Paraffin Deposition Progress Report
May through July 2001

At the Advisory Board meeting in May 2001, a discussion was held and it was decided by vote of member companies to eliminate the quarterly reports between Advisory Board meetings and replace them with a progress update. This will make the reporting requirement for the member companies the same as those for the U.S. Department of Energy. The quarterly reports that were eliminated will be replaced by a progress report. This is the first of the progress reports.

Facilities

The single-phase flow loop is being commissioned and has been loaded with the Garden Banks condensate. The facility will be used in August to conduct the single-phase turbulent Garden Banks tests. The two spool pieces equipped with the coupon samplers have been mounted on the facility and their performance will be tested when running the next turbulent tests. With these spool pieces, up to three samples per test can be taken for analysis. These samples will be very useful for the deposit aging studies.

The multiphase flow facility was depressurized, emptied and cleaned with diesel oil and kerosene. The Garden Banks condensate will be transferred into the facility in August for the multiphase flow tests. The instrumented spool piece is being replaced with a "blank" spool piece to allow pigging and wax strength measurements. This spool piece will be modified to later accommodate the coupon samplers if the system is proven successful on the single-phase flow loop.

The DSC laboratory is now operational and will allow measurements of the wax melting point and solubility curves for crude oils. Our pigging skid intended to measure mechanical strength of the deposits is being calibrated and is expected to be operational for the next test run on either facility.

Wax Deposition Tests

Additional South Pelto single-phase tests have been successfully concluded on the multiphase paraffin deposition flow loop. A total of 10 tests were performed in order to study the flow regime dependence and the effect of ΔT on the paraffin deposition process. These tests were intended to provide more insight on important issues such as shear stripping effects under turbulent flow conditions, trapped oil content dependence on the test conditions, transition between laminar and turbulent flow regimes, and proper scaling criteria between data from both the single-phase and multiphase paraffin deposition flow loops. The results of these tests and the analytical results, such as oil content and melting points of the wax samples, will be discussed at the next Advisory Board meeting.

Single-phase testing with the Garden Banks condensate will commence in late August. Plans are to conduct eight of these tests by operating both the single-phase and

multiphase loops simultaneously. Upon completion of these tests, multiphase testing will begin with the Garden Banks condensate.

Third Fluid

The third fluid to be tested will most likely be Cote Blanche Island (CBI) crude from Texaco. This fluid is a heavier oil (API about 24) and is twice as viscous as South Pelto crude oil. The wax deposition potential (solubility curve) is expected to be similar to South Pelto, but will be confirmed by DSC runs. This fluid will allow us to assess the effect of viscosity on deposition phenomena. Discussions have also been held with Marathon regarding using their Troika and/or Pompano fluids in our wax studies.

Modeling Efforts

Unified Model for Gas-Liquid Flow in Pipelines

During oil and gas production, fluids are transported upwards from vertical or deviated wells, through hilly-terrain pipelines to downstream processing facilities. Steam injection in some enhanced oil recovery operations, and flow from platforms to subsea pipelines involve steeply inclined downward multiphase flow. Thus, gas-liquid two-phase flows at all inclination angles from vertical downward to vertical upward are frequently encountered in the oil and gas industry. In order to predict wax deposition, a unified model is required which can accurately predict two-phase flow behavior at all inclination angles.

Development of a unified hydrodynamic model was reported at the TUPDP Advisory Board meeting in May 2001. The new model can be used for predictions of flow pattern transitions, pressure gradient, liquid holdup and slug characteristics in gas-liquid pipe flow at different inclination angles from –90 to 90 deg. The model is based on the dynamics of slug flow, which shares transition boundaries with all the other flow patterns. The equations of slug flow are used not only to calculate the slug characteristics, but also to predict transitions from slug flow to other flow patterns.

Significant effort has been made to eliminate discontinuities among closure relationships in the unified model through careful selection and generalization. The flow pattern classification was also simplified according to the hydrodynamic characteristics of two-phase flow. The new model has been verified with extensive experimental data acquired with different pipe diameters, inclination angles, fluid physical properties, gas-liquid flow rates and flow patterns. Good agreement was observed in every aspect of the two-phase pipe flow.

Two Phase Heat Transfer Modeling

Estimating heat transfer, including the prediction of convective heat transfer coefficients, for gas-liquid two-phase flow is an important concern in modeling thermal behavior of petroleum multiphase systems. However, the petroleum industry has paid less attention to predicting heat transfer in multiphase flow than to the hydrodynamics. As part of a previous Joint Industry Project (JIP), “Paraffin Deposition Prediction in Multiphase Flowlines and Wellbores” a literature search on gas-liquid two-phase heat

transfer was carried out by Oklahoma State University (OSU). In this JIP it was concluded that improvements in the prediction of convective two-phase heat transfer are an immediate need.

TUPDP and TUFFP are jointly sponsoring a project to improve prediction of convective heat transfer coefficients under multiphase flow conditions. In previous reports, modification of the multiphase paraffin deposition flow loop for verifying flow patterns at elevated pressures and obtaining extensive heat transfer data was presented.

Analysis of two-phase heat transfer measurements has been completed. A total of 75 test results were analyzed, including 5 tests for single-phase liquid, 6 tests for single-phase gas, 8 tests for vertical bubbly flow, 27 tests for vertical intermittent flow, 9 tests for vertical annular flow, 10 tests for horizontal stratified flow and 10 tests for horizontal annular flow. However, the 12 tests for horizontal intermittent flow could not be validated due to inaccurate fluid temperature measurements. Experimental convective heat transfer coefficients were calculated from the experimental data for each test. The sensitivity of the experimental data was analyzed with respect to the superficial liquid and gas velocities and reasonable results were obtained. An experimental database was generated for the model evaluation.

The modeling study is still underway. Since the Advisory Board meeting in May 2001, preliminary model development for stratified flow, horizontal intermittent flow, bubbly flow, annular flow and vertical intermittent flow has been completed. Model evaluation is still underway. Model predictions for convective two-phase heat transfer coefficients were compared against the experimental database. Good agreement, in general, was obtained from the comparison, although it was found that model modifications were necessary for some flow patterns, including laminar liquid film annular flow and high gas velocity stratified flow.

Comparisons of heat transfer data with predictions from the heat transfer correlations recommended by OSU are also under way. This study is planned for completion in September 2001. The final results will be presented at the next Advisory Board meeting.

Future Meetings

The next Tulsa University Paraffin Deposition Projects (TUPDP) Advisory Board meeting will be held on October 4, 2001 in New Orleans, Louisiana. The Advisory Board meeting will be held in the Pan-American Life Conference Center which is directly across the street from The Whitney, a Wyndham Historic Hotel. The meeting will be held in the Orleans Room. A continental breakfast will be served starting at 8:00 a.m. with the Advisory Board meeting commencing at 8:30 a.m. Lunch will be served in the Bayou Rooms. The reception will be held in 56°, The Whitney's Lobby Restaurant, at 6:00 p.m.

A workshop on utilizing the Wax Deposition Model will be held on October 5th in the Pan-American Life Conference Center. The workshop will also be held in the Orleans Room. A continental breakfast will be served at 8:00 a.m. with the workshop

commencing at 8:30 a.m. Lunch will be served in the Bayou Rooms. The workshop will adjourn at 4:00 p.m.