Paraffin Deposition Progress Report October through December 2001

Facilities

No significant changes have been made on the single phase or multiphase flow loop as both flow loops are now operational. A new spool piece, equipped with coupon samplers, was built and installed on the multiphase facility. This new spool piece will allow us to take wax samples during high pressure multiphase flow tests in order to study the aging process of the deposit.

The design of the water phase for the multiphase flow loop continues. The Natco separator is under construction and should be delivered during the next reporting period. The design of the water system will be finalized and the remaining equipment ordered in the coming months.

Small Scale Facility

During this reporting period, the design of the small scale loop was completed. The main equipment from an existing TUFFP heavy oil-water facility will be reutilized in order to keep the cost at a minimum.

This new facility will be equipped with three 8-ft long test sections of different diameters: ½", 1" and 1-½". Each test section is adequate for a given flow rate range up to 1,200 BPD.

A new 2-bbl oil tank will be constructed since depletion is an issue with some oils in the existing 1-bbl tank. The 2-bbl oil charge will give a deposition area / total oil volume ratio similar to the multiphase flow loop, therefore minimizing depletion. The existing sliding vane pump will be re-utilized. A new chiller will be purchased since the existing one is undersized and needs extensive repairs. The oil temperature will be controlled directly with electric heaters placed on the oil system; allowing complete elimination of the hot glycol system and realizing substantial cost savings in equipment, piping and construction time.

Existing glycol tanks and heat exchanger will be used for the glycol systems. Control valves will be purchased to control the glycol flow rate in the test section, as well as its temperature. The oil flow rate will be controlled using the existing oil pump variable speed drive.

Instrumentation includes oil and glycol temperature transmitters and pressure drop transmitters to monitor the wax buildup. Three sampling ports on each test section will allow us to take samples at determined times during tests. A pig launcher and receivers will allow us to pig the largest test section in the same manner used in the field while monitoring pressure drops across the pig during the pigging operation. All parameters will be recorded with a Labview-based data acquisition and control system.

The equipment required for the facility was ordered and construction has begun. During the next three months, the facility will be assembled with an expected commissioning in April. Un-manned long term deposition physics tests will then be conducted in this facility, as well as miscellaneous tests to study shear stripping, scale-up parameters and oil-water preliminary tests. A test matrix for this facility will be presented in the next report and discussed at the April Advisory Board meeting.

Wax Deposition Tests

Garden Banks Single-Phase Testing:

A total of 8 single-phase tests were completed with the Garden Banks fluid during the last quarter of 2001 in both single-phase and multiphase flow loops.

On the single-phase flow loop, 5 tests were conducted under turbulent flow conditions to study the effect of DT and flow regime on the paraffin deposition process for Garden Banks Condensate. The flow rates studied were 1000, 1500 and 1800 BPD with temperature differences between oil and glycol of 15°F and 30°F. A temperature difference of 45°F could not be studied on this facility because of limited chilling capacity. For all these tests, the oil inlet temperature was 85°F and the wax appearance temperature of the oil was 94°F. Laminar flow tests were not conducted on this flow loop in order to avoid any depletion problems that may occur since the wax content of Garden Banks Condensate is quite low (less than 1 %).

Shear stripping verification tests were also conducted on the single-phase flow loop in which the oil was flowed at 1800 BPD with a temperature difference of 30°F for 24 hours. After flowing for 24 hours, the oil temperature was lowered to the glycol temperature (55°F) to achieve isothermal conditions and avoid further deposition. During the test, isothermal conditions were not fully achieved; however, the temperature difference between the oil and the glycol was less than 2°F. These conditions were maintained for another 24-hour period before the test was shutdown and both spool pieces inspected. The data gathered from this test shows a constant decrease in the pressure drop readings during the "isothermal" period. The decrease in pressure drop can be attributed to various phenomena or a combination of them. The most compelling argument is that the deposit thickness decreases due to possible shear stripping. It might also be argued that the pressure change would be due to the change in the characteristic of the deposit roughness, which can also be attributed to shear stripping. Another plausible explanation would be the possible reduction in oil content of the deposit. LD – LD measurements were conducted after this test and were compared to the measurements for the similar test studying only the deposition period (24 hours); unfortunately, the error bands for these measurements are significantly large (+/- 0.1 mm) resulting in inconclusive results. This test will be repeated during the month of January to increase our confidence in these results. The isothermal period will be extended to 3 days thereby resulting in a large enough change in deposit thickness to produce meaningful results.

The coupon samplers were used to collect wax deposit samples during the single phase tests. These samples are being analyzed in order to measure the wax content change in time for the different conditions studied. A few samples will also be sent to

ChevronTexaco for HTGC analysis in order to compare results and better calibrate DSC analyses. This data will be reported in the April Quarterly Report. A few more tests with the Garden Banks Condensate will be completed using the single-phase flow loop in January. After completion of these tests, tests with CBI (Cote Blanch Island) stock tank oil will begin. CBI oil has characteristics similar to South Pelto oil with a higher viscosity.

Two single-phase tests were also conducted in the multiphase flow loop; one at a flow rate of 2500 BPD and one in the transition zone between laminar and turbulent flow (flow rate of 200 BPD). Both of these tests were conducted with a temperature difference between the oil and the glycol of 30°F. No significant amount of wax deposit was found after 24 hours for either of these tests. Therefore, further single-phase testing using this flow loop was stopped.

Third Fluid

The third fluid to be tested will be the Cote Blanche Island crude from ChevronTexaco. A storage tank was shipped to Humble November 8, 2001 and a sample was taken on November 26, 2001 and shipped to Tulsa. This fluid will be loaded into the single-phase flow loop in January. This fluid is a relatively heavier oil (API of 24) and is twice as viscous as South Pelto crude oil. The wax deposition potential (solubility curve) is being established by DSC runs. The solubility curve is expected to be similar to South Pelto. This fluid will allow us to assess the effect of viscosity on deposition phenomena.

The fourth fluid to be obtained is for the model validation work. Potential candidates are Troika and/or Pompano fluids from Marathon, Blake from BG International, and Caratinga and/or a fluid from the Albacora field in the Campos basin from Petrobras. Table 1 summarizes the measured characterization data for these fluids. It is noted that the Caratinga oil has two Wax Appearance Temperatures (determined by DSC) and a lot of wax deposition data.

Property	Texaco	BG	Marathon		Petrobras	
	CBI	Blake	Pompano	Troika*	Caratinga	Albacora
API Gravity	24.0	31.7	25.3	34.8	24.3	24.0
WAT, F	105	~86	80	~85	Two peaks 117 and 63	Two peaks 95 and 68
Pour Pt, F	44	43	<-10	?	0	10
Wax, wt%	6.3	6.4	1.8	?	5.4	4.7
Viscosity @ 60, cp	48	~25	17	?	~110	~110
Viscosity @ 100, cp	15	~9	7	?	~40	43
Asphaltenes	3.4	0.7	6.2	?	18	N/A
Resins	3.4	1.4	14.7	?	27	N/A
Water Cut%	?	0	?	?	?	16

***The Troika samples have undergone several lab characterizations – BP will be providing this data at a later date and will be included in the next progress report.**

Discussions are ongoing with these three companies regarding the amount of deposition data they have for their respective fluids, their willingness to share this data, as well as the production history. Plans are to select the fluid for utilization in the study before the end of February so a sample can be taken as soon as possible.

Modeling Efforts

Single-Phase Wax Deposition Model

Several modifications have been made to the single-phase paraffin deposition prediction model. One modification is the segmentation of the pipe, which may have different specifications such as inner and outer diameters, length, inclination angle, insulation characteristics, roughness and ambient temperature. The pipe file for single-phase wax deposition calculation is now similar to the pipe file used for the multiphase calculation.

The convective mass transfer model was incorporated into the computer program. The user can select either the molecular diffusion of convective mass transfer, or a "hybrid" between both models for the deposition process. The Singh et al. model is still under review, and will probably be added to the software in the future.

Another modification made for the single-phase model is the addition of the shear stripping term. Shear stripping is currently being investigated. Until we improve our model about this phenomenon, the user can arbitrarily set a percentage of what has been deposited as shear stripping.

Multiphase Wax Deposition Model

Hydrodynamics

The newly developed unified hydrodynamic model for gas-liquid pipe flow was incorporated into the multiphase wax deposition model. The model can predict flow pattern transition, liquid holdup, pressure gradient and slug characteristics in gas-liquid pipe flow at different inclination angles from –90 to 90 deg. The flow pattern transitions are predicted based on slug dynamics. There is no inconsistency between the flow pattern transition model and the hydrodynamic model. Compared with previous mechanistic models for flow pattern transitions, the present model gives better prediction of flow pattern transitions.

Heat Transfer

A comprehensive two-phase heat transfer model was developed by Ryo Manabe as part of his PhD study. The model consists of a flow pattern prediction model and a set of individual mechanistic models for predicting hydrodynamics and heat transfer. The new two-phase heat transfer model was evaluated by comparisons with experimental data. It was shown that the model can predict the convective two-phase heat transfer coefficient better than OSU recommended correlations.

The computer program for the two-phase heat transfer model will be modified and debugged before being integrated into the wax deposition software. Further studies are needed before the newly developed unified multiphase hydrodynamic model can be integrated with the heat transfer model. If participants wish for this to be done, it can be included in future studies.

Mass Transfer

In the multiphase wax deposition model, the molecular diffusion method for mass transfer was replaced with the convective mass transfer approach.

New GUI Development

Two separate subroutines were added to the computer program to handle the pipe profile (distribution along pipeline) and trend (change with time) outputs. Through these subroutines, the program can output any number of parameters with a standardized format similar to the outputs generated by OLGA. The GUI can now display the outputs either by tabular listing or by graphic plotting. The package is currently under Beta test. The expected release date is late January 2002.

Future Meetings

The next Tulsa University Paraffin Deposition Projects (TUPDP) Advisory Board meeting will be held on April 24, 2002 in Tulsa, Oklahoma at the Doubletree Hotel at Warren Place. A continental breakfast will be served starting at 8:00 a.m. with the Advisory Board meeting commencing at 8:30 a.m. A joint reception will be held on Tuesday, April 23rd at 6:00 p.m. Below is a table for April 2002 Advisory Board activities.

Day	Date	Event	Time	Location
Monday	April 22	Tulsa University Severe Slugging Advisory Board Meeting	9:00 a.m. - 1:00 p.m.	Doubletree Hotel at Warren Place, Tulsa, Oklahoma
		Tour of Test Facilities	3:00 - 5:00 p.m.	University of Tulsa North Campus, Tulsa, Oklahoma
		Joint BBQ	5:00 - 7:00 p.m.	University of Tulsa North Campus, Tulsa, Oklahoma
Tuesday	April 23	Tulsa University Fluid Flow Projects Advisory Board Meeting	8:00 a.m. - 5:00 p.m.	Doubletree Hotel at Warren Place, Tulsa, Oklahoma
		Joint Reception	6:00 - 9:00	Doubletree Hotel at Warren Place, Tulsa, Oklahoma
Wednesday	April 24	Tulsa University Paraffin Deposition Projects	8:00 a.m. - 5:00 p.m.	Doubletree Hotel at Warren Place, Tulsa, Oklahoma