THE UNIVERSITY of TULSA

Office of Research and Sponsored Programs

Hydrate Flow Performance JIP

13th Semi-Annual Advisory Board Meeting Brochure and Presentation Slide Copy Hydrate Risk Management Program

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Pages 11-14 are public information

Hydrate Risk Management Program – Executive Summary

1. Scope of Work: This phase of hydrate studies at the University of Tulsa continues the investigation of hydrate formation and plugging during production and restart conditions, as well as investigates plug characteristics and dissociation methods. In the first project additional flow loop data will be gathered and modeling performed to focus on key variables affecting plugging in normal production conditions; variables such as liquid loading (or GOR), flow patterns and velocity, as well as salinity will be investigated since they have been demonstrated to play a significant role in plugging. In the second study, transient water displacement in a jumper system configuration based on several operating conditions will be investigated, as well as how this displacement is affected once hydrates start forming. In this study the efficiency of hydrate prevention strategies consisting of displacing the water out of the system, e.g. with dead oil or MeOH will be investigated. Parameters such as liquid/water loading, displacement rates and oil/water properties will be investigated. The third study generates solid hydrate plugs for characterization in a high pressure flow loop. Plug characteristics, such as density, porosity and permeability will be measured for plugs formed under different scenarios. Different dissociation strategies, such as depressurization, wall heating and thermodynamic inhibitors will be evaluated and a comparison of their efficiency provided.

2. Tasks: Twelve major tasks are envisioned for the three projects:

Project 1: Risk assessment of hydrate plugging during steady-state operations
- Task 1: Simulation of new and past experiments (12 months)
- Task 2: Steady-state hydrate formation experiments (6 months)
  - Variables of interest: GOR, rates, oil viscosity, brine salinity and slurry flow
- Task 3: Risk assessment matrix development
- Task 4: Hydrate Particle Size Characterization Studies

Project 2: Risk assessment of hydrate plugging during restart operations
- Task 5: Simulation runs to optimize design of facilities
- Task 6: Flow loop design/construction/shakedown
- Task 7: Experimental studies with transient flow facilities (18 months)
  - Effect of liquid loading, water cut, brine concentration, flow velocity
    Gas vs. liquid dominated restart
  - Brine in jumpers and risers if possible
  - With Hydrates
- Task 8: Risk assessment matrix development
- Task 9: Olga simulation correlations/improvements

Project 3: Hydrate Plug Characteristics
- Task 10: Facility Modification
- Task 11: Formation of plugs & measurements of plug characteristics (6 months)
- Task 12: Evaluation of dissociation methods (18 months)
  - Depressurization, methanol injection, MEG injection

The schedule for completing the complex and interrelated tasks is shown in Figure 1. The study will last two years, finishing in 2009. Figure 1 also shows when significant deliverables in the form of reports, model validations, and data will be provided to the participants. Those activities colored in green are completed while those colored in blue are scheduled.

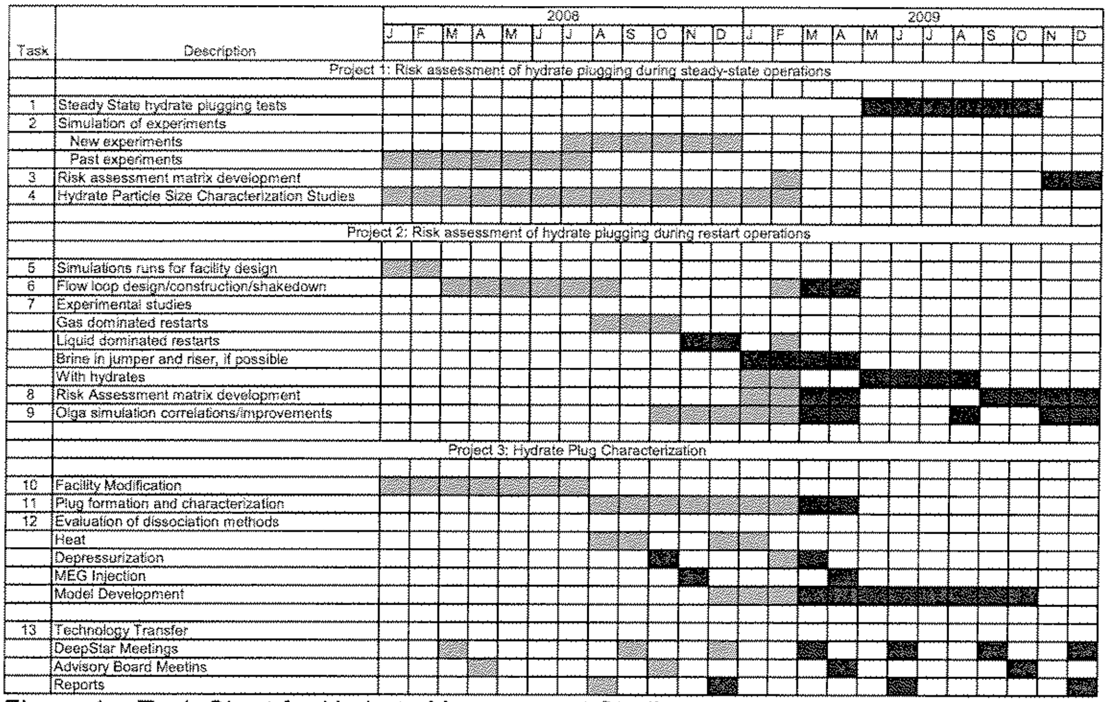

Figure 1 – Task Chart for Hydrate Management Studies

3. Activity Summary: The first six month of the project were focused on constructing or modify facilities and shaking them down to generate high quality data. Since that time, the focus has been on simulating proposed tests and conducting experiments and analyzing data. The progress for the three projects is discussed below.

Project 1: Forty experiments were simulated using PVTSim to establish the steady state test matrix and hydrate formation rates were calculated. LL, viscosity, GOR and salinity were identified as key variables. Hydrate formation rates were found to be very fast and ranged primarily from 0.13 to 0.18 lb_m/min. Higher formation rates were seen when AA's were used and lower rates were seen for high liquid loadings. Gas-water tests were conducted with high liquid loadings and minimal hydrate formation was seen. A second approach was tried to determine kA rate constant data for the pumping experiments conducted. Salinity and water cut were found to have minimal effect on the formation rate constant while liquid loading, fluid velocity and fluid properties have the largest effect on the formation rate constant. A preliminary test matrix for future steady state tests was developed based on these findings. Calcep completed the flow loop simulator and began modeling experiments.

Project 2: One hundred ninety-nine (199) gas restart experiments have been conducted through February of which one hundred fifty-one (151) experiments were conducted during this reporting period. Four (4) were gas water restarts, sixty four (64) were for single phase oils while eighty three (83) were for oil water mixtures. Simulation runs were made and the two were compared. The liquid restart tests were begun.

It was cold enough during the month of January to test the feasibility of forming hydrates in the jumper facility with cyclopentane at atmospheric pressure. The first low spot in the jumper was bridged with water with cyclopentane on top of it in the left leg (4 gallons of water and 2.5 gallons of cyclpentane). Airflow at a flow rate that varied from 1 to 4 ft/s was used to mix without carryover. Within ten minutes all of the water was converted to hydrates. A permeable hydrate plug had formed in the elbow while the walls of the 18' long vertical pipe were coated with hydrates. The test was shut in for about an hour and then a restart was attempted. The plug was still permeable to gas flow at rates up to 4 ft/s but no displacement was observed. The flow rate was then slowly increased to 30 ft/s without an increase in pressure. At 30 ft/s the hydrate plug displaced and hydrate chunks were carried over into the second low spot.

Efforts were begun on simulation of the formation of cyclopentane hydrates in the jumper facility by using the CSM's hydrate kinetic module in conjunction with the OLGA simulator. The modeling of the flow behavior outside the hydrate region was finished. A liquid displacement test was conducted in the jumper facility in order to obtain the volumes of cyclopentane and water remaining in the low spots after airflow at velocities that varied from 1 to 4 ft/s was injected into the system. The results of the OLGA model were compared with the experimental runs.

The simulation of hydrates in the jumper test was begun. In order to accurately predict the location and timescale of cyclopentane hydrate plugs, it is necessary that certain parameters related to the intrinsic kinetics are adjusted before the CSMHyK module can be used. Work is underway to find out the best fitted factors to model the formation and agglomeration of cyclopentane hydrates.

Project 3: Six shakedown tests were run to make hydrate plugs for characterization and dissociation studies. No plugs were made with the gas-water mixture and the hydrates were smeared throughout the loop. Porous and permeable plugs were made when gas-oil-water mixtures were used.

Upon completion of the shakedown tests, eighteen plugging experiments were conducted with the Citgo 19 lube oil. No agglomeration and limited accumulation in front of the restriction plates was seen. Plugs were formed when the slug of hydrate slurry stopped flowing due to wall friction. These preliminary results suggest that adhesion forces are the dominant mechanism for the 19 cp model oil being tested. A modified procedure that allowed draining of the plugs from free liquids was also tried. Plug permeability was found to be in the order of 10s to 100s of Darcys if calculated using Darcy's law, even though non-permeable plugs have been formed, mainly with fresh water. Preliminary results indicate that the permeability of the plug decreases as gas is circulated through it.

Ten experiments were then conducted to investigate plug formation and dissociation with the facility in the low spot configuration, simulating the leaky valve scenario. The new experimental results provided more insight on previous results by Estanga on plug formation mechanisms. It was observed under the leaky valve scenario that the water column is slowly replaced by a matrix of hydrate-covered gas bubbles. The effect of gas leak rate and salinity (fresh, 3.5% and 7.0% wt.) were tested and data is currently being processed. The observed mechanism for plug formation did not change for the parameters tested and plugs are fairly reproducible with respect to porosity. The plug density varies from 0.28 to 0.36 g/cc. The minimum permeability observed is around 10

D and occurs for 100 psi differential pressure across the plug. For safety reasons, it may not be possible to study lower permeabilities in the current setup. It was also observed that the plug permeability is very sensitive to spikes in flow rate or pressure; a couple times these very porous plugs collapsed with 100 psi differential pressure across them.

4. % Completed: 60%

5. Conclusions/Observations: Hydrate formation rates are very rapid. Lower rates are seen for high liquid loadings and higher values are seen when AA's are used. Additional high liquid loading tests were conducted with water and similar results were seen as with oils, that is, little hydrates are formed. This is being further pursued as a possible cold flow approach. kA constants were also calculated for these 40 experiments. Salinity and water cut were found to have minimal effect on the formation rate constant while liquid loading, fluid velocity and fluid properties have the largest effect on the formation rate constant.

Olga was found to under predict holdup for the gas-water and gas-oil transient experiments. Final liquid holdup was found to be a function of velocity. For multiphase mixtures not only the viscosity but also the density has an impact on the liquid carry over. As expected the mixture curves fall in between the single phase curves.

Gas-oil hydrate plugs were found to form when the slug of hydrate slurry stops flowing due to wall friction. Plug permeability is in the order of 10s to 100s of Darcy's if calculated using Darcy's law, even though non-permeable plugs have been formed, mainly with fresh water. Preliminary results indicate that the permeability of the plug decreases as gas is circulated through it. When gas-water was used to make hydrate plugs none were formed. The hydrates were found to smear throughout the flow loop.

Experiments were conducted to investigate plug formation and dissociation with the facility in the low spot configuration, simulating the leaky valve scenario. The plug density varied from 0.28 to 0.36 g/cc. The minimum permeability observed is around 10 D and occurs for 100 psi differential pressure across the plug. It was also observed that the plug permeability is very sensitive to spikes in flow rate or pressure; a couple times these very porous plugs collapsed with 100 psi differential pressure across them.

6. Future Work: Liquid dominated restarts will be conducted in the jumper facility. This will complete the experimental phase. Simulation and analysis of the data will be completed and the results will be documented in a report. The new "pipe in pipe" jumper facility for studying hydrate formation and dissociation will be constructed and shakedown tests will begin. The non-equilibrium simulations will be completed and correlations for hydrate formation rates as a function of LL, WC and fluid properties will be completed. Calsep will continue modeling the flow loop experiments using the recently developed flow loop simulator. The hydrate characterization studies will be completed and the findings documented in a report. Evaluation of dissociation methods compared to plug dissociation simulation tools will continue as will the comparison of pressure dissociation and chemical dissociation techniques.