# Paraffin Deposition Progress Report
# April – June 2003

***Single-Phase Studies***

The single phase paraffin project is now in the final phase using the Cote Blanche Island (CBI), CBI is the third fluid used in testing, South Pelto and Garden Banks are the previously used fluids. A fourth fluid, Caratinga, from Petrobras, is ready to be loaded in the facility after CBI testing is completed at the end of this summer.

During the CBI phase, the heavier fluid loaded in the single phase facility, a total of 3 tests have been conducted to study the effect of the oil and glycol inlet temperature difference ($\Delta T$) on the deposition phenomena. Three cases, 45ºF, 30ºF and 15ºF $\Delta T$ were chosen with the same basic conditions: 85ºF oil inlet temperature, 1500 BPD oil flow rate and 2000 BPD glycol flow rate. Higher wax thickness was measured for the 30ºF $\Delta T$ test, a trend that does not match our experience with the previous fluids (Garden Banks and South Pelto) where a fairly linear relationship was found between the thickness and $\Delta T$. To study the effect of flow rate, a total of 6 tests were run. The test conditions were 85ºF oil inlet temperature; 55ºF glycol inlet temperature; 2000 BPD glycol flow rate and oil flow rates of 200, 600, 900, 1200, 1500, and 1650 BPD. No important dependence of the thickness on flow rate was found for the CBI fluid. On the other hand, to study the time effect, three tests at the same conditions were run but with different duration (92 hours, 24 hours, and 3 hours). The CBI data is limited to laminar flow regime due to its higher viscosity and oil pump limitations.

Another long run and oil inlet temperature effects remain to be studied before switching to the Caratinga fluid. Interesting results have been found during the data processing of the CBI fluid; the high viscosity of the oil plays an important role in the deposition which is slightly different from the previous fluids; from the experimental data, CBI exhibits an almost linear deposit thickness growth, small increases in the pressure drop and oil outlet temperature due to deposition and a very soft wax layer.

After last Advisory Board Meeting, a couple of trial runs using temperature tracers were conducted by increasing the temperature of the oil using the electrical trimmer. The idea was to track the velocity of the fluid along the test section and try to calculate the thickness by the corresponding changes in velocity (the volumetric flow rate being constant). However, due to data acquisition limitations these tests were not successful. Temperature tracers were chosen as an attempt to work with tracers without altering the composition of the oil.

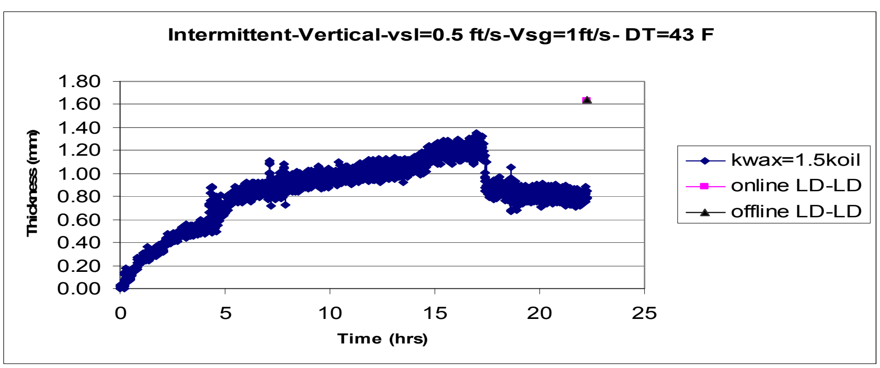
A test for wax layer movement detection was conducted in the small scale loop using South Pelto as the test fluid. The idea was to run a normal deposition test with an isothermal pipe section at the end of the test section. This isothermal section was bypassed and sampled according to a pre-established sampling schedule during a 5 days test. No visual evidence of a wax layer inside the isothermal section was found. DSC analyses of the samples are still being conducted for further conclusions.

The modeling of the phenomena was picked up by studying and summarizing the existing models. Discussion about the validity of the equilibrium or non-equilibrium condition is underway. Unification of the experimental data format and processing of the whole fluids was done for easier and fair manipulation of the information. A comparison between the previous models was done for comparison purposes against the existing experimental data. The inclusion of the thermal diffusion term and its effect on the results is also a short term objective in the project.

***Multiphase Studies***

After the Advisory Board Meeting in April, we ran two 24-hour repeat experiments with Garden Banks condensate; one horizontal and one vertical. The horizontal test was an annular test with superficial liquid velocity of 0.2 ft/s and superficial gas velocity of 30 ft/s. The vertical test was an intermittent test with superficial liquid velocity of 0.5 ft/s and superficial gas velocity of 1.0 ft/s. The temperature difference between glycol and oil was 42ºF for both experiments. The thicknesses from both online and offline LD-LD were reproducible. The thicknesses for both original and repeat annular tests were about 0.9mm from offline and 0.5 mm from online LD-LD. The thicknesses for both original and repeat intermittent tests were both greater than 1 mm from offline and online LD-LD. Significant improvement in data was obtained with new start-up procedure.

For the vertical intermittent test, the wax thickness from the temperature data was calculated with a thermal conductivity of wax 1.5 times greater than the oil thermal conductivity ($k_{wax}=1.5k_{oil}$). All measured and calculated thicknesses from temperature data and LD-LD are shown in the figure below.




***Average Wax Thicknesses for Intermittent Vertical Flow Test.***

After 18 hrs, due to fluctuations in gas flow rate, there was a shift in calculated thickness plot.

Due to trimmer problems, testing time was delayed. Testing has now resumed and will be completed by the next Advisory Board Meeting.

***Three-Phase Studies***

Since last Advisory Board Meeting, four single phase cold finger tests have been conducted using South Pelto at different ΔTs. Each test was done with the same duration (24 hr) and ΔTs of 15°F, 30°F and 45°F. These tests did not show repeatable results due to the difficulty in maintaining flow rates evenly at the four cold finger cells. Flow meters were installed on the cold finger device in order to properly adjust the flow rates. Effect of ΔT ranging from 15°F to 45°F, effect of water salinity – 35g/l and fresh water – and effect of aging, with periods of time ranging from 3 hrs to 24 hrs, are now being evaluated with the three oils and condensate samples. Most of these tests are expected to be complete by the Advisory Board Meeting.

Below is a preliminary test matrix for cold finger testing. The first six tests are designed to serve as a baseline with single phase oil tests, under conditions similar to the deposition facilities. Test number 001 failed and tests number 002, 003 and 004 have been done and will be repeated after the flow meters are in place.

Concerning water salinity, it is planned to have two cold finger cells with salt water and two cells with fresh water simultaneously in a test, with the same water cuts, in order to better compare the deposition within the same test conditions.

| Test # | Fluid | Water | rpm | Oil T | CF T | ΔT | Hours |
|---|---|---|---|---|---|---|---|
| 001 | **SP** | - | 500 | 105 | 75 | **30** | 24 |
| 002 | **SP** | - | 500 | 105 | 75 | **30** | 24 |
| 003 | **SP** | - | 500 | 105 | 90 | **15** | 24 |
| 004 | **SP** | - | 500 | 105 | 60 | **45** | 24 |
| 005 | **GB** | - | 500 | 105 | 90 | **15** | 24 |
| 006 | **GB** | - | 500 | 105 | 75 | **30** | 24 |
| 007 | **GB** | - | 500 | 105 | 60 | **45** | 24 |
| 008 | **SP** | 20 | 500 | 105 | 90 | **15** | 24 |
| 009 | **SP** | 40 | 500 | 105 | 90 | **15** | 24 |
| 010 | **SP** | 60 | 500 | 105 | 90 | **15** | 24 |
| 011 | **SP** | 80 | 500 | 105 | 90 | **15** | 24 |
| 012 | **SP** | 20 | 500 | 105 | 75 | **30** | 24 |
| 013 | **SP** | 40 | 500 | 105 | 75 | **30** | 24 |
| 014 | **SP** | 60 | 500 | 105 | 75 | **30** | 24 |
| 015 | **SP** | 80 | 500 | 105 | 75 | **30** | 24 |
| 016 | **SP** | 20 | 500 | 105 | 60 | **45** | 24 |
| 017 | **SP** | 40 | 500 | 105 | 60 | **45** | 24 |
| 018 | **SP** | 60 | 500 | 105 | 60 | **45** | 24 |
| 019 | **SP** | 80 | 500 | 105 | 60 | **45** | 24 |
| 020 | **GB** | 20 | 500 | 105 | 90 | **15** | 24 |
| 021 | **GB** | 40 | 500 | 105 | 90 | **15** | 24 |
| 022 | **GB** | 60 | 500 | 105 | 90 | **15** | 24 |
| 023 | **GB** | 80 | 500 | 105 | 90 | **15** | 24 |
| 024 | **GB** | 20 | 500 | 105 | 75 | **30** | 24 |
| 025 | **GB** | 40 | 500 | 105 | 75 | **30** | 24 |
| 026 | **GB** | 60 | 500 | 105 | 75 | **30** | 24 |
| 027 | **GB** | 80 | 500 | 105 | 75 | **30** | 24 |
| 028 | **GB** | 20 | 500 | 105 | 60 | **45** | 24 |
| 029 | **GB** | 40 | 500 | 105 | 60 | **45** | 24 |
| 030 | **GB** | 60 | 500 | 105 | 60 | **45** | 24 |
| 031 | **GB** | 80 | 500 | 105 | 60 | **45** | 24 |

| | |
|---|---|
| **SP** | **South Pelto** |
| **GB** | **Garden Banks** |

| | |
|---|---|
| **Cell A** | **Salt** |
| **Cell B** | **Fresh** |
| **Cell C** | **Salt** |
| **Cell D** | **Fresh** |

**Water Phase Equipment**

All equipment and instrumentation have been installed for the water phase studies. The water phase piping is now complete on the multiphase flow loop. Electrical hookup of the pump and instruments is currently underway. Modifications to the data acquisition interface will take place this summer after all multiphase tests with Garden Banks condensate are completed. Pressure testing and commissioning is anticipated by early Fall. Our objective is to run two deposition tests with water before freezing weather occurs in 2003.

***Small Scale Studies***

At the April Advisory Board Meeting, test results for test Wax2003-10 were reported. This test was conducted using South Pelto in the 1.5" test section, with an oil temperature of 105°F, a glycol temperature of 75°F, a Reynolds number 6300 and a test duration of 27 days.

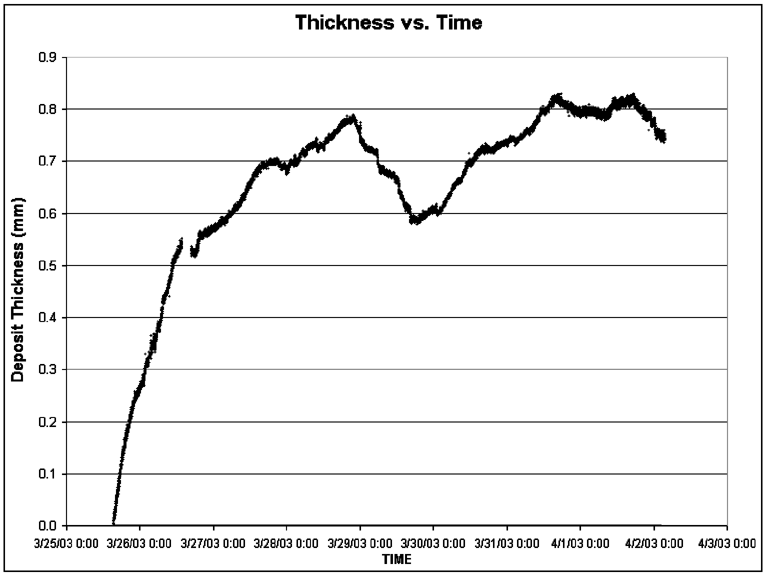
After the Advisory Board Meeting, two other tests using South Pelto were completed in the 1.0" and 0.5" test sections using the same Reynolds number of 6300 to investigate the deposition process under same Reynolds number conditions. The tests numbers are Wax2003-17 and Wax2003-19. The duration for both tests was 7 days and other test conditions are shown below.

1. **Deposition test: 1.0" test section**

Test conditions are shown below.

| | |
|---|---|
| Test number | Wax2003-17 |
| Facility | Small scale 1.0" |
| Fluid | South Pelto |
| Flow pattern | Single phase turbulent |
| Flow direction | Co-current |
| Duration | 7 days |
| $\Delta$T | 30 F |
| Oil inlet temperature | 105 F |
| Oil flow rate | 570 BPD |
| Oil velocity | 6 ft/sec |
| Glycol inlet temperature | 75 F |
| Glycol flow rate | 1500 BPD |
| Reynolds Number | 6300 |
| Shear Stress | 14 Pa |

The evolution of thickness versus time can be seen below. The thickness reached 0.8 mm after 7 days and was verified after shut-down and sampling. Thorough analysis is being conducted to find out if the decrease in thickness could be a result of shear stripping or other process fluctuations..

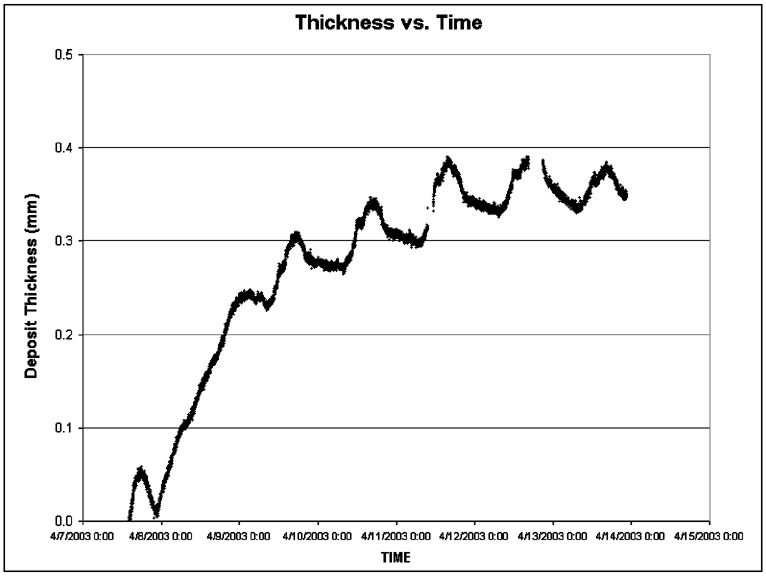



**2. Deposition test: ½" test section**

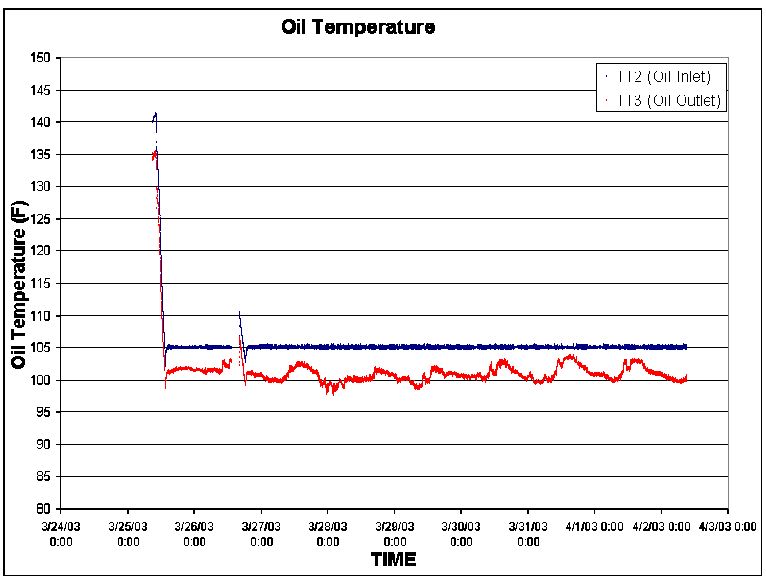
Test conditions are shown below with a Reynolds number of 6300.

| | |
|---|---|
| Test number | Wax2003-19 |
| Facility | small scale 0.5" |
| Fluid | South Pelto |
| Flow pattern | single phase turbulent |
| Flow Direction | Co-current |
| Duration | 7 days |
| $\Delta$T | 30F |
| Oil inlet temperature | 105F |
| Oil flow rate | 333BPD |
| Oil velocity | 10.3 ft/sec |
| Glycol inlet temperature | 75F |
| Glycol flow rate | 1500BPD |
| Reynolds number | 6300 |
| Shear stress | 43 Pa |

The evolution of the calculated thickness from pressure drop measurement is shown below and reached 0.35 mm after 7 days. Cycles on the wax thickness can be seen and here too, thorough data processing is underway to investigate the possibility of shear stripping.




The two previous tests were successful. However, temperature oscillations for the oil outlet temperature were observed and correlations were found with the ambient temperature as can be seen on the graph below from test Wax2003-17.




Extensive troubleshooting was performed to detect which part of the facility was influenced by ambient temperature. The checked points included RTD/thermocouple temperature transducers, Micro Motion flow meter, oil pump controls and other equipment.

The inlet temperature probe was finally moved closer to the jacketed section. The temperature fluctuations were eliminated. The most probable cause is that heat was picked up in the developing section, exposed in full sun during daytime hours.

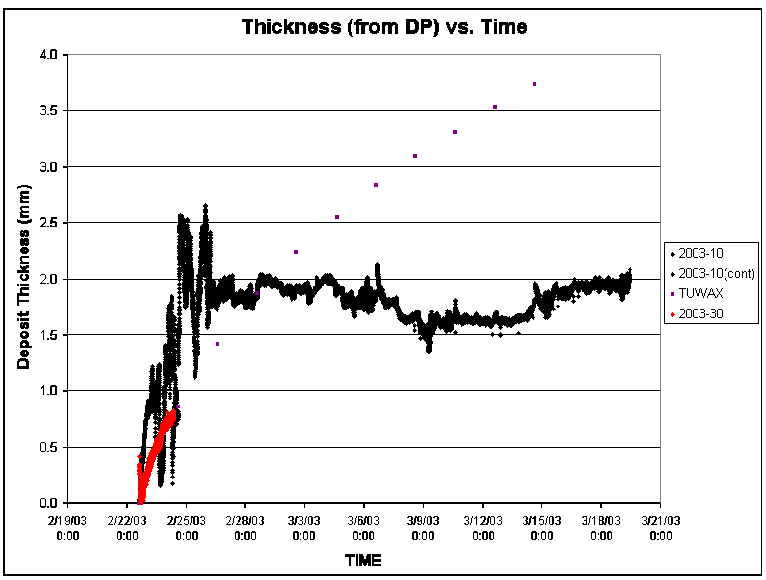
After the position of the inlet temperature probe position had been moved, three repeat tests were done in all three sections to check the repeatability of the data after this major change in the facility. The results are presented below.

### 3. Test Wax2003-30 (repeat test in 1.5" test section)

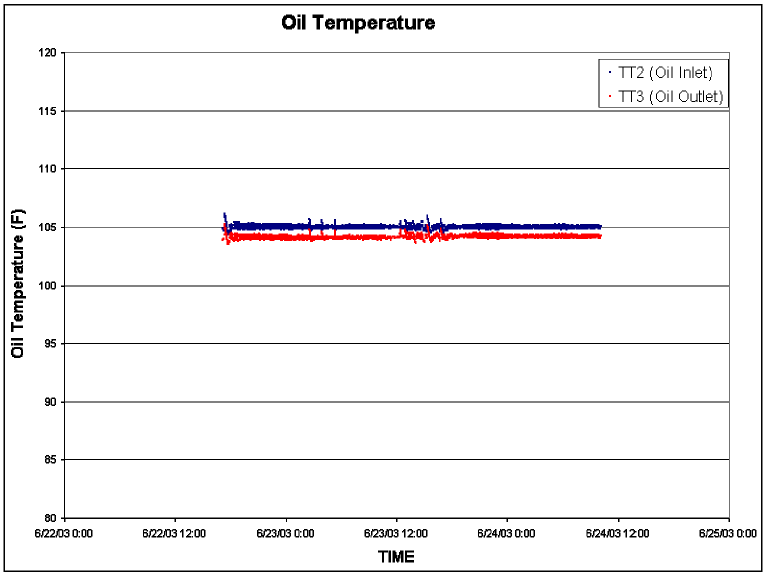
This is a repeat test of Wax2003-10 in the 1.5" test section. The test conditions are shown below. This repeat test was run for only two days.

| | |
|---|---|
| Test number | Wax2003-30 |
| Facility | small scale 1.5" |
| Fluid | South Pelto |
| Flow pattern | single phase turbulent |
| Flow direction | Co-current |
| Duration | 2 days |
| $\Delta$T | 30F |
| Oil inlet temperature | 105F |
| Oil flow rate | 850 BPD |
| Oil velocity | 3.9 ft/sec |
| Glycol inlet temperature | 75F |
| Glycol flow rate | 1600 BPD |
| Reynolds number | 6300 |
| Shear stress | 5.6 Pa |

The calculated thickness is shown below and matches quite well the initial slope of the previous deposition test. The dotted line is a simulation of this test with the TUWAX software.




This repeat test shows that the temperature oscillations have been eliminated; however wax buildup still can not be calculated from the heat transfer method. The chart below shows the oil inlet and outlet temperatures for test Wax2003-30.

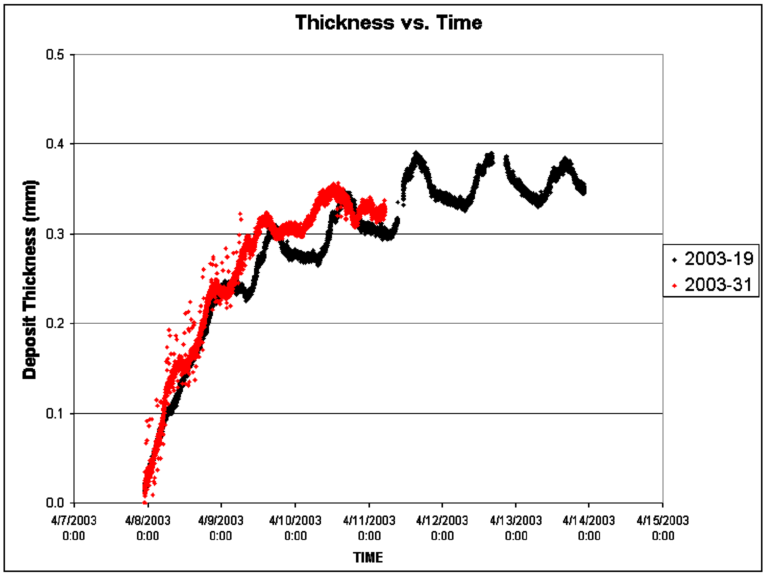



### 4. Test Wax2003-31 (repeat test in 0.5" test section)

This is a repeat test of Wax2003-19 in the 0.5" test section. The test conditions are shown below. The only difference in test conditions is that this test lasted 5 days rather than 7 days as in test Wax2003-19.

| | |
|---|---|
| Test Number | Wax2003-31 |
| Facility | small scale 0.5" |
| Fluid | South Pelto |
| Flow pattern | single phase turbulent |
| Flow direction | Co-current |
| Duration | 5 days |
| $\Delta$T | 30 F |
| Oil inlet temperature | 105 F |
| Glycol flow rate | 330 BPD |
| Oil velocity | 10.3 ft/sec |
| Glycol inlet temperature | 75 F |
| Glycol flow rate | 1500 BPD |
| Reynolds number | 6300 |
| Shear stress | 43 Pa |

The thickness is shown below. We can see the data for this test was repeatable. The temperature fluctuations were also eliminated on this test.

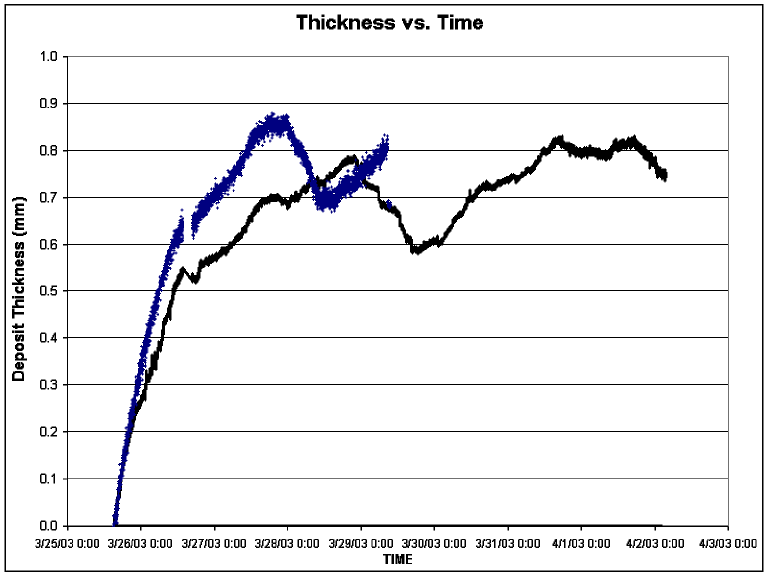



### 5. Test Wax2003-32 (repeat test in 1.0” test section)

This is a repeat test of Wax2003-17 in 1.0” test section. The test conditions are shown below. The only difference in test conditions is this test lasted 3.5 days rather than 7 days as in test Wax2003-17.

| | |
|---|---|
| Test number | Wax2003-32 |
| Facility | small scale 1.0" |
| Fluid | South Pelto |
| Flow pattern | single phase turbulent |
| Flow direction | Co-current |
| Duration | 3.5 days |
| $\Delta T$ | 30 F |
| Oil inlet temperature | 105 F |
| Oil flow rate | 570 BPD |
| Oil velocity | 6 ft/sec |
| Glycol inlet temperature | 75 F |
| Glycol flow rate | 1500 BPD |
| Reynolds number | 6300 |
| Shear stress | 14 Pa |

The thickness calculation shows a very similar trend as the former test, but the thickness seems to peak earlier than former test. This could be due to the higher inlet temperature (since the probe has been moved) than for the previous test, resulting in a higher driving force. A similar observation can be made with the 0.5” repeat test, but could not be seen with the 1.5” test section (possibly because the repeat was only 2 days in the 1.5” test section).




## 6. Conclusion and Future Plan

These tests were conducted under the same Reynolds number of 6300. Tests seemed repeatable even though the inlet temperature probe has been moved. The tests in the 1.0" and 0.5" test section show a saw tooth growth as opposed to the tests in the 1.5" test section.

Investigation is under way to verify a possible shear stripping effect in these section with a higher shear stress of 14 Pa and 43 Pa, as opposed to 5.6 Pa in the 1.5" test section.

The test matrix was discussed at the April 2003 ABM with the technical committee and then reviewed with the participants. As a result of the input received, the following tests will be conducted:

1. Run water-oil tests with the South Pelto black oil using water cuts of 25 and 50% to gain insight as to the impact of water on the deposition process prior to running gas-oil-water tests,
2. Run tests with the South Pelto black oil using the 0.5, 1.0 and 1.5 inch flow loops at constant velocity and constant shear to better understand how to scale-up the results,
3. Run tests with the Garden Banks condensate using the 0.5, 1.0 and 1.5 inch flow loops at the best scaling parameter determined in step 2 above,
4. Run a long term test (27 days) with the Garden Banks condensate to understand the effects of shear stripping and aging,
5. Run water-oil tests with the Garden Banks condensate using water cuts of 25 and 50% to gain insight as to the impact of water on the deposition process,
6. Run tests with a heavy oil, Cote Blanch Island, using the 0.5, 1.0 and 1.5 inch flow loops at constant Reynolds Number, velocity and constant shear to better understand how to scale-up the results, and
7. Run a long term test (27 days) with the Cote Blanch Island heavy oil to understand the effects of shear stripping and aging.

Tests 1 through 5 will be completed during the $3^{rd}$ and $4^{th}$ quarters of 2003 while tests 6 and 7 will be conducted during the $1^{st}$ quarter of 2004.

Discussions are underway on possible ways to quantify the respective shear stripping, insulation and depletion effects on our flow loop tests. A couple long term tests with changes in $\Delta T$ during the experiment, as well as changes in the initial oil charge, backed up by specific DSC analyses could provide answers on the relative importance of insulation, shear stripping and depletion effects in flow loop tests. This could have a significant impact on system design should the wax growth in turbulent flow turn out to be limited by the shear stripping effects. If finalized, these tests could be run between phase 1 and 2 of the above test matrix.