improved assessment, and successful deployment, of new hydrate management strategies.