**TUPDP Phase VII Proposed Scope of Work and Deliverables**

April 1, 2019 – March 31, 2022

**Project 1– Wax Deposition under Two-Phase Oil-Gas at Different Flow Patterns**

**Objectives**

The general objectives of this study are to develop the more reliable model for two phase (oil-gas) flow by integrating the deposition behavior observed from the available experimental data and to elucidate the impact of flow patterns in two-phase oil and water flow on wax deposition mechanism.

**Project Description**

This project will be conducted in two parallel tracks. It is well known that the flow patterns influence the behavior of wax deposition in multiphase flow. In the past, TUPDP successfully has experimentally studied the wax deposition in slug and stratified flow of Garden Banks oil and natural gas. The experimental data are essential to develop a more reliable mechanistic model for wax deposition in two-phase flow.

* Track 1: More reliable and comprehensive model for two phase flow will be developed by integrating the deposition behavior observed from the systematic experimental approach. This will be accomplished by utilizing the data of two-phase flow studies such as Chi (2018), Rittirong (2014), Kilincer (2003), Manabe (2001) and Matzain (1999).
* Track 2: Understanding of two-phase (oil and water) flow wax deposition will enhance our fundamental understanding and improve the ability of the systematic study of more complex cases (multiphase flow of oil-gas-water). The experimental data will be essential to develop a more reliable mechanistic model for wax deposition in multiphase flow. This project will be a continuation of the previous project (Chi, 2018) in TUPDP. The multiphase flow loop facility will be used for oil-water wax deposition in different flow patterns. Experiments will be conducted to investigate the effect of flow patterns, heat transfer on oil-water wax deposition process. Hydrodynamic tests will be conducted first utilizing the high pressure sapphire window cell to determine the flow pattern, pressure drop, liquid holdup and any other required parameters. Once the hydrodynamic conditions for flow patterns are determined, the wax deposition experiments at different heat transfer and shear will be conducted.

**Project 2– Mechanistic Study of Turbulent Flow Wax Deposition**

**Objective**

The objective of this study is microscopic visual investigation of the wax deposition at the fluid-deposition interface under different shear rates. The possible outcomes of this study will enhance our understanding of mechanisms of wax deposition under flowing conditions and serve as a basis for the development of better deposition models or closure relationships.

**Project Description**

High uncertainties are common in wax deposition models. The inherent problems with available wax deposition models are:

* **Can the models be used as reliable predictive tools for field cases?** - Available models use fitting parameters which were obtained from limited laboratory data set. A model cannot be used as predictive tool unless those fitting parameters values can be pre-determined in reasonably accurate manner based on known inputs. The absence of adequate closure relationships in available models prevent the utilization of them as reliable predictive tools. With substantial degree of empiricisms, up-scaling of wax deposition models to field cases is difficult due to diversity of the produced fluids and operating conditions. The models need to have stronger physical basis to reduce uncertainties.
* **Physical mechanisms by which shear force affect deposition are still unclear** - Various hypotheses, which require satisfactory physical validation, have been proposed. The hypotheses affect the mathematical formulation of the model and all associated closure relationships. Consequently, the model formulations tend to be empirical and not mechanistic. Microscopic visualization investigation of wax deposition is aimed to elucidate the physical mechanisms due to shear (low and high) and drive towards reliable closure relationships in the existing and new models.

A step-by-step process from static to laminar and finally to turbulent flow conditions is required given the limited references on experimental setup and procedures. Since the initiation of this project in fourth quarter of 2013, TUPDP has completed project scoping, establishment of experimental setup, procedure, and semi-quantitative analysis technique, and completion of static test experiments. A dynamic visualization setup has been built and incorporated into TUPDP mini loop facility. This setup will be modified with high resolution camera and new cell and used for microscopic experiments using model oil (mineral oil – food grade wax mixture). Semi-quantitative analysis will be applied to the visualization results as applicable.

**Project 3 – TUWAX Software Maintenance and Development**

**Objectives**

The objectives of this project are to maintain TUWAX software compatibility and functionality and to improve TUWAX software by updating and incorporating additional paraffin deposition models and simulation algorithms

**Project Description**

TUWAX software is a paraffin deposition simulator developed by Tulsa University Paraffin Deposition Projects (TUPDP). It is capable of simulating single-phase and multiphase mixture paraffin deposition e.g. average deposit thickness and wax fraction as a function of axial length and time. The software is composed of graphic user interface written in MS-Excel VBA for parameter input and result visualization, while the main simulation modules are developed with FORTRAN language. WAXPro Steady State model has several modules, subroutines and functions. The main modules are momentum, heat transfer, pipeline integration, PVT properties and numerical methods. Continual maintenance is required in order to ensure the program functionality and run effectively without any bugs. Moreover, further improvements by incorporating additional paraffin deposition models, simulation algorithms and experimental results into the program are necessary. The proposed TUWAX software maintenance and development can be summarized as follows:

**Project 4 – Experimental Investigation into the Role of Gelation on Wax Deposition to Guide Scale-up and the Design of Wax Inhibitor Treatment Programs**

**Objectives**

The general objectives of this study are:

* To develop a reliable wax deposition modeling workflow, involving experimental characterizations at lab-scale and modeling approaches, to predict wax deposition at field scale.
* To improve the current practice for wax inhibitor treatment design using the aforementioned workflow and to achieve reliable quantitative recommendations with the improved testing and/or scale-up methods

**Project Description**

It has been well understood that wax deposition on the inner wall of oil transportation pipelines is driven by radial molecular diffusion of dissolved wax molecules. As a result, contemporary wax deposition models are largely developed based on mathematical descriptions of molecular diffusion. However, it should be noted that diffusion-based wax deposition models present significant limitations when applied to study the effect of wax inhibitors on wax deposition as the altered rheology of the oil and deposit due to additives is not captured. Because of the same limitation, existing wax deposition models, in general, cannot predict the reduction of wax deposit with increasing shear. To model the effect of shear and wax inhibitors on wax deposition, the wax deposition model needs to link the shear imposed by the fluid with the rheology and the gelation process in the vicinity of the pipe wall. Preliminary investigations jointly conducted by SWTS and Chevron have shown that combining rheological characterization with wax deposition modeling is promising to enhance wax deposition models for the application of wax inhibitor treatment design. In order to advance the understanding of the role of gelation on wax deposition and develop more reliable methodologies to predict wax deposition rates under various conditions and with chemical treatments, an experimental investigation into the role of gelation on wax deposition is proposed.

**Proposed Program**

*Experimental:*

Step 1: Wax deposition experiments under controlled temperature driving force and wall shear stress (rate) to form the incipient deposit layers for rheological characterizations

* With and without wax inhibitor
* Different geometry
	+ Microscopic flow cell – the goal is not to quantify deposit mass but use this technique as a visual aid to observe morphological change induced by chemicals.
	+ Flow loop (with different pipe diameter, start with the 1-in loop)

Step 2: Characterization of the incipient deposit gelation solid fraction under the same controlled shear stress using a rheometer.

*Simulation:*

Explore tweaks in TUWAX to incorporate the effect of the solid fraction of the incipient deposit and predict the change in the wax deposition rate due to addition of chemicals or varying shear conditions in the experimental programs.

**Project 5 *– Thermal removal of wax deposits***

**Objective**

The general objective of this study is to provide guidelines in terms of temperature target to remove wax deposits by heat tracing the wall and by circulating a warm fluid.

**Motivation**

Operators are considering more and more single line with electrical heating to manage wax and hydrates, without any facility to deploy operational pigging. In order to limit the power utilization, an idea could be to maintain the temperature below the WAT during nominal production and to periodically heat the line to remove the deposit.

With no electrical heating, another remediation method could be to circulate hot fluid in the line. The question for both cases is: what is the minimum temperature to remove the deposit?

It is well known that the WAT of wax deposits is significantly higher than the WAT of the oil. Therefore, it could be foreseen to bring the deposit at a temperature much higher than the WAT of the oil. This is implicitly associated with a removal based on a melting process of the deposit.

A few feedbacks from field and a few observations in laboratory cells seem to indicate that the deposit removal can be achieved at a temperature even lower than the WAT of the oil. In these cases, the removal may be explained by a ‘disbondment’ of the deposit from the wall.

**Project description**

It is proposed to form different wax deposits in loop under single flow conditions and to detect the onset temperature above which a removal process is observed.

A typical series of tests is as follows:

* Wax deposit formation in loop
	+ Record of the evolution of the pressure drop during deposit formation
	+ Recover the wax deposit for characterization (wax content, WAT)
* Repeat the wax deposit formation to investigate the deposit removal by wall heating
	+ Check the repeatability by comparing the evolution of the pressure drop during formation
	+ Increase the wall temperature step by step
		- Detection of the removal process from the evolution of the pressure drop
* Repeat the wax deposit formation to investigate the deposit removal by fluid heating
	+ Check the repeatability by comparing the evolution of the pressure drop during formation
	+ Increase the fluid temperature step by step
		- Detection of the removal process from the evolution of the pressure drop