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Heavy Viscous Oil Pressure, Volume, and Temperature

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ABSTRACT

Understanding the physical properties of heavy viscous oil systems is a key aspect of a successful exploitation strategy and production design. However, heavy viscous oils present challenges in fluid property and pressure-volume-temperature (PVT) measurements. First, it is always a challenge to remove water from a heavy oil sample (<20 API) due to its near-water density (10 API) and high viscosity (slow separation). Second, it is a challenge to obtain accurate, consistent, and repeatable viscosity data since the heavy oil viscosity measurements are affected by sample handling, storage, cleaning procedures, as well as the selection of viscometers and their corresponding experimental procedures. Third, it is a challenge to reasonably predict the viscosities of heavy oil-diluent blends and the reliability of predictions by various viscosity models depends, to some extent, on the development of a reliable property database that covers a broad range of composition and operating conditions.

The objectives of this project were to evaluate current techniques in heavy viscous oil handling and dewatering, to evaluate current practices in heavy viscous oil (dead and live) viscosity measurements, to recommend laboratory procedures of live heavy oil reconstitution and validation and to generate a reliable viscosity and density database of heavy oil and solvent mixtures.

Three dead heavy oil samples ranging from 20 to 11 API gravity and with viscosities ranging from 100 to 5,000 mPa·s at 310.9 K [100 degF] were selected for this project. Using these heavy oil samples, first, a systematic study on three common heavy oil dewatering procedures ─ centrifugation, the addition of demulsifiers and distillation ─ were performed. Their impact on dewatered oil properties was evaluated and compared. Based on that comparison, recommendations and guidelines for laboratory heavy oil dewatering procedures were provided. Second, the project validated the applicability and limitations of three types of viscometers commonly used in heavy oil viscosity measurements including a capillary viscometer (CV), an electromagnetic viscometer (EMV) and a rheometer (Rheo). A systematic comparison on both dead heavy oil and live heavy oil sample measurements performed by the different viscometers was carried out at a series of temperature and pressure conditions. Based on the viscometer validation and comparison results, recommendations regarding viscometer selection and practical procedures to be used in both dead and live heavy oil viscosity measurements were provided. Third, procedures for live heavy oil reconstitution and validation were provided and validated. Finally, a reliable heavy oil-solvent viscosity data set that will support viscosity model validation and development was generated.

This systematic study provides insight into the effects of three common heavy oil dewatering procedures, provides insight into the applicability of three typical viscometers for heavy viscous oil viscosity measurements, provides guidelines and procedures on heavy oil handling, reconstitution and validation, and provides a database of heavy oil/solvent mixtures at a range of temperature and pressure conditions.

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Project Final Report

Subcontract #: 08121-2201-02

"Heavy Viscous Oil Pressure, Volume, and Temperature"

1. INTRODUCTION

1.1 Background

Understanding the physical properties of heavy viscous oil systems is a key aspect to a su ccessful exploitation strategy and production design. However, heavy viscous oils present challenges in fluid property and pressure-volume-temperature (PVT) measurements. The first challenge is in obtaining a representative and clean heavy oil sample. Here clean is defined as solids and water contents (BS&W) are less than 1 percent by weight (wt%), which is a typical export specification on stock tank oil and hence represents a limiting water content being used in reservoir, flow line, and facilities design. Such low solids and water contents are also required to ensure accurate fluid property measurements (Zabel, et al., 2010). The challenge lies mainly in the near-water density and high viscosity of the heavy oil, which can result in very slow separation (Memon et al., 2010). The second challenge is in obtaining accurate, consistent, and repeatable viscosity data, especially as viscosity is considered the most important fluid property in heavy oil production, processing, and transportation (Miller et al., 2006). Accuracy and repeatability of heavy oil viscosity measurements can be affected by sample handling, storage, and cleaning procedures. In addition, the selection of viscometers and their corresponding experimental procedures can also impact the accuracy of viscosity measurements. A third challenge is the ability to reasonably predict the viscosity of heavy oil-diluent blends. While this partially depends on the previously mentioned requirement for reliable viscosity data from properly prepared, representative samples, the real difficulty lies in the ability to predict the blend fluid properties. Empirical models that depend on heavy oil-diluent property databases have been successfully applied (Barrufet and Setidarma, 2003, Yarranton et al., 2012), although their application is limited to the samples and operating conditions captured in the database used to generate the models. Compositional based viscosity models (Schmidt et al, 2005, Motahhari et al., 2013) offer the ability to predict blend viscosities based on tuning to a limited data. However, experience with these relatively new models is limited. The range and reliability of the predictions can only improve over time as heavy oil-diluent property databases expand. Thus, reliable blend viscosity prediction depends, to some extent, on the development of a reliable property database that covers a broad range of composition and operating conditions.

To address the challenges in heavy oil fluid property and PVT studies, the Heavy Viscous Oil Pressure, Volume, and Temperature project was initiated by RPSEA and led by the program champion Jefferson Creek (Chevron). After a bidding process, this project was awarded to Schlumberger to carry out all experimental and investigation work. A Working Project Group (WPG) teamed with heavy oil expertise from Chevron, Shell, ConocoPhillips, Marathon, Statoil, BP and Schlumberger was established to provide technical support and guidance on this project. This is a 3-year program and the contract was signed in 2011.

1.2 Objectives

The objectives of this study are, as follows:

- Evaluation of current techniques in heavy viscous oil dewatering.
- Evaluation of current practices in heavy viscous oil (dead and live) viscosity measurements.
- Recommendation of best practices to handle heavy oil, and laboratory methods for heavy oil dewatering and viscosity measurements.

- Study of the impact of solvent on viscosity change of heavy viscous oil.
- Recommendation of procedures of live heavy oil reconstitution, viscosity and density measurements.

2. SAMPLE INFORMATION

Three types of heavy viscous oils were specified for this project:

- Low viscous oil (LVO): viscosity @ 311K (100°F) = 50-200 mPa·s
- Medium viscous oil (MVO): viscosity @ 311K (100°F) = 500-1000 mPa·s
- High viscous oil (HVO): viscosity @ 311K (100°F) = 4,000-10,000 mPa·s

The LVO and MVO samples were supplied by Chevron in July 2012, and the HVO sample was supplied by Schlumberger in April 2013. The three samples were all clean oils (i.e. BS&W <1%) and their detailed characterization results are described in Section 5.1. These three dead oil samples were used throughout the whole project.

3. SCOPE OF WORK

To achieve the project goals, the main technical tasks of this project were defined as follows:

- Task 5: Dead heavy oil dewatering
- Task 6: Dead heavy oil viscosity measurement
- Task 7: Live heavy oil reconstitution and dead oil/solvent mixture preparation
- Task 8: Live heavy oil, dead oil/solvent mixture viscosity and density measurements

Initially, the plan was to use heavy viscous live oil samples in the project but due to unavailability of proper live samples in the given timeline, the scope of work was changed to use of dead heavy viscous oils as base fluid samples instead. The revised scope of work was finalized with the approval of RPSEA and the WPG members in July 2012. The detailed scope description and specified deliverables for each sub-task, including the scope defined in July 2012 and adjustments made during project execution to meet project objectives, are as follows.

3.1 Task 5 – Dead Oil Dewatering

This task was proposed to qualify four dewatering methods to determine which method(s) would be feasible for dewatering heavy viscous oils. The dewatered oils should be suitable for laboratory PVT tests and property analyses. Prior to carrying out all experiments the WPG agreed to remove the dewatering method with an absorbent or membrane process from the investigation list due to a limited timeline and budget. The remaining three dewatering methods that were systematically verified were centrifugation, mini-distillation and addition of chemical demulsifiers. As per directions received from the WPG, sample handling and dewatering tasks was concentrated on dead oil only.

3.1.1 Heavy Viscous Oil/Water Emulsion Preparation

Due to the unavailability of field emulsion samples, an additional sub-task was to prepare water-in-heavy viscous oil emulsions for use in validating the dewatering processes. This included:

a. Preparation of synthetic brine solutions for all selected oils.

b. Preparation of water-in-oil emulsions using selected oils and their corresponding brine solutions. The target water cut was set as 30 percent of total fluid by volume.
c. Stability tests of prepared emulsions.
d. Water content measurement of prepared emulsions by Karl-Fischer method.

3.1.2 Dewatering with Centrifugation Process

The scope of work specified in July 2012 included:

a. Initial water content measurement by Karl-Fischer method of received dead oil sample
b. Water and sentiment (BS&W) analysis of received dead oil by ASTM D1796
c. Dead oil dewatering with centrifugation process. An allowance was made for two to three trial tests to tune centrifugation parameters
d. Water content measurement with Karl Fischer after the dewatering process with centrifugation
e. BS&W measurement with ASTM D1796 method after dewatering process with centrifugation
f. Preparation of an agreeable procedure or guideline for dewatering of dead oil with centrifugation process

As clean oils were used in this study, the BS&W test in "item e." above was not required and it was removed from the testing list. To understand the impact of the dewatering process on dewatered sample properties additional tests were added, including:

g. Compositional analysis of dewatered sample by gas chromatography (GC)
h. Viscosity measurement of dewatered sample by a high temperature and pressure capillary viscometer at three temperatures and three pressures for each temperature
i. Density measurement of dewatered sample by a high pressure Anton-Paar Densitometer at three temperatures and three pressures for each temperature

3.1.3 Dewatering with Mini-distillation Process

The scope of work specified in July 2012 included:

a. Min-distillation at about 105°C with two-traps to capture light ends. An allowance was made to perform this process 2-3 times to optimize the conditions of the distillation process
b. Water content measurement with Karl Fischer after the dewatering process with mini-distillation
c. BS&W measurement with ASTM D1796 method after the dewatering process with distillation
d. Development of an agreeable procedure or guideline for the dewatering of dead oil with the mini-distillation process

As clean oils were used in this study, the BS&W test on the dewatered sample in "item c." above was not required and it was removed from the testing list. To understand the impact of the dewatering process on dewatered sample properties additional tests were added, including:

e. Compositional analysis of dewatered sample by GC
f. Viscosity measurement of dewatered sample by a h igh temperature and pressure capillary viscometer at three temperatures and three pressures for each temperature
g. Density measurement of dewatered sample by a high pressure Anton-Paar Densitometer at three temperatures and three pressures for each temperature

3.1.4 Dewatering with Chemical Demulsifier Process

The scope of work specified in July 2012 included:

a. Viscosity measurements of clean dead oil with a capillary viscometer at about (293K) 20°C, base viscosity measurement to check the impact of chemical demulsifier on the viscosity
b. Preparation of synthetic brine at typical formation water salinity or composition
c. Create a heavy oil emulsion at 50% water cut (or whatever water cut is achievable) under bench-top laboratory conditions with a stirrer at room temperature (bottle test)
d. Water content measurement with Karl-Fischer on the created emulsion
e. Dewatering with two commercially available water-based chemical demulsifiers. Mix the chemical demulsifiers with dead oil under bench top conditions and separate free water by decanting.
f. Water content measurement with Karl Fischer on the 'clean' sample
g. Viscosity of 'clean' dead oil obtained from chemical demulsification process with capillary viscometer at 293K (20°C), base viscosity measurement to check the impact of chemical demulsifier on the viscosity

To better understand the impact of chemical demulsifiers on the dewatered sample properties, additional tests were added:

h. Compositional analysis of dewatered sample by GC
i. Viscosity measurement of dewatered sample by a high temperature and high pressure capillary viscometer at three temperatures and three pressures for each temperature
j. Density measurement of dewatered sample by a high pressure Anton-Paar Densitometer at three temperatures and three pressures for each temperature

3.2 Task 6 – Dead Oil Viscosity Measurements.

Dead oil viscosity measurements were performed with three types of viscometers: an electromagnetic viscometer (EMV), a capillary viscometer (CV) and a rheometer (Rheo) with bob and cup mode (replaced parallel plate mode after discussions during the 3rd WPG meeting). The detailed sub-tasks and deliverables are as follows:

a. Viscosity measurements on three viscosity standards (variation with temperature) with an EMV at three temperatures and three pressures as a reference
b. Viscosity measurements on three viscosity standards with a CV (variation with temperature and pressure) as a reference
c. Viscosity measurements on three viscosity standards with a rheometer (variation with temperature) at two low temperatures only for a reference
d. Viscosity measurements of clean dead oil sample using an EMV at three temperatures (311K, 366K, and 422K or 100°F, 200°F, and 300°F) and three pressure points above atmospheric pressure
e. Viscosity measurements of clean dead oil sample using a CV at three temperatures (311K, 366K and 422K or 100°F, 200°F and 300°F) and three pressure points above atmospheric pressure
f. Viscosity measurements of clean dead oil sample using rheometer at two temperatures (80°F and 130°F) and at various shear rates

g. Preparation of a report on Task 6 that includes a guideline on variations of viscosity measurements with each type of viscometer and a guideline or brief procedure on e ach measurement methodologies used.

The scope above was followed except for a change to "item f". Viscosity measurements by rheometer were performed at three temperatures (293, 333 & 373K or 68, 140 & 212°F) instead of two temperatures to allow a plot of viscosity vs. temperature for comparison purpose.

3.3 Task 7 – Live Oil Reconstitution and Dead Oil/Solvent Mixture Preparation

This task included:

a. Preparation of synthetic gas to a given composition or use methane as the solution gas for live oil reconstitution
b. Recombination of synthesis gas and 'clean' dead oil sample at specified gas-oil-ratio (GOR)
c. Restoration and homogenization of recombined live oil sample for several days (as agreed upon)
d. Measurement of the GOR of the reconstituted live oil sample with a low GOR apparatus (low volume cylinders, no/minimum dead volume), measurements to be made three times
e. Compositional analysis of flashed gas
f. Compositional analysis of flashed liquid and live reconstituted sample, including API
g. Constant composition expansion (CCE) testing at one temperature using specially designed heavy oil PVT cell
h. Preparation of one synthetic solvent e.g., HEPTOL (40% toluene + 60% heptane) (Note: recommended two solvents, to be done if the budget allows)
i. Recombination of reconstituted live oil sample with 1 solvent, 1 concentration
j. Restoration and homogenization of live oil sample and solvent mixture (2 solvent, 1 concentration) for five days
k. Preparation of a Task 7 report with guidelines

For "item g", the CCE/bubble-point pressure (P_{sat}) tests were performed on each prepared live sample at the same three temperatures as used in dead/live oil viscosity measurements instead of at one temperature. For "items h-j", WPG discussed and agreed to revise them as follows:

l. Selection of two solvents: one aromatic and one paraffinic solvent
m. Determination of the asphaltene precipitation onset concentration using the paraffinic solvent and each heavy oil sample at 323K (50°C) to define the highest solvent concentration to be used.
n. Preparation of dead oil/solvent mixtures: three solvent concentrations for each solvent; six mixtures for each oil; 18 mixtures in total
o. Homogenization of prepared mixtures

3.4 Task 8 – Live Oil, Dead Oil/Solvent Mixture Viscosity and Density Measurements

Live oil viscosity measurements using two types of viscometers, EMV and CV, were proposed. A comparison was to be made between viscosities measured by both types of viscometer in order to recommend a 'best practice' guideline for viscosity measurements.

Proposed measurements were:

a. Viscosity measurements of live recombined sample using an EMV at three temperatures and 3-5 single phase pressure points (pressure sweep).
b. Viscosity measurements of live recombined sample using a CV at three temperatures and 3-5 single phase pressure points (pressure sweep).
c. Viscosity measurements of heavy oil sample + solvent, using an EMV at two temperatures and 5 pressure points with one solvent (one concentration only).
d. Viscosity of heavy oil sample + solvent using CV at two temperatures and 5 pressure points with one solvent (one concentration only).
e. Density measurements of clean sample using a high pressure Anton-Paar densitometer at three temperatures and 3 - 5 pressure points (pressure sweep), pressure ranging from above reservoir pressure through bubble-point pressure to stock tank oil condition.
f. Density measurements of heavy oil sample + solvent using high pressure Anton-Paar densitometer at two temperatures and 5 pressure points with two solvents (one concentration only).
g. Preparation of a Task 8 report documenting the recommended guidelines for measuring heavy viscous oil viscosity and the resulting data set of experimental results.

To well meet the objectives of this task, the actual scope of work of performed under this task are listed as follows:

a. Viscosity measurements of reconstituted live oil samples using both an EMV and a CV at three temperatures and 3 - 5 single phase pressures
b. Density measurements of reconstituted live oil samples using a high pressure Anton-Paar densitometer at three temperatures and 3 - 5 single phase pressures
c. Viscosity measurements of prepared dead oil/solvent mixtures using a CV at three temperatures and three single phase pressures
d. Density measurements of prepared dead oil/solvent mixtures using a high pressure Anton-Paar densitometer at three temperatures and 3 single phase pressures

4. EXPERIMENTAL

The sub-sections below describe the details of the methodologies and instruments that were used in this project.

4.1 Sample Restoration

Proper sample restoration was the key to preserving sample integrity as much as possible over the course of the entire project. The three heavy viscous oil samples were delivered in several steel cans for each sample. To avoid any property differences between the samples stored in different cans, after they were conditioned at 323K (50°C) for one hour, the oils belonging to the same sample were transferred to a large container for blending. After homogenization, one liter of the blended oil was transferred to a one-liter cylinder which was then pressurized to 3.45 MPa (500 psia) and maintained at 323K (50°C). The remaining blended oil was transferred to several one-liter jars and properly sealed. When a sub-sample was required for a test it was taken from the pressurized cylinder which was refilled with the oil stored in the one-liter jars as necessary. This procedure helped prevent the loss of light/intermediate components during each heating and sub-sampling process and prevented the oil oxidization over time that would have occurred if it had been stored in a can at ambient conditions.

4.2 Sample Characterization

4.2.1 Compositional Analysis

Compositional analysis of the gas sample was performed on a gas chromatograph (GC) – 7890A Natural Gas Analyzer (Agilent, US). Compositional analysis of the liquid component was performed by a temperature programmed GC – 6890 System (Agilent, US). The liquid GC utilizes Schlumberger DBR proprietary technology to determine hydrocarbon liquid carbon number distribution. The C30+ fraction of the liquid was determined by an internal standard method, and its accuracy was ± 2.5 wt%.

All GCs were on a monthly preventative maintenance schedule, and calibration was performed prior to all tests. Column compensation cleanliness checks and bracketing reference runs were also completed to assure the quality of GC results.

4.2.1 Stock Tank Oil Property Measurement

The molecular weight (MW) of a st ock tank liquid was measured by the freezing-point-depression method using a Cryette WR Wide Range Cryoscope (Precision Systems Inc., US).

The water content of the stock tank liquid was measured by the Karl-Fischer titration method using a 756 Coulometer Karl-Fischer Titrator (Metrohm, Switzerland).

The water and solid content was analyzed by the ASTM method of D1796. The boiling point distribution of each oil sample was determined by the simulated distillation method – ASTM D7169. The total acid number (TAN) of each oil sample was analyzed by the ASTM method WK26624.

4.3 Heavy Oil Dewatering

The three dewatering methodologies, selected from methods that are widely used and which can easily be set up in industrial laboratories, were centrifugation, addition of demulsifiers combined with gravity or centrifugal separation, and distillation.

4.3.1 Water/Heavy Oil Emulsion Preparation

A common emulsion sample preparation procedure, which was suggested by DeepStar/Chevron and used in laboratories at CSM (Colorado School of Mines), NTNU (Norges teknisk-naturvitenskapelige universitet) and IFPEN (Institut Francais du Petrole Energies Nouvelles), was followed (with only necessary modifications) in this project. The emulsion preparation procedure referred to is outlined as follows: The crude oil was homogenized by stirring for 2.5 minutes at 8000 rpm using a Virtis Cyclone homogenizer. Water was slowly added during the first minute of homogenization. The emulsions were prepared with up t o 30 percent of water and the resulting water-in-oil emulsions were aged for a minimum of 24 hour s at ambient temperature and pressure conditions prior to being used in measurements.

For this study, a high speed homogenizer DIAX 900 made of Heidolph Instruments (US) was used to prepare water-in-oil emulsions containing 30 percent water. About 800 mL of emulsion was prepared per batch for each dead oil sample. Mixing time for different samples varied but adding the water very slowly under continuous mixing was emphasized as the key to obtaining stable emulsions. After the water had been added, the oil/water mixture was mixed at 8000 rpm for no more than three additional minutes to avoid over heating the sample. Once homogenized, the emulsion was properly stored in a glass jar with a sealing cap. To minimize any possible component vaporization or oxidization, the gap between the sample and the jar cap was filled with helium. To ensure that the dewatering method comparison is meaningful, the prepared water-in-oil emulsions have to be very stable over time. Hence, each prepared emulsion was kept at room temperature under 1-g gravity segregation for at least five days. The emulsion stability was examined by visual observation, micro-imaging and via further water content analysis.

4.3.2 Dewatering by Centrifugation

Two centrifuges were used for dewatering by centrifugation. One was a low speed machine (Centrifuge Model 225, Fisher Scientific, US) with a maximum relative centrifugal force (RCF) of 4,109, and the other was a high speed machine (3K3OH, Sigma, Germany) with a maximum RCF of 40,695 (20,000 rpm) and a highest working temperature of 40°C.

A 50 mL sub-sample of an emulsion was warmed to 40°C and transferred into a centrifuge tube for centrifugation at various speeds. Residual water content of the dewatered sample was measured by the Karl-Fischer method.

4.3.3 Dewatering by Distillation

Distillation is a physical separation process of separating a liquid mixture's component substances by the difference in each component's boiling point without chemical involvement. The set-up for a simple, classic and universal distillation apparatus, namely "Dean-Stark" apparatus (Dean and Stark, 1920), is shown in Figure 1, and it was the method used in this study. The apparatus essentially consists of three parts:

i. A heating flask equipped with an outlet tube through which the distilled vapor is emitted.
ii. A condenser that consists of two tubes of different diameters placed one within the other. The vapor is condensed in the smaller tube by a stream of coolant counter-flowing through the larger tube.
iii. A graduated receiver in which the condensed vapor is collected and where its volume can be measured.

The Dean Stark procedure involved placing a known amount of water-in-oil emulsion in the flask and then gently heating it with proper mixing. During heating, the components with the lowest boiling point, usually water in the prepared water-in-heavy oil emulsions, vaporized out of the flask first and then condensed and accumulated in the receiver tube. Once water vaporization was completed, i.e., no additional water condensed in the receiver, the process was ended. The collected water was weighed for mass balance calculations and if possible, any hydrocarbons condensed on top of the oil-water interface were weighed and recovered back into the distillation flask. For good homogenization, the dewatered oil was blended with the recovered components at 50°C and under adequate mixing using a magnetic mixing stirrer for two hours.

The distillation in this study was carried out at atmospheric pressures rather than under vacuum to reduce the amount of light and intermediate component vaporization. Distillation temperature was controlled at a temperature just above water boiling temperature or as low as possible to minimize hydrocarbon vaporization (105°C to 130°C).

4.3.4 Dewatering by Adding Demulsifiers

This demulsification method involves applying an appropriate chemical demulsifier to promote destabilization of the emulsion, followed by a gravitational or centrifugal settling process. A typical demulsifier usually contains surface-active components, a carrier solvent and flocculants. When the demulsifier solution is added to a water-in-oil emulsion, the surface-active components migrate to the oil/water interface where they help to weaken and then rupture the interface to enhance water droplet coalescence.

The chemical demulsifier dewatering process used in this study is outlined as follows:

i. Decide the chemical and concentration to be used
ii. Add 100 mL emulsion into glass bottles

iii. Check for initial water content of the stable emulsion by Karl-Fischer method
iv. Add a known volume of demulsifier solution using a syringe
v. Agitate the mixture by hand or use a machine
vi. Allow the water to settle down by placing the bottles in a temperature controlled water bath or oven for two to four hours
vii. Observe water settling process and determine residual water content when no more water settles down
viii. Apply centrifugal force if necessary
ix. Check final residual water content by the Karl-Fischer method

In this study, Baker Hughes and M-I SWACO, Schlumberger helped search for demulsifiers that were successfully applied in dewatering field samples. Supplied chemicals for each water-in-oil emulsion are listed as follows:

i. Three demulsifiers DMO 8633, DMO 277, and DMO 4348, were recommended for the high viscous oil by Baker Hughes
ii. Two demulsifiers, DMO 7030 and DMO 7050, were recommended for the medium viscous oil by Baker Hughes
iii. Two demulsifiers, EB-8725 and EB-8834, were recommended for the light viscous sample by M-I SWACO, Schlumberger

A Roto-Shake Genie rocker (Scientific Industries, Inc.) was used in mixing the chemicals with emulsions. The mixtures were settled by gravity at 80°C/90°C for two to four hours and then allowed to further settle at room temperature for at least another eight hours. If a residual water content of less than one percent by weight could not be achieved using all available chemicals at their optimum concentrations, the dewatered oil was transferred to a centrifuge tube and then centrifuged at 40°C (the highest working temperature of the machine) and under 5000 rpm (8,217 RCF) for one hour. The resultant further dewatered sample was analyzed for water content.

4.4 Heavy Oil Viscosity Measurement

The objectives of this task were to evaluate and compare commercially available viscometers typically used in heavy oil viscosity measurements and to provide a recommendation on viscometer selection and corresponding measurement procedures for heavy oils.

Three well established viscometers were chosen for this study: a capillary viscometer (CV), an electromagnetic viscometer (EMV), and a rheometer (Rheo). Viscosity measurements were performed on three dead and three live oil samples at temperatures over the range of 293.2K to 422.0K and at various pressures above their respective saturation pressures.

4.4.1 Viscosity Measurement by Capillary Viscometer

Capillary viscometers (CV) have been widely used in heavy oil viscosity measurements by various researchers (Alboudwarej et al., 2007, Frauenfeld et al., 2002, Abivin et al., 2012, Alshmakhy and Maini, 2012). A CV, which was developed and assembled in DBR Technology Center, a division of Schlumberger Canada Limited, was used for the viscosity measurement. The CV has an operating temperature range of 283 to 470 K (10 to 200°C) and a pressure range of atmospheric to 68.9 MPa (10,000 psia). The CV is able to measure viscosities in the range of 1 to 500,000 mPa·s.

As shown in Figure 2, the CV setup consists of two 50 mL high pressure cylinders connected to a capillary coil and a differential pressure transducer that monitors pressure drop across the capillary coil. The capillary coils usually are 1.5 - 6.1 m (5 - 20 feet) in length, 0.05 - 0.216 cm (0.02 - 0.085 inches) in diameter, and have a coil diameter of ~ 23 cm (9 inches). The temperature of the test fluid is measured by a temperature sensor, which is attached to the outside of the capillary coil. Two pumps were connected to

the cylinders on the hydraulic side. Both the static system pressure and the flow rate of the fluid in the coil were measured by the pumps.

A single phase fluid (live or dead) is charged to one of the cylinders to start the test. The two pumps are used to transfer the fluid through a capillary coil, from one cylinder to the other, at a specified volumetric flow rate (Q). The corresponding pressure drop (ΔP) across the coil is measured using the differential pressure transducer. For a Newtonian fluid, the viscosity can be calculated using the following equation for laminar flow as follows,

$$\mu = \frac{\Delta P}{Q} \times k \tag{1}$$

Where,

μ	=	Viscosity of the fluid
ΔP	=	Pressure drop across the capillary coil
Q	=	Flow rate of the fluid through the capillary coil
k	=	Calibration coefficient of the capillary coil

When making viscosity measurements, several factors need to be considered to ensure that the flow in the capillary obeys the fundamental assumptions of the above equation. The Reynolds Number, *Re*, for the flow should be less than 2100. Also, Dean's Number, *De*, (Dawe, 1973) should be below six to ensure that radial velocity components are negligible. In addition, the capillary coil should be sufficiently long to ensure that end effects will be negligible

Capillary Viscometer Calibration. The calibration coefficient of the coil, *k*, was determined by the above equation using a viscosity standard with known viscosity. In the calibration process, the flow rate versus the pressure drop across the capillary coil for a viscosity standard was measured at three pressures and at a given temperature. The viscosity of the standard at atmospheric pressure was obtained through the linear correlation between measured viscosities and pressures. The coefficient of the coil at the testing temperature was then determined by matching the measured viscosity to the given standard value at atmospheric pressure. Due to the lack of any viscosity standards with viscosity data as a f unction of pressure, the calibration coefficient for each capillary coil was calibrated at different temperatures. Typically, the coefficient, *k*, had a linear correlation with temperature.

Capillary Viscometer Viscosity Measurement. The sample was transferred isobarically to an evacuated viscometer cylinder (1) with the hydraulic side filled and then connected to the capillary viscometer system. The system dead volume was minimized by filling the second system cylinder's hydraulic side and the differential pressure (ΔP) transducer legs outside the heated chamber with water. The evacuated system was then isobarically filled from cylinder 1, and then the fluid was mixed by transferring it back forth between the cylinders until any flashed vapors during initial charging were re-dissolved and the fluid was homogeneous. Homogeneity was usually achieved within three mixing cycles and was indicated by consistent ΔP measured across the entire sample volume.

Fluid viscosity was measured at three flow rates and at the given test temperature and pressure and an average value was used. Capillary coils with various diameters were used to ensure that the pressure drop across the coil was less than 551.6 kPa (80 psia), and that flow rates did not exceed 300 mL/hr. Normally, 30 - 40 mL of sample was required to execute the measurement.

4.4.2 Viscosity Measurement by Electromagnetic Viscometer

The Electromagnetic Viscometer (EMV) is another commercial viscometer used in heavy oil viscosity measurements (Alshmakhy and Maini, 2012, Kariznovi et al., 2012, Alomair et al., 2011). The EMV used in this study was the VISCOlab PVT with a Cambridge Viscosity SPL440 sensor. It is a high temperature,

high pressure viscometer designed to measure the viscosity of gas, gas condensate, and petroleum fluid samples. Developed by Cambridge Applied Systems, the EMV is widely used in petroleum laboratories. It is capable of continuous operation up to 138 MPa (20,000 psia) over a temperature range from 268 to 458 K (32 to 365°F). The SPL440 system can be configured as a stand-alone system or as an in-line component within the visual PVT phase behavior system. With a variety of available pistons, the EMV is capable of measuring viscosity over the range of 0.02 to 10,000 mPa·s. The VISCOlab PVT only requires a small volume of sample, approximately 12 mL per measurement.

The EMV sensor relies on electromagnetic principals to drive the slow oscillation of a metal piston inside a measurement chamber, as shown in Figure 3. Tracking the piston location and travel time gives a direct measure of the fluid sample viscosity as the piston shears the fluid. For each viscosity measurement, the test fluid is charged to the vessel and the piston is surrounded by fluid. Subsequently, the piston is moved inside the measurement chamber by imparting a force on the piston using two electromagnetic coils inside the sensor body. After traveling the length of the chamber, the piston is returned to its starting location by reversing the magnetic field of the electromagnet. The motion of the piston inside the chamber is impeded by viscous flow around the annulus between the piston and the measurement chamber wall. Viscosity is determined by measuring the piston transit time for a complete cycle of piston movement and comparing the measured transit time to times obtained using calibrated standards.

EMV Calibration. The EMV utilized two calibration levels, a primary and a secondary level of calibration. Calibrations were carried out using Cannon™ mineral oil viscosity standards. The primary calibration was a high end viscosity calibration in which the magnetic force on the piston was adjusted so the cycle time would be within two percent of the desired maximum (26 seconds) at the piston's rated full scale viscosity. Secondary level calibrations (high and low end) would produce mathematical corrections without a change to the magnetic drive levels.

EMV Viscosity Measurement. A set of EMV pistons covering different viscosity ranges were used. Each EMV piston was calibrated and validated prior to use. The operating procedure involved charging the heavy oil sample isobarically into the evacuated measurement chamber at the desired test temperature and pressure. During charging the sample was transferred from a sample cylinder isobarically to the evacuated, upright viscometer. The "volume to fill" the viscometer was measured during filling, and that volume was purged through the viscometer before initiating measurements and setting the device to its 45 degree measuring position. The viscosity was then monitored and system was isobarically purged in "volume to fill" steps until the indicated viscosity between steps was constant. Once charged, any additional temperature and/or pressure steps for the fluid could be completed as long as they were monophasic with no risk of solids precipitation.

4.4.3 Viscosity Measurement by Rheometer

Rheometers (Rheo) are widely used in various rheology studies to measure the stress strain relationships of fluid. They have been applied to viscosity measurement for heavy oil, especially extra heavy oil viscosity measurements (Abivin et al., 2012, Bazyleva et al., 2010). The rheometer utilized in this study was the ViscoAnalyser Var 100 by Reologica Instruments, which is shown in Figure 4. The rheometer was only used for dead oil viscosity measurements since it is not capable of live oil liquid viscosity measurements in the under-saturated region. While the rheometer is equipped with a high-pressure cell, a gas cap is required above the sample liquid during high-pressure viscosity measurement. Any gas used in filling the gas cap could dissolve into the sample and thus alter the sample composition and its corresponding liquid viscosity. Two modes, an open cup and bob mode and a parallel plate mode, are available for viscosity measurement at ambient pressure. The cup and bob mode was proposed to be used in this study due to the expected measured viscosity range. It is also considered the most popular rheometer set up due to its direct measurement of torque and requirement for constant shear rate (Macosko, 1994). The testing temperature ranges from 263 to 423 K (14 to 302°F). The applied torque

can be controlled between 0.0005 and 50 mN·m, and viscosities as low as 2 - 3 mPa·s can be measured. The required sample volume for the open cup and bob arrangement is about 25 mL.

The fundamental principle behind the rheometer is given below:

$$\tau = \mu \cdot \dot{\gamma}$$

Where,

μ	=	Viscosity of the fluid
τ	=	Shear stress
$\dot{\gamma}$	=	Shear rate

This can be derived from the fluid moving along two parallel plates as shown in Figure 5. The upper plate is moving and the lower plate is fixed. When a fluid is moving along the solid boundary, it will incur a shear stress ($\tau = dF/dA$) on the boundary. For all Newtonian fluids in laminar flow, the shear stress is proportional to the shear rate ($\dot{\gamma} = dV_x/dy$) in the fluid and the viscosity is the constant of proportionality. However, for non-Newtonian fluids, this is no longer the case since the viscosity is not constant with changes in shear rate. However, past experience (Abivin, 2012) suggested that all of the heavy oil samples to be used in this study were expected to be Newtonian over the planned test conditions.

Rheometer Calibration The system initial motor calibrations were completed by the supplier. The system temperature was measured in the heating jacket of the cup, and an offset to the measured point was attained by comparison to a 0.16 cm (1/16") thermocouple that was located in the annular space between the cup and bob. This offset was completed and incorporated into the software set-point by the supplier during setup and annual maintenance. The temperature offset was then checked and further adjusted by comparing calculated viscosities to listed values of two Cannon mineral oil viscosity standards at multiple temperatures over the temperature range of interest.

Viscosity Measurement The operating procedure involved loading the system with approximately 13 mL of fluid with a syringe at a slightly elevated temperature at which the viscosity was low enough to facilitate loading. At each defined test temperature, a shear rate sweep measurement was conducted over a range of shear rates. The shear rate sweep could be used to study the effect that shear has on the fluid, although it was expected to confirm the Newtonian behavior of the heavy oil samples.

4.5 Live Oil Reconstitution and Dead Oil/Solvent Mixture Preparation

4.5.1 Live Oil Reconstitution

Live heavy oil reconstitution with a specified gas-oil ratio was prepared by charging a pre-calculated amount of heavy oil into a cylinder and then adding a pre-calculated amount of gas that had been boosted to 13.8 MPa (2000 psia) at room temperature. The mixture was heated to 423K (302°F) in order to significantly reduce the oil viscosity and thus ensure thorough mixing. The mixture was pressurized to a high pressure to ensure that the mixture was in single phase. The mixture was homogenized at this temperature and pressure conditions for a minimum of five days using a continuous rocking mechanism. Upon homogenization, a sub-sample was taken for GOR validation by a regular/direct flash test.

4.5.2 Live Oil Validation

A direct flash GOR test, an alternative procedure designed to measure the gas-oil ratio of oils with 15° API gravity and lower, is schematically illustrated in Figure 6. The live sample was stored in a sample vessel (or in a PVT cell). A flask was connected to the sample vessel and a GOR apparatus. The flask was placed in a temperature controlled ultrasonic bath, and the ultrasonic bath was maintained at 333K (140°F) to lower the oil viscosity in order to facilitate the gas evolution from the viscous oil. The GOR

apparatus was at ambient temperature and pressure conditions. During flashing, the live sample was isobarically displaced from the vessel and flashed into the flask. The flashed oil was collected in the flask and the flashed gas filled the dead volume of the set up and then the GOR apparatus. An ice bath trap between the flask and the GOR apparatus was used to collect any carry-over components that tend to vaporize at 333K (140°F) but condense at room temperature. Once the flash was complete, i.e. when no further gas evolved, the ultrasonic bath and ice bath were removed and the system was allowed to stabilize at ambient conditions. The flashed oil in the flask was subject to mass measurement, density measurement using a hand-held Anton-Paar densitometer and compositional analysis by a liquid gas chromatograph (GC). The flashed gas was quantified by volume using a gas meter and analyzed by a gas chromatograph. Any liquid that condensed in the ice trap was quantified by mass and subject to compositional analysis if in sufficient quantity. The composition of the original live sample was calculated from the analyzed composition and mass of each phase.

To accurately measure low GOR values (less than 100 SCF/STB), a Low GOR apparatus, developed in DBR, was used instead of a normal GOR apparatus.

4.5.3 Dead Oil/Solvent Mixture Preparation

In this project, mixed xylenes were used as a representative aromatic solvent and n-heptane as a representative paraffinic solvent were used in the preparation of dead oil/solvent mixtures. For one oil sample, three oil/solvent ratios were used for a given solvent. The mixture with a specified oil-solvent ratio was prepared in a closed system by charging a pre-calculated amount of oil/solvent into a thoroughly cleaned and evacuated PVT cell, which is described in Section 2.4. The oil and solvent were prefilled into high pressure cylinders prior to use. The amount of oil/solvent charged into the cell was calculated according to its volume and density at charging temperature and pressure conditions. The mixture was heated to 373K (212°F) in order to reduce the oil viscosity and thus enabling thorough mixing. At elevated temperature, the mixture was still maintained in single phase by increasing system pressure to a pressure higher than the fluid's bubble-point pressure. The mixture was then homogenized at the high temperature and high pressure conditions for a minimum of eight hours utilizing continuous mixing. Upon homogenization, a sub-sample of the mixture was transferred into a high pressure cylinder for viscosity and density measurements.

4.5.4 Heavy Oil PVT Cell

A DBR heavy oil PVT cell was used in heavy oil-solvent mixture preparation and live heavy oil saturation pressure (P_{sat}) measurement. This cell is mercury-free, equipped with floating piston and viewable using cathetometer to determine volume. Different from a standard DBR PVT cell, the heavy oil cell is equipped with an enhanced magnetic mixer that allows effective mixing for oils with viscosities up to 1,000 mPa·s at test conditions.

As shown in Figure 7, the main body of the heavy oil cell consists of a Pyrex tube housed inside a steel shell and equipped with vertical tempered glass plates that permit visual observation of the tube contents. The Pyrex glass tube, which is 15.2 cm (6.0 inches) long and has an internal diameter of 3.2 cm (1.26 inches), has an effective working volume of approximately 120 mL. A floating piston is mounted inside the Pyrex tube, allowing for mercury-free operation.

Both the volume and the pressure of the fluid under investigation are controlled by a variable volume displacement pump that allows injection or removal of a transparent hydraulic fluid. The hydraulic fluid is also connected to the outer steel shell to maintain a balanced (minimal) differential pressure on the Pyrex tube. Equilibration of the fluid under investigation is achieved by a magnetically coupled impeller mixer that is mounted on the bottom end cap of the cell. This bottom end cap is designed to shield the cell contents from any magnetic effects/flux and provide for charging and sampling of the test fluid.

The Heavy Oil PVT cell is mounted inside a temperature controlled, forced air circulation oven. The cell temperature is measured by a platinum resistance temperature detector (RTD) and displayed on a digital indicator that has an accuracy of 0.1°C (0.2°F). Cell pressure is monitored by a calibrated digital Heise pressure gauge accurate to ± 0.1 percent of full scale. The maximum operating pressure and temperature of the Heavy Oil PVT system are 34.5 MPa (5,000 psia) and 523K (482°F) respectively.

4.5.5 Bubble-point Pressure (P_{sat}) Measurement

A P_{sat} test was initiated by charging a known volume of live fluid into a heavy oil PVT cell at test temperature and a pressure much higher than P_{sat}. Fluid density was measured at the initial charging conditions and the initial mass of the fluid in the cell was calculated. While maintaining the fluid in the single-phase region, it was then isothermally expanded to a lower pressure. Total system volume was measured after equilibration and this volume was used to calculate the single-phase density at this pressure. The procedure was repeated a number of times until the bubble point pressure was reached. Pressure was then further reduced by selected pressure intervals into the two-phase region and at each pressure point the vapor and liquid phases were equilibrated. Phase volumes were measured and plotted as a function of pressure. The intersection of the single phase and two-phase lines in the P-V plot, and visual observations of the first bubbles through the PVT cell were used to define the bubble-point.

5. RESULTS AND DISCUSSIONS

5.1 Sample Characterization Results

Properties of the selected three heavy oil samples ─ low viscous oil (LVO), medium viscous oil (MVO) and high viscous oil (HVO) ─ were characterized and the results with corresponding characterization methods used are summarized in Table 1. Compositions of the heavy oils were analyzed by a liquid GC method and the results are given in Tables 2 - 7. Chromatography of these three oils is compared and plotted in Figure 8. The simulated distillation results of the three samples are plotted in Figure 9 and detailed data are included in Table A1 in the Appendix. Densities of each oil were measured at three temperatures (310.9, 366.5, and 422.0K or 100, 200, and 300°F and at three pressures (3.45, 6.89, and 10.34 MPa or 500, 1000, and 1500 psia). The obtained density data are listed in Tables 8 - 10 and correlations between densities versus pressure are plotted in Figures 10 - 12.

The LVO sample had an API gravity of 20, viscosity of 116 mPa·s at 310.9K/100°F and ambient pressure, and a total acid number (TAN) of 0.18 mg KOH/g. There were some light components and normal alkanes present in the LVO and 94.9 mol% of components were heavier than C7.

The MVO sample had an API gravity of 13, viscosity of 917 mPa·s at 310.9K/100°F and ambient pressure, and a TAN of 5.04 mg KOH/g. It was biodegraded oil with 99.9 mol% of components heavier than C7.

The HVO sample had an API gravity of 11, viscosity of 4660 mPa·s at 310.9K/100°F and ambient pressure, and a TAN of 1.05 mg KOH/g. It was also biodegraded oil with 99.9 mol% of components heavier than C7.

The solid and water contents (BS&W) of the oils, measured by ASTM D1796 method, were 0.20, 0.04, and 0.10 for LVO, MVO, and HVO, respectively. The water contents of LVO, MVO, and HVO, measured by Karl-Fischer method, were 0.14, 0.01, and 0.68 wt%, respectively, which were comparable with the BS&W data except for the slightly high HVO sample water content analyzed by Karl-Fischer method.

For all three oils, a linear correlation between measured density and pressure was obtained, and this correlation was used to extrapolate the density at atmospheric pressure conditions.

5.2 Results of Dead Oil Dewatering

As introduced in previous sections, the objectives of this task included qualifying three heavy oil dewatering methodologies, determining their impact on heavy oil properties, and recommending suitable method(s) for preparing heavy oil samples for laboratory fluid phase behavior and property measurements.

The selected three dewatering methodologies were centrifugation, distillation, and addition of demulsifiers combined with gravity or centrifugal separation. These three processes were systematically tested, evaluated and compared in terms of residual water content in the dewatered oil and impact of dewatering method on sample property and compositional change. In this project, residual water content less than one percent by weight (1 wt%) was set as the criteria to evaluate feasibility of the dewatering methods.

5.2.1 Results of Emulsion Stability Tests

Emulsions with about 30 percent water were prepared following procedures prescribed in Section 4.3.1. Three heavy viscous oils and their corresponding brine solutions, which are given in Table 11, were used in emulsion preparation. The brine solution formulas for the MVO and HVO samples were determined

referring to the actual field brine compositions, courtesy of Baker Hughes. For the LVO sample 3.5 wt% of sodium chloride (NaCl) solution was used due to lack of field water sample information.

Upon preparation of the emulsions, a stability check was performed for each by simply visual observation over time and by the micro-imaging method. The visual observation results are given in Figure 13, and the obtained micro-images of the emulsions are provided in Figure 14. There was no observable water settling on the tube bottom after the emulsions were allowed to separate under gravity at ambient conditions for over 20 and even up to 50 days. The micro-images further showed that the emulsified water droplets, which had an average droplet size much less than 10 µm, were distributed uniformly in the bulk oil phase, except for a few relatively large droplets. The water content of each prepared emulsion was also analyzed by Karl-Fischer method and found to be 28.5±1 wt%.

Once the prepared emulsions were confirmed to be stable, they were used in the next dewatering studies.

5.2.2 Results of Dewatering by Centrifugation

Feasibility of centrifugation method in demulsification of prepared emulsions was tested and the results are summarized in Table 12. The centrifugation temperature was set at the maximum working temperature of the centrifuge machine utilized, 313 K/40°C, to help reduce oil viscosity and increase density difference between water and oil. Centrifugation speed/force and spinning time were the two main remaining parameters adjustable for this method, and they were increased step by step whenever necessary.

The residual water content for the LVO sample emulsion could be reduced to less than one percent after spinning the emulsion at 15,000 rpm (24,652 RCF) for four hours. However, extra centrifugation force had to be applied for water separation from both the MVO and HVO sample emulsions. After spinning the water-in-MVO emulsion sample at 20,000 rpm (40,695 RCF) for 20 hours, its residual water content was reduced to be around one percent. The residual water content of dewatered HVO emulsion sample was about two percent after spinning under the same conditions. Another eight hours spinning was applied; however, the residual water content was just barely further reduced, most likely due to HVO sample's high viscosity and density. Therefore, it was concluded that, the residual water content could not be reduced to one percent solely by the centrifugation method for the water-in-HVO emulsion sample.

5.2.3 Results of Dewatering by Distillation

The distillation method was tested for each water-in-oil emulsion, and results are summarized in Table 13.

During trial tests, removing water from the HVO emulsion sample by the Dean-Stark distillation method failed because the oil splashed in the system during heating even though mild heating was used. To solve the problems, the heating pot was replaced by a magnetic heating plate, which allows oil mixing during heating by utilizing a magnetic mixer. Meanwhile, the flask body and the tube connecting the flask with condenser were heated by applying a heating tape and wrapped with an insulation layer to maintain the distillation temperature. In addition, a ceramic sieve was mounted within the outlet of the flask's top tube to prevent oil from splashing into it. After making these modifications successful water separation by Dean-Stark distillation was achieved for all three oil emulsions.

To minimize/reduce the amount of light/intermediate components vaporized with water, all distillation tests were performed at atmospheric pressure (94.5 kPa /13.7 psia), and the heating temperature was controlled as low as possible. The heating temperature was controlled at just slightly above 378K/105°C but less than 388K/115°C for the LVO and MVO samples. It was controlled at no greater than 398K/125°C for the HVO sample. However, despite taking these precautions a small amount of hydrocarbons inevitably vaporized with water in the sample tests. In this study, the hydrocarbon

vaporized then condensed in the receiver was collected and mixed back to the dewatered oil under continuous mixing by a magnetic mixer at 323K (50°C) for two hours.

As shown in Table 13, given sufficient time (5 - 11 hours for different amounts of emulsion in the feed) the residual water in the dewatered oil could be reduced to less than one weight percent.

5.2.4 Results of Dewatering by Adding Demulsifiers

Results of dewatering by adding chemical demulsifiers are summarized in Table 14, which includes the chemical name, optimum concentration, conditions used in gravity settling, conditions used in the further centrifugation process, and the final residual water content of dewatered samples. The key of demulsification by adding demulsifiers is to use the right chemical and at its optimized dosage. In this project, the chemicals were supplied by Baker Hughes (for MVO and HVO) and by MI-SWACO, Schlumberger (for LVO). Demulsifier candidates DMVO 7030 and DMO 7050 were suggested for dewatering the MVO emulsion samples; chemicals DMO 8633, DMO 277 and DMO 4348 were suggested for demulsification of the HVO emulsion samples, and emulsifier EB8834 was targeted as the best demulsifier for the LVO emulsion samples.

A concentration screening test was performed with a concentration stepwise increase of 200 - 300 ppm for each chemical candidate. Maximum concentrations were suggested to be around 1000 ppm by all suppliers. Once the proper chemical was added, the emulsion was mixed and then conditioned at 90°C for the MVO/HVO samples and at 80°C for the LVO sample for two hours, followed by a gravity settling period at room temperature (about 294K/21°C) of another 8 - 15 hours.

All of these chemicals were claimed to be capable of decreasing water content of corresponding field samples down to half percent; however, they were only able to reduce the water content of all laboratory prepared emulsions to 3 – 5 percent, even with their respective optimized chemical dosages provided in Table 14. Two reasons might possibly contribute to the differences in performance. First, the laboratory prepared emulsions were much stronger than the field emulsions. Second, the oil chemistry might have been altered to some extent during previous dehydration and cleaning processes prior to their delivery.

For this study, the samples were further dewatered after gravity settling with chemical addition by a mild centrifugation at 5,000 rpm (5,478 RCF) for one hour. The final water content was analyzed following this last step and is summarized in Table 14. The residual water content for the LVO and MVO samples was reduced to less than a half (0.5) percent, it was about one percent for the HVO sample.

5.2.5 Impact of Dewatering Method on Oil Property Change

To address the concerns on the impact of different dewatering process on the sample integrity change, the properties of dewatered samples, especially viscosity and density, were measured at various conditions and compared with those of the original oils. Dewatered oil viscosity was measured using CV, and oil density was measured using a high pressure Anton-Paar Densitometer. Both measurements were performed at three temperatures (310.9, 366.5, and 422.0K or 100, 200, and 300°F) and at three pressures (3.45, 6.89, and 10.34 MPa or 500, 1,000, and 1,500 psia) for a comparison purpose. Post viscosity and density measurements, water content of each dewatered sample was analyzed again to ensure it was less than one percent, thus to exclude the effect of high water content on oil viscosity and density change. The residual water contents are plotted in Figure 15.

Viscosity. Viscosity comparison between samples of dewatered oils and their original oil are summarized in Tables 15 - 17 and plotted in Figures 16 - 18. Detailed experimental records of dewatered oil viscosity measurements using CV are provided in Tables A 2 - 10 in Appendix.

Compared with the original LVO oil sample, viscosity of all the dewatered LVO samples increased, and their increment was dewatering method dependent. The viscosity increments were generally high at the lowest temperature, and became smaller as temperature increased. Among the three methods, distillation

had the strongest effect on viscosity increase: viscosity increased by two times at 310.9K (100°F). Next was the method of adding demulsifiers, in which the viscosity increased by 90 percent at 310.9K (100°F). Centrifugation had the smallest effect on the viscosity change, but the viscosity still increased by 50 percent at 310.9K (100°F).

For the MVO samples, similar trends but with some differences were observed:

i) Compared with the original MVO sample, viscosities of dewatered samples all increased at the two lower temperatures but showed only a minor change at the highest temperature. The increment was much less than that observed for the LVO samples, and the highest relative difference was 30 percent.
ii) For each dewatering method, viscosity increments were diminished with temperature increase. At 422.0K (300°F), the absolute relative differences were less than 5 percent using all three dewatering methods.
iii) The distillation method had the greatest effect on viscosity increase, while the effects caused by methods of centrifugation and adding demulsifiers were quite similar to each other.

For the HVO samples, the relative viscosity differences fell in between those trends observed for the LVO and MVO samples:

i) Compared with the original HVO sample, viscosities of dewatered samples all increased. The highest relative difference, which involved using the distillation method, was 100 percent at 310.9K (100°F).
ii) The viscosity increments reduced with temperature increase for all dewatering methods.
iii) The distillation method had the greatest effect on viscosity increase, followed by centrifugation, and then the method of adding demulsifiers. The viscosity difference between centrifugation and adding demulsifiers was less than 10%.

Density. Density comparison between samples of dewatered oils and their original oils are summarized in Tables 18 - 20 and plotted in Figures 19 - 21. The relative density differences between dewatered samples and the original oils were very small – less than three percent for the LVO, 0.3 percent for the MVO, and 0.7 percent for the HVO samples. Distillation had the strongest impact on density increase for all three oils, while the impacts caused by centrifugation and adding demulsifiers were relatively close to one another.

Composition. To understand the observed viscosity/density differences between samples of dewatered oils and their original oils, the composition of each dewatered sample was analyzed by a liquid GC method and compared with its respective original oil sample. The compositional and property results are included in Tables 2-3, 4-5 and 6-7 for LVO, MVO and HVO, respectively. The compositional and property results are also plotted in Figures 22 – 24 a and b.

For all three heavy oil samples, compositions of dewatered oils had a good agreement with those of their respective original oil samples for components greater than C10. However, concentrations of components less than C10 of the dewatered samples were slightly lower than those of their original oil samples, especially for samples dewatered by distillation. The differences in C10+ between dewatered and original oil samples were less than 0.1 percent for both the MVO and HVO samples, given that only 0.01 - 0.02 wt% of components less than C10 were present in the original HVO or MVO samples. In the case of the LVO samples, relatively large concentration reduction in components less than C10+ were observed: it was 2 wt% for the oil dewatered by distillation, 1.6 wt% for the oil dewatered by adding demulsifiers, and 0.4 wt% for the oil dewatered by centrifugation. The loss of light/intermediate components explained the above observed viscosity and density differences between dewatered oils and their original oil samples.

5.2.6 Summary and Recommendation for Dead Oil Dewatering

Based on the above study results, summary and recommendation for dead oil dewatering are as follows:

a. Using the emulsion preparation method introduced in Section 4.3.1, stable strong water-in-oil emulsions with 30 percent of water cut could be made for the LVO, MVO and HVO samples.
b. Under high centrifugation force/speed and given sufficient spinning time, the centrifugation method was able to separate water from laboratory prepared strong emulsions. However, the final residual water content of dewatered oil samples increased with increases in oil density and viscosity: it was less than one percent for the dewatered LVO sample; close to one percent for the dewatered MVO sample; and around two percent for the HVO sample.
c. With proper mixing and temperature control, Dean-Stark distillation at ambient pressure removed water from all prepared emulsions. Residual water content of the dewatered LVO, MVO, and HVO samples were all achieved at less than one percent.
d. Despite using proper dosage for recommended chemical demulsifiers that worked well in demulsification of corresponding field samples, water could not be completely removed from the laboratory prepared strong emulsions using only gravity settling. However, residual water content of less than one percent was achieved for all three types of heavy oils with further separation by mild centrifugation.
e. Viscosities of dewatered oil samples were affected by the dewatering method applied. In general, dewatered oil viscosities were higher than those of the original oil samples, and the difference was temperature, oil nature, and dewatering method dependent: a) the viscosity difference, mainly incremental, decreased with increases in temperature; b) viscosity increments caused by the distillation method were greater than by the centrifugation/adding demulsifiers method; c) viscosity change caused by the centrifugation method was close (less than 10 percent) to that caused by adding demulsifiers; d) when using the distillation method, the viscosity of the dewatered LVO sample increased by up to three times that of its base oil sample at the lowest testing temperature of 310.9K (100°F), while it was only 30 percent higher for the dewatered MVO sample at that temperature.
f. The impact of the dewatering method on dewatered oil density was not significant, especially when compared with the impact on viscosity. Within the testing conditions, the largest relative density difference between dewatered oil and original oil was less than three percent (for the LVO sample dewatered by distillation), and in general, the relative density difference was less than 0.8 percent.
g. Post dewatering, obvious light/intermediate component mass loss was observed for the LVO sample, but losses were negligible for the MVO and HVO samples. This was due to the fact that about 7 wt% of components less than C10 were present in the original LVO sample but less than 0.2 wt% of components less than C10 were present in the original MVO and HVO samples.
h. The distillation method had a greater impact on component mass loss than the other two methods. For the method of adding demulsifiers, trace amount of chemicals, at the ppm level, were left in the dewatered oil samples.
i. Based on the above results, centrifugation is recommended for dewatering low and medium viscous heavy oil samples.
j. Addition of chemical demulsifiers is recommended for dewatering medium and high viscous oils if centrifugation does not perform adequately.
k. Distillation is <u>not</u> recommended for dewatering heavy oils with greater than 0.5 - 1 wt% of light/intermediate components.

5.3 Results of Dead Oil Viscosity Measurement

The objectives of this task were to validate three types of viscometers typically used in heavy oil viscosity measurement, to understand the difference in viscosity measured by different viscometers, and thus to provide guidelines on viscometer selection for heavy viscous oil viscosity measurements.

In this project, the three viscometers studied were the capillary viscometer (CV), electromagnetic viscometer (EMV) and rheometer (Rheo). Validation results and comparisons of viscosities measured by different viscometers are provided as follows.

5.3.1 Validation Results of Three Viscometers

Before validation tests, all three types of viscometers were calibrated following procedures described in the Experimental Sections.

Capillary Viscometer. In this study, three capillary coils were used to cover the overall viscosity measurement range. The CV equipped with one of the coils was validated at various temperatures ranging from 298 to 373K (25 to 100°C). Various viscosity standards were used. At a given temperature, viscosity measurements of these standards were performed at three pressures: 3.45, 6.89, and 10.34 MPa (500, 1000, and 1,500 psia). As linear correlation between measured viscosity and pressure was obtained, viscosity at atmospheric pressure was calculated by linear extrapolation, which was then compared with the given viscosity of the standard at a given test temperature.

All validation results of the CV are summarized in Table 21 and plotted in Figures 25 a and b. For all three coils and at all testing conditions, the measured viscosities agreed very well with given viscosities of viscosity standards. The absolute relative differences between measured and given viscosities were less than 3 percent.

Electromagnetic Viscometer. In this study, five pistons were used to cover the overall viscosity testing range. Once a piston was installed, a validation test was always performed prior to its usage. Measurements of viscosity standards were also carried out at three high pressures, and each extrapolated viscosity at atmospheric pressure was compared against the given viscosity. All validation results of the EMV are summarized in Table 22 and plotted in Figures 26 a and b. For all five pistons and at all testing conditions, the measured viscosities agreed very well with given viscosities of viscosity standards with a maximum absolute relative difference less than five percent.

Rheometer. Validation of the rheometer was performed at atmospheric pressure and at various temperatures. The validation results are summarized in Table 23 and plotted in Figures 27 a and b. The absolute relative differences between measured viscosities and given viscosities were less than three percent in general, except the viscosity of standard N100 at 100°C, 9 mPa·s. The reason for the relatively large difference of 16% percent was because the viscosity value was close to the lower absolute measurement limitation of the instrument.

5.3.2 Dead Oil Viscosity Measurement by Three Viscometers

Viscosity measurements of dead LVO, MVO and HVO samples using CV and EMV were performed at 311, 367, and 422K (100, 200, and 300°F) and at 3.45, 6.89, and 10.34 MPa (500, 1000, and 1,500 psia). Viscosity measurements of these three oils using rheometer were performed at atmospheric pressure and at 293, 333, and 373K (68, 140 and 212°F).

For a comparison purpose, viscosities measured at high pressures using CV/EMV were used to calculate viscosities at atmospheric pressure conditions. The data are summarized in Tables 24 and 25. Viscosities of the three oils measured by rheometer are summarized in Table 26 and plotted in Figures 31 - 33.

Measured viscosities at high pressures using CV and EMV are included in Tables 27 - 29 for LVO, MVO, and HVO samples in sequence. Detailed experimental records of measurements using CV,

including flow rates used, pressure drops along the coil, relative differences among three measurements, and calculated *Re* and *De* numbers, are provided in Tables A 11 - 13 in the Appendix. Detailed experimental records of rheometer measurements are provided in Tables A 14 - 22 in the Appendix.

5.3.3 Comparison of Stock Tank Oil Viscosity Measured by Capillary Viscometer and Electromagnetic Viscometer

Viscosity comparisons between CV and EMV are summarized for the LVO samples in Table 27 and plotted in Figure 28. As shown in Figure 28a, linear correlation existed between viscosities measured by either CV or EMV versus pressure at all three testing temperatures. The measured viscosities had a good agreement with relative viscosity differences (($Viscosity_{EMV}$ - $Viscosity_{CV}$)/Average Viscosity × 100%) of less than 5 percent at 311K/100°F, less than 10 percent at 367K/200°F), and greater than -6 percent at 422K/300°F.

Viscosity comparisons between CV and EMV are summarized for the MVO samples in Table 28 and plotted in Figure 29. Similarly, viscosities measured by CV agreed with viscosities measured by EMV with absolute relative differences less than seven percent.

Viscosity comparisons between CV and EMV are summarized for the HVO samples in Table 29 and plotted in Figure 30. Again, viscosities measured by CV agreed with viscosities measured by EMV with absolute relative differences less than five percent.

It was noted that during the viscosity comparison for the MVO sample, viscosities measured by two different pistons using EMV were found to have an 18 percent relative difference. The data are summarized in Table 30. Two pistons were used: one was the Piston 100 - 2,000, i.e., the lower viscosity limitation of this piston was 100 mPa·s and the upper limitation was 2,000 mPa·s; the other one was Piston 500 - 10,000, which had lower and upper viscosity limitations of 500 mPa·s and 10,000 mPa·s, respectively. The sample viscosity was around 1,300 mPa·s, which fell within the measurement ranges of both these pistons. The viscosities measured by the Piston 100 - 2,000 were found to have a better agreement with those measured by the CV. The difference lies in the fact that during calibration of each piston, the acceptable error was 1.5 percent of its upper limitation. As a result, if Piston 100 - 2,000 was used the acceptable error was ± 30 mPa·s, but if Piston 500 - 10,000 was used the acceptable error was ± 150 mPa·s instead. Thus, if the viscosity to be measured falls within the viscosity range of more than one piston, the one with the lower value of upper limit should be selected, so that the relative experimental error is smaller.

5.3.4 Comparison of Stock Tank Oil Viscosity Measured by Three Methods

For comparison, viscosities of the three heavy oil samples measured by three different methods versus temperature were plotted in two ways as shown in Figures 34a and 34b. The plots show that viscosities measured by CV agreed well with those measured by EMV, as indicated by the overlaid curves between viscosity and temperature. However, most viscosities measured by rheometer were higher than those measured by both the CV and EMV, and the differences increased with decrease in sample density and increase in test temperature: a) for HVO, viscosities measured by rheometer were 7 – 11% of higher than those measured by CV or EMV at all three temperatures; b) for MVO, viscosities measured by rheometer were 5% lower at 293K/68°F, 10% higher at 333K/140°F, and then about 17% higher at 373K/212°F than those measured by CV and EMV; c) for LVO, measured viscosities by rheometer were close to those measured by CV and EMV at 293K/68°F with absolute difference less than 5%, however, the difference increased to 35% at 333K/140°F, and more than 60% at 373K/212°F. One possible reason behind these phenomena was that because the measurements by rheometer were performed in an open system, there was potentially light/intermediate component mass loss during the measurements, especially at high temperatures, thus as a result the viscosities measured by rheometer were overestimated as the sample were altered during heating. To verify this, after the viscosity measurement at the highest test temperature

(373K/212°F) using the rheometer, the sample temperature was reduced to the lowest temperature again and viscosity measurement was repeated at that temperature to determine if there had been any change. This process was only performed with the LVO and MVO samples, and the results are plotted in Figures 31 and 32, respectively. The results showed that the viscosity measured at 293K/68°F was repeatable for the MVO sample; however, it was not repeatable for the LVO sample, which showed an 80 percent increase. Post viscosity measurements, the tested LVO and MVO samples were analyzed by GC; results are included in Tables 2 and 3 for the LVO and Tables 4 and 5 for MVO samples. The composition of the MVO sample post viscosity measurement was comparable with its original composition. However, for the LVO sample, composition of the sample post viscosity measurement indicated that components less than C10 were about one weight percent less than that of the original LVO sample. The compositional analysis results confirmed that the viscosity measured by rheometer tends to be overestimated at high temperatures, especially for samples with some amount of light/intermediate components.

5.3.5 Summary and Recommendation on Dead Oil Viscosity Measurement

Based on the above results, a summary and recommendations regarding dead oil viscosity measurements are as follows:

a. Validation test results indicated that in general all three types of viscometers could reproduce viscosities of viscosity standards, with absolute relative differences of less than three percent for CV, five percent for EMV, and three percent for rheometer. For rheometer measurements the relative difference was high (16 percent) when measured viscosity approached the instrument's lower limitation.
b. Measured viscosity by either EMV or CV had a linear correlation with pressure for all three types of heavy oils under test conditions (311K < T < 422K and P < 10.34 MPa).
c. For all three types of heavy oils, viscosities measured by EMV agreed well with viscosities measured by CV, with absolute relative differences of less than 10 percent.
d. Compared to viscosities measured by EMV/CV, viscosities measured by rheometer at three test temperatures (293, 333, and 373K) were about 10% higher for the HVO sample, up to about 17% higher for the MVO, and 5 – 65% higher for the LVO samples.
e. CV is recommended for heavy viscous oil viscosity measurements once its fundamental requirements are met, which are *Re* number should be less than 2,100 and *De* number less than six (6.0).
f. EMV is also recommended for heavy viscous oil viscosity measurements provided that clean samples are used. The experimental error of measured viscosity might be piston dependent (the acceptable calibration error was 1.5 percent of its upper limitation); therefore, it is suggested to choose the piston with an upper viscosity limitation higher than, but as close as possible to, the sample viscosity to be measured.
g. A rheometer with an open system is not recommended for heavy viscous oil viscosity measurements at temperatures above the oil's initial boiling point (IBP), especially for those samples with greater than 0.5 – 1.0 wt% of light/intermediate components.

5.4 Results of Live Oil Reconstitution and Validation

The objectives of this task were to validate existing experimental procedures of live oil reconstitution, gas-oil-ratio (GOR) measurement, and bubble-point pressure (P_{sat}) measurement of live heavy oil samples, thus to provide laboratory 'best practices' procedures.

The target GORs, which were suggested by the WPG members based on the common GOR values for the selected heavy oils, were 250, 170, and 100 SCF/STB for live LVO, MVO, and HVO, respectively. Methane was selected as the solution gas. The live oils were prepared with methane to given GOR values following procedures described in Section 4.5.1.

5.4.1 Validation Results of Reconstituted Live Oils

The prepared live oils were validated by GOR tests, and three parallel tests were performed to examine the repeatability of the procedure. Based on the corresponding dead oil viscosity and live oil GOR, the regular flash method with a regular GOR apparatus was used in the validation tests of live LVO samples, while the direct flash method with a low GOR apparatus (five of six tests) was used in the validation tests for live MVO and HVO samples. The purposes of the GOR validation tests were to quantify the differences between the actual measured GORs and planned GORs of the reconstituted live oils and to quantify the repeatability the GOR test procedures. Results are summarized in Table 31, which also lists the flash method and GOR apparatus used. Flashed gas and flashed oil from each GOR test were analyzed by GC, and the compositional results are shown in Tables 32 - 49.

For live LVO, as shown in Figure 35, measured GOR values from three repeat tests had good repeatability with a standard deviation (STDEV) of only 2.8 SCF/STB. The relative differences between measured GORs and required GORs were in the range of 6 – 8 percent, within normal expected error of GOR measurement (~10%). However, it was interesting to observe that all measured GORs were higher than planned GORs for the live LVO. To understand such differences, compositions of the flashed gases were analyzed and the results are provided in Tables 32, 34, and 36. In the flashed gas, the concentration of methane was only about 95 mol%, and the remaining 5 mol% was light and intermediate components that had initially been present in the dead LVO sample but were carried over to the flashed gas during the flash process. If the 5 mol% of extra gases was excluded from the flashed gas, the measured GORs would agree well with the target value with only 1 - 3 percent of difference.

For live MVO samples, as shown in Figure 36, measured GOR values were reproducible with STDEV of 1.8 SCF/STB, and their average value was only 3 percent less than the planned GOR. The compositions of flashed gases are provided in Tables 38, 40, and 42, and 99.8 mol% of the gases were dominated by methane. This was reasonable because the original MVO sample had only about 0.2 wt% of components less than C10.

For live HVO samples, detailed compositions of flashed gas and flashed oil are provided in Tables 44 - 49 and a GOR comparison is plotted in Figure 37. The validation results were very similar to the results of the live MVO samples. The measured GOR values had a STDEV of only 0.4 SCF/STB, and their average value was 1.8 percent less than the target. The flashed gases contained 99.8/99.9 mol% of methane.

5.4.2 Summary and Recommendation of Live Oil Reconstitution and Validation

Results of live oil reconstitution and validation are summarized as follows.

a. Live oil reconstitution method described in Section 4.5.1 is recommended for live heavy oil reconstitution, if the correct gas composition is used as the solution gas.
b. The direct flash procedure described in Section 4.5.2 had a good repeatability (STDEV/Average < 0.01), and it is recommended for live high viscous oil validation (dead oil API < 15).
c. The regular GOR flash procedure also had good repeatability (STDEV/Average < 0.01), and is recommended for live low viscous oil validation (dead oil API > 15).
d. A low GOR apparatus is recommended for low GOR measurements (GOR < 100 SCF/STB).

5.5 Results of Live Oil Bubble-point Pressure (P_{sat}), Density and Viscosity Measurements

5.5.1 Results of Live Bubble-point Pressure (P_{sat}) Measurement

To ensure live oil viscosity and density measurements are performed at single phase pressures, the P_{sat} of each live oil at a given temperature is needed. In this study, P_{sat} values of three prepared live oils were measured at three temperatures (311, 366, and 422K or 100, 200, and 300°F) and results are summarized in Table 50 and plotted in Figure 38. Detailed P_{sat} measurement results of live LVO samples at three

temperatures are provided in Tables 51 - 53, results of live MVO samples are given in Tables 54 - 56, and results of live HVO samples are summarized in Tables 57 - 59. For comparison purposes, the relative volume ratios (V_{tot}/V_{sat}) at three temperatures are plotted in Figures 39 - 41. Correlations of single phase density versus pressure are plotted in Figures 42 - 44.

As shown in Figure 38, measured P_{sat} increases with temperature increase for each live oil sample, and at a given temperature the measured P_{sat} of live LVO is greater than that of live MVO, which in turn is greater that of live HVO. As shown in Figures 39 - 41, for all three live oil samples, relative volume (V_{tot}/V_{sat}) measured at 422K/300°F is higher than that measured at 366K/200°F and in turn higher than at 311K/100°F, while the differences shrink with an increase in dead oil's density. As shown in Figures 42 - 44, single phase density linearly decreases with a decrease in pressure, as well as for an increase in temperature for all three live oil samples. These results were expected and further verified the sample quality of prepared live oil samples.

5.5.2 Results of Live Oil Density Measurement

Density for each live oil sample was measured at three temperatures and five single phase pressures. The test conditions and density results obtained are summarized in Tables 60 - 62 and plotted in Figures 45 - 47 for live LVO, MVO and HVO in sequence. In general, linear correlation between live oil density and pressure was observed.

5.5.3 Comparison of Live Oil Viscosity Measured by Capillary Viscometer and Electromagnetic Viscometer

Live oil viscosities were measured at three temperatures and five single phase pressures using both CV and EMV. Results and comparisons are provided respectively in Tables 63 - 65 and plotted in Figures 48 - 50 for live LVO, MVO, and HVO samples. Detailed experimental records of CV are provided in Tables A 23 - 25 in the Appendix.

In general, linear correlation between measured live oil viscosity and pressure was observed using either EMV or CV.

Comparisons for live LVO samples are provided in Table 63 and plotted in Figure 48. The relative differences between viscosities measured by CV and EMV were less than five percent at the two highest temperatures; while at the lowest temperature (311k/100°F) viscosities measured by EMV were 12 - 15 percent higher than those measured by CV.

Comparisons for live MVO samples are provided in Table 64 and plotted in Figure 49. Viscosities measured by EMV at 311k/100°F were 4 - 14 percent less than those measured by CV, the absolute viscosity differences at 366K/200°F were less than 5 percent, while viscosities measured by EMV at 422K/300°F were 18 - 27 percent higher than those measured by CV.

Comparisons for live HVO samples are provided in Table 65 and plotted in Figure 50. At all three temperatures, viscosities measured by EMV were all lower than those measured by CV, while the absolute differences were all less than 9 percent.

5.5.4 Summary and Recommendation of Live Oil Viscosity Measurement

In Section 5.3.5, we concluded that viscosities measured by EMV agreed well with viscosities measured by CV with absolute relative differences less than 10 percent for all three types of dead heavy oil samples. However, for live oils this conclusion was only valid for the live HVO sample. For the live LVO sample, the relative differences in viscosities measured by EMV and CV increased to 16 percent. For the live MVO sample, even though at the two lowest temperatures the relative differences were less than 14 percent, while at the highest temperature of 422K/300°F the relative difference was as high as 27 percent.

To verify the large difference, viscosities were measured again with another piston using the EMV, and similar results were obtained. Further investigation is needed to explain the large difference.

To this end, both EMV and CV are recommended for live heavy oil viscosity measurements. In most cases live oil viscosities measured by EMV agreed with those measured by CV, with relative differences of less than 15 percent. However, a large difference nearly as high as 30 percent was observed for the live MVO sample at 422K/300°F.

5.6 Results of Dead Oil/Solvent Mixture Preparation

The objective of this task was to generate a viscosity and density database of heavy oil/solvent mixtures, which would be useful to validate existing heavy oil viscosity models and/or develop new models. Relative to this objective, in this study heavy oil/solvent mixtures were prepared using LVO, MVO, and HVO samples with two selected solvents. Viscosities and densities of each mixture were measured at three temperatures and three pressures.

5.6.1 Results of Asphaltene Titration Tests Using Heptane

Two solvents commonly used in oil industry were selected. A xylene mixture made of m-xylene and p-xylene with one-to-one ratio by weight was used as a representative aromatic solvent. Heptane was selected to be the representative paraffinic solvent. Purity of the two solvents was analyzed by GC, and obtained compositions are provided in Table 66.

To determine the highest heptane concentration that can be added in the heavy oil samples without asphaltene precipitation issue, asphaltene onset titration tests were performed using solvent heptane and dead LVO and MVO samples. The titration tests were performed at 323K/50°C and 3.45 MPa/500 psia using an organic solid detection system (OSS). The OSS system was equipped with two high pressure cylinders and a high pressure microscopy (HPM), which was installed in between the two cylinders. When fluid flows through the HPM window from one cylinder to another under pump control, micro-images of the flowing fluid could be captured by the HPM. For a titration test, a known amount of dead oil was added into a cylinder, and heptane was added step by step and then mixed with the oil. When asphaltene precipitation initiated, precipitated micro-sized particles were captured by the HPM images and onset solvent concentration was determined.

The HPM images captured from the asphaltene titration tests using the LVO sample and heptane are provided in Figure 51. Results of the asphaltene titration tests using the MVO sample and heptane are given in Figure 52. Concentrations of heptane in the mixture post each step addition are summarized in Table 67. The results indicated that asphaltene onset was reached when the heptane concentration was increased close to 51.5 vol% for the LVO sample, and asphaltene onset was reached when heptane concentration was around 70.6 vol% for the MVO sample.

5.6.2 Preparation of Dead Oil/Solvent Mixtures

Based on the titration results, 40 vol% was set as the highest heptane concentration for dead oil/heptane mixtures. Dead oil/solvent mixtures were prepared using a heavy oil PVT cell following the procedures described in Section 4.5.3. Actual solvent concentrations of 18 prepared mixtures are summarized in Table 68.

5.6.3 Results of Dead Oil/Solvent Mixture Viscosity Measurement

Viscosities of each dead oil/solvent mixture were measured using CV at three temperatures (311, 366, and 422K or 100, 200, and 300°F) and three pressures (3.45, 6.89, and 10.34 MPa or 500, 1000, and 1,500 psia). Viscosity data of LVO/solvent mixtures are summarized in Table 69, and correlations of viscosity versus solvent weight fraction are plotted in Figures 53 and 54. Measured viscosity data of MVO/solvent mixtures are summarized in Table 70, and correlations of viscosity versus solvent weight fraction are

plotted in Figures 55 and 56. Measured viscosity data of HVO/solvent mixtures are summarized in Table 71, and correlations of viscosity versus solvent weight fraction are plotted in Figures 57 and 58. Experimental records of each viscosity measurement are provided in Tables A 26 - 43.

5.6.4 Results of Dead Oil/Solvent Mixture Density Measurement

Densities of each dead oil/solvent mixture were measured using a high pressure Anton-Paar densitometer at three temperatures (311, 366, and 422K or 100, 200, and 300°F) and three pressures (3.45, 6.89, and 10.34 MPa or 500, 1000, and 1,500 psia). Measured densities of LVO/solvent mixtures are summarized in Table 72, and correlations of density versus solvent weight fraction are plotted in Figures 59 and 60. Measured viscosity data of MVO/solvent mixtures are summarized in Table 73, and correlations of density versus solvent weight fraction are plotted in Figures 61 and 62. Measured viscosity data of HVO/solvent mixtures are summarized in Table 74, and correlations of viscosity versus solvent weight fraction are plotted in Figures 63 and 64.

5.6.5 Results of Solvent Viscosity and Density Measurement

Viscosities of xylenes and heptane used in heavy oil/solvent mixture preparation were also measured by CV at the same temperature and pressure conditions used in heavy oil/solvent viscosity measurements. Densities of xylenes and heptane were also measured at these conditions using a high pressure Anton-Paar Densitometer.

Measured viscosities of xylenes are summarized in Table 75, and detailed experimental data records are given in Table A 44 in the Appendix. Measured viscosities of heptane are provided in Table 76, and detailed experimental data records are given in Table A 45 in the Appendix. Measured densities of xylenes are summarized in Table 77, and measured densities of heptane are summarized in Table 78.

Linear correlations between measured viscosity/density and pressure were obtained for both xylenes and heptane. These correlations were subsequently used to extrapolate viscosity/density at atmospheric pressure conditions.

Measured solvent viscosity and density data were compared with available public data. Data for m-xylene or p-xylene at ambient pressure were from DIPPR database (American Institute of Chemical Engineers Design Institute for Physical Property Data) and data at pressures were from a few other literatures (Caudwell, et al., 2009; Wu, et al., 2013; Guan, et al., 2013). The relative viscosity differences between measured viscosities of xylenes in this study and viscosities of m-xylene or p-xylene from DIPPR were less than four percent at the two lowest test temperatures but were 6 to 8 percent at the highest temperature. The relative viscosity differences between measured and data of m-xylene reported in Caudwell's paper were less than five percent (5%). On the other hand, measured densities agreed well with density data from literatures with relative differences less than one percent (1%): (-0.3) to 0.4 percent from DIPPR's data; (-0.3) to 0.8 percent from Wu's results; and (-0.6) to (-0.2) percent from Guan's results.

Public high pressure viscosity and density data of heptane were obtained from the NIST Chemistry WebBook and Sagdeev's work (Sagdeev, et al., 2013). The measured heptane viscosities were in between the literature data with relative differences of (-3) to 11 percent higher than the data from NIST and 3 to 9 percent lower than Sagdeev's data. On the other hand, measured densities agreed well with literature data with relative differences of (-0.3) to 0.0 percent from the NIST data and (-0.6) to 0.0 percent from Sagdeev's results.

5.6.6 Summary of Dead Oil/Solvent Mixture Preparation and Viscosity/Density Measurement

A summary of dead oil/solvent mixture preparation and measurements of viscosity and density are as follows:

a. One aromatic solvent, a mixture of m-xylene and p-xylene mixed by one-to-one mass ratio, and one paraffinic solvent were used in preparing dead oil/solvent mixtures.
b. For a given heavy oil sample, six mixtures were prepared: three with xylenes and three with heptane. In total, 18 heavy oil/solvent mixtures were prepared. The highest heptane concentration was below asphaltene onset concentration.
c. All mixtures were prepared in a closed mixing system under pressure and transferred in pressurized cylinders to ensure good mixing and no solvent mass loss during mixture preparation and sample transfer.
d. Viscosity and density of each mixture were measured at three temperatures and three high pressures, thus generating a good viscosity and density database of heavy oil/solvent mixtures.
e. Viscosity and density of each solvent were measured and compared with available literature data.

6. CONCLUSIONS

First, through a systematic study on three common dewatering procedures in heavy oil dewatering and their impact on de watered oil properties, recommendations and guidelines for laboratory heavy oil dewatering procedures were provided.

Second, this project also validated the applicability and limitations of three viscometers typically used in heavy oil viscosity measurements. A systematic comparison on both dead heavy oil and live heavy oil sample measurements by different viscometers was performed at a series of temperature and pressure conditions. Based on t he viscometer validation and comparison results, recommendations regarding viscometer selection and practical procedures to be used in viscosity measurements for both dead and live heavy viscous oils were provided.

Third, procedures of live heavy oil reconstitution and flash test procedures were provided and validated.

Last but not least, a reliable heavy oil-solvent viscosity data set that will support viscosity model validation and development was generated.

7. FUTURE WORK

Based on the work performed in this project and the obtained results, we suggest some future work for consideration:

a. Further investigate the reasons behind the observed relatively large differences in live oil viscosities measured by CV and EMV. For example, another viscometer, such as vibrating wire viscometer, can be used to measure the viscosity at given conditions and compare with results from the CV and EMV measurements.
b. In this project, heavy viscous oil samples were clean samples, while real field samples normally contain some amount of water and solids. Similar tests to those performed in this study should be performed on raw field samples to determine the effects of unclean oils on the results/conclusions/recommendations provided herein.
c. Study the rheology of water-in-oil or oil-in-water emulsions of heavy viscous oils.
d. Validate current existing heavy oil viscosity models with especially current viscosity dataset, and improve on or develop new models.
e. Extend the heavy oil types to cover extra heavy oils (API gravity < 10).

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10. FIGURES

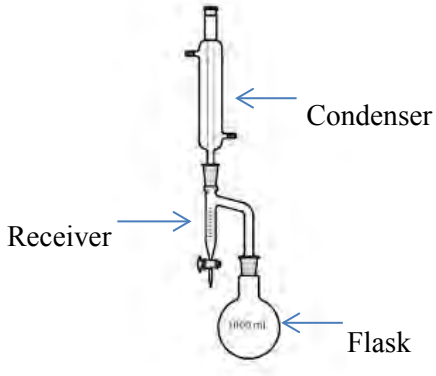


Figure 1: Schematics of a Dean-Stark Distillation Setup

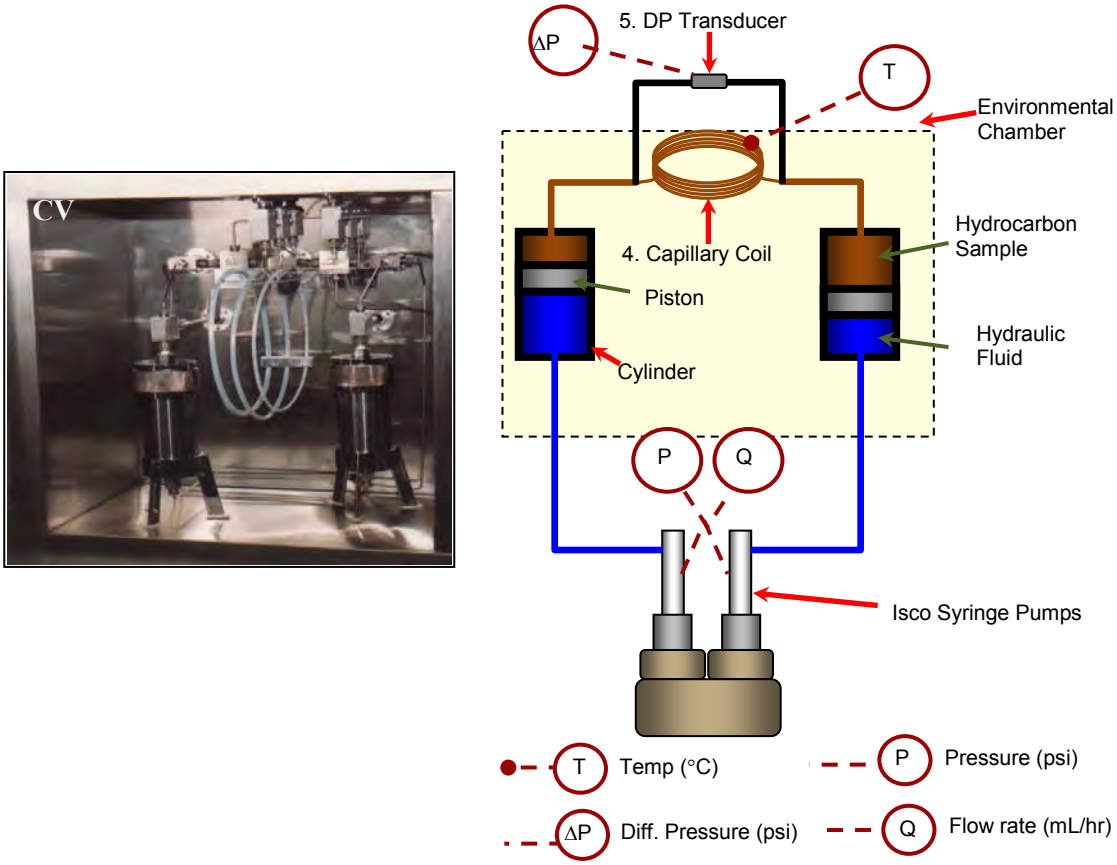


Figure 2: Setup and Schematic of a Capillary Viscometer.

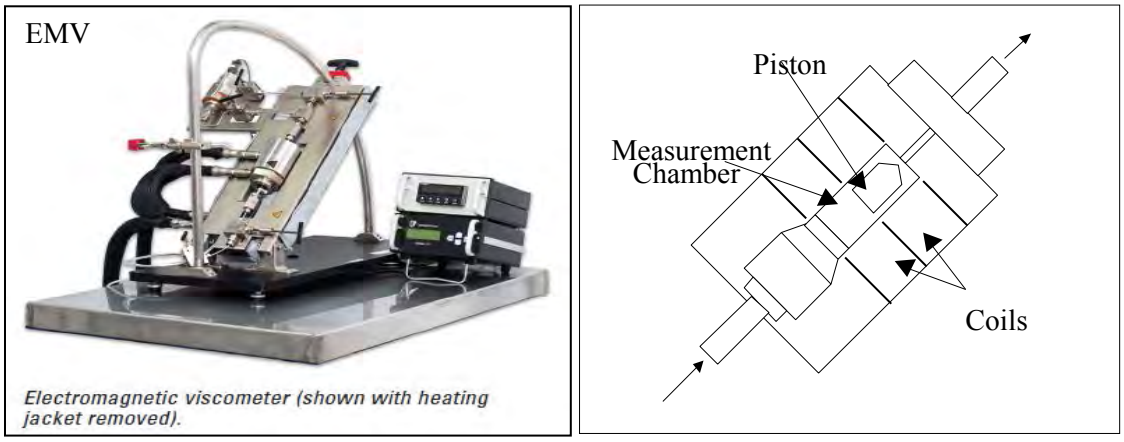


Figure 3: Setup and Schematic Diagram of a Cambridge Electromagnetic Viscometer

Figure 4: Setup of a Rheometer, Var 100

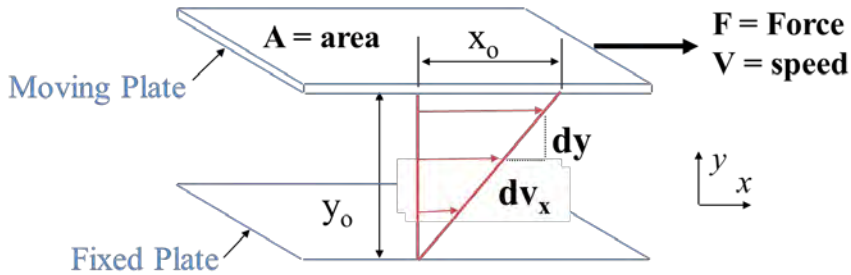


Figure 5: Simple Shear Flow along Two Parallel Plates

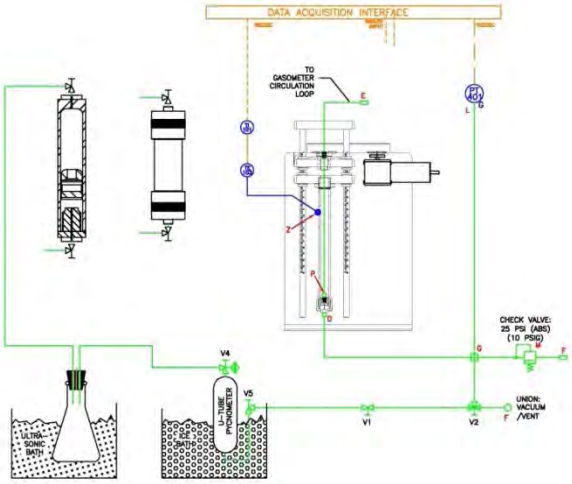


Figure 6: Diagram of the Direct Flash Setup with a Low GOR Apparatus

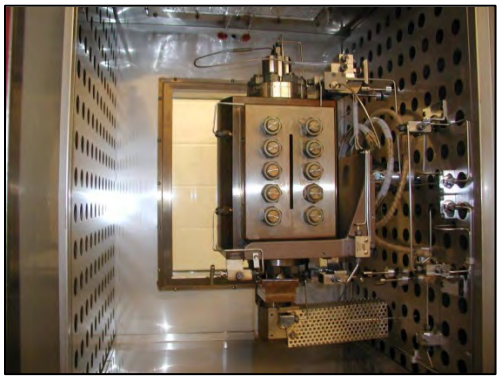


Figure 7: Setup of a Heavy Oil Cell

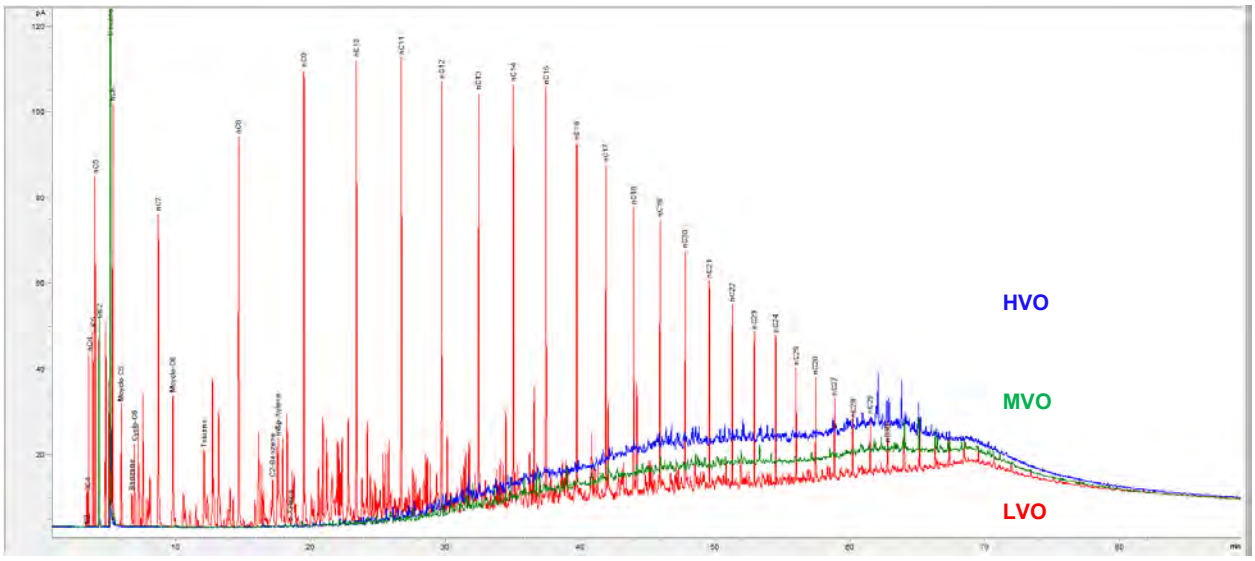


Figure 8: Chromatography of Three Dead Oil Samples: Low Viscous Oil (LVO), Medium Viscous Oil (MVO) and High Viscous Oil (HVO).

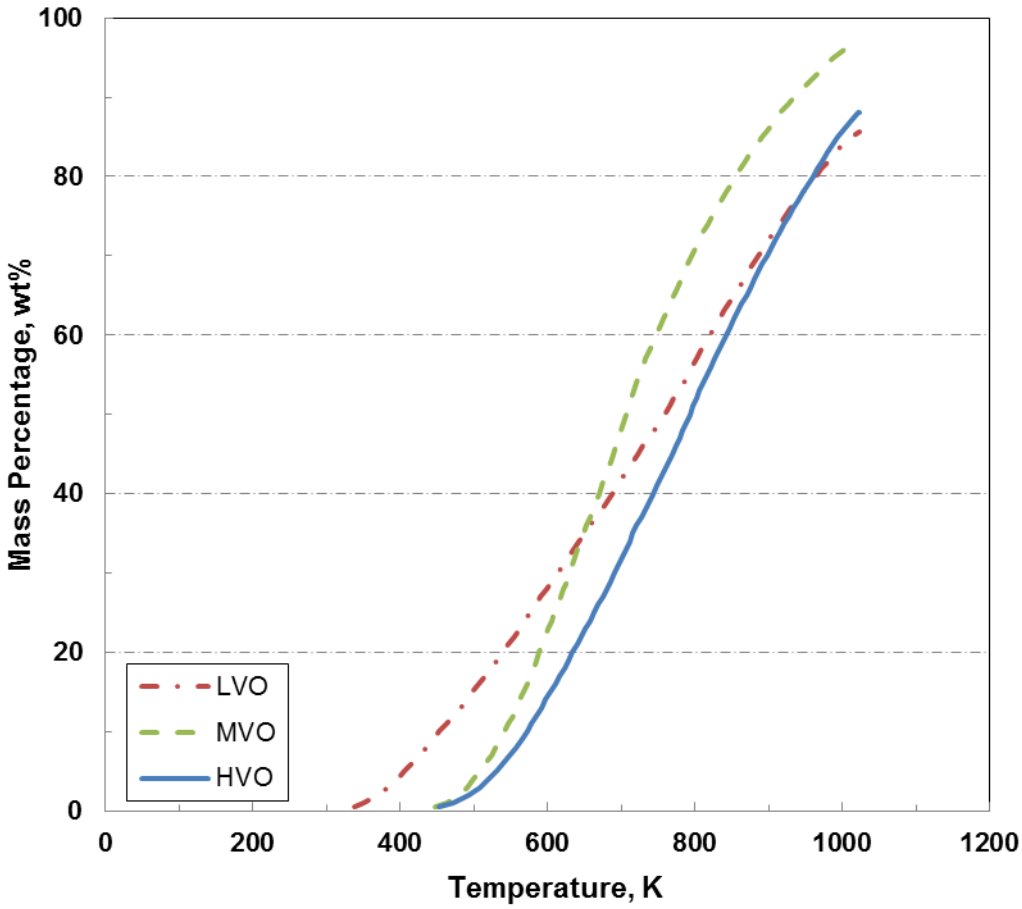


Figure 9: Simulated Distillation Results of Three Dead Oil Samples: Low Viscous Oil (LVO), Medium Viscous Oil (MVO) and High Viscous Oil (HVO).

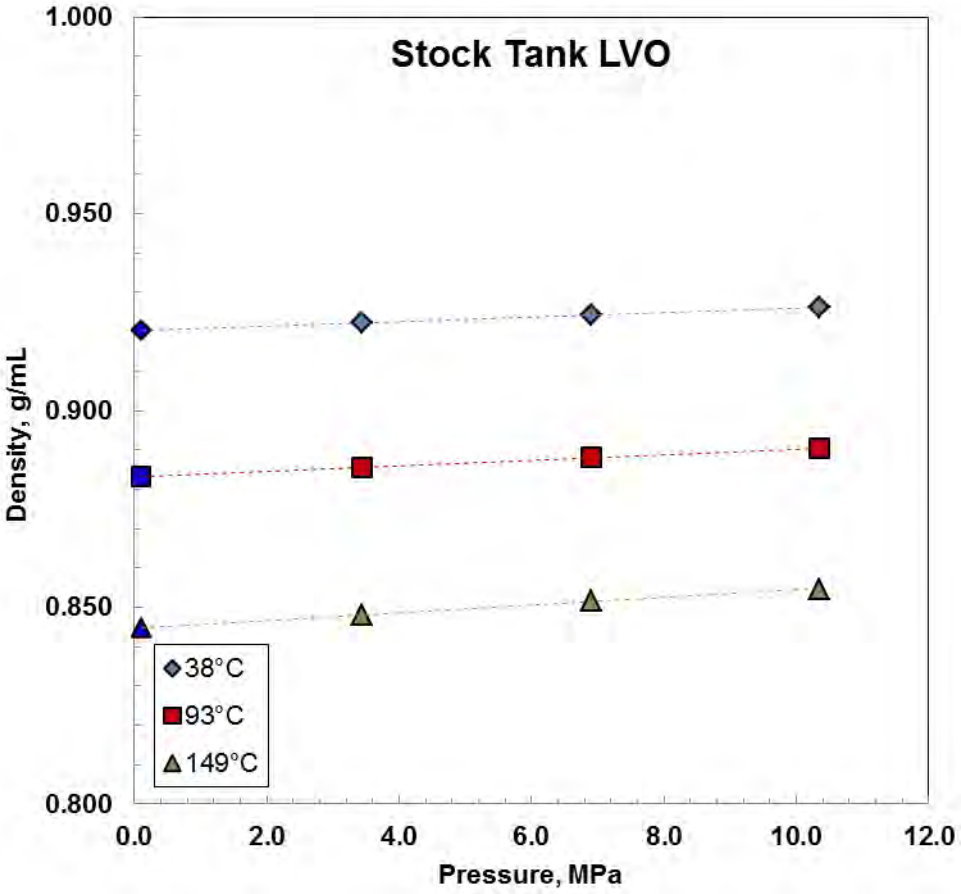


Figure 10: Stock Tank Oil Density vs. Pressure – Low Viscous Oil (LVO)

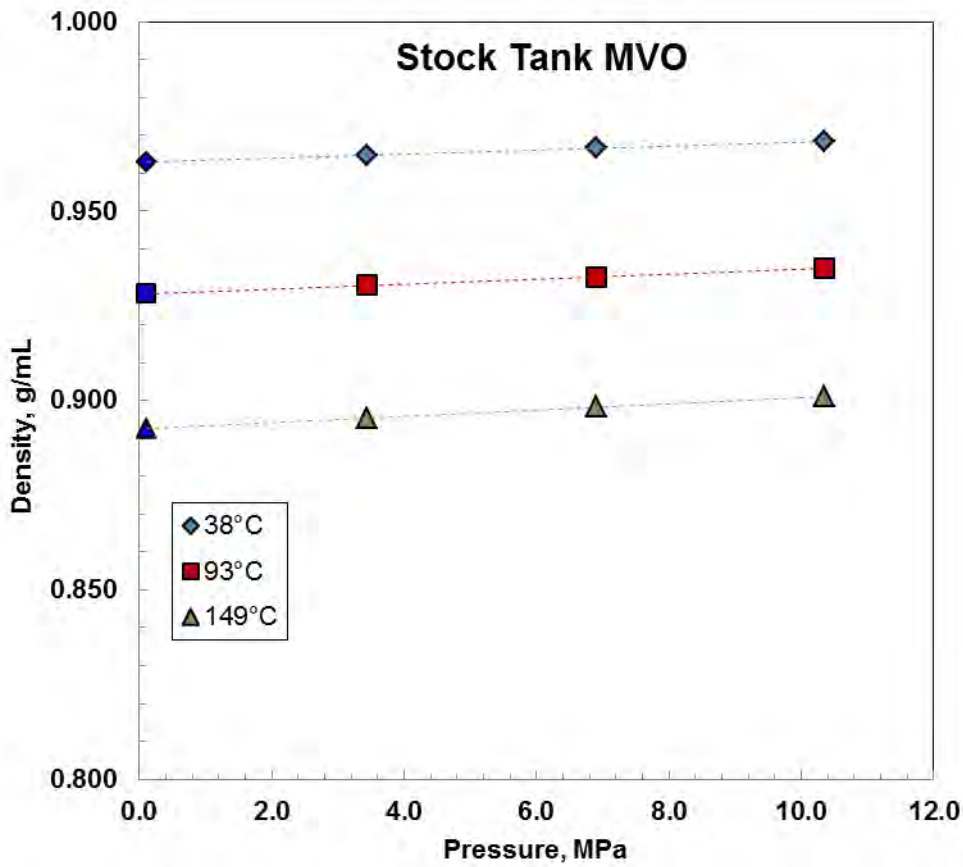


Figure 11: Stock Tank Oil Density vs. Pressure – Medium Viscous Oil (MVO)

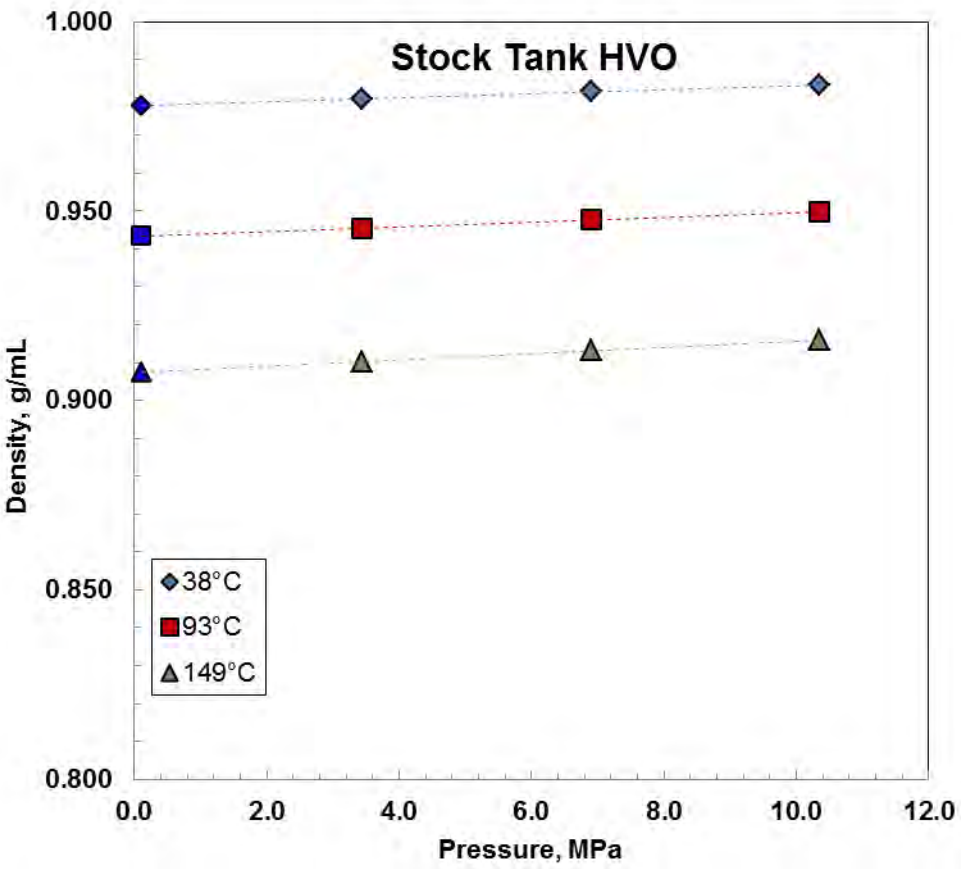


Figure 12: Stock Tank Oil Density vs. Pressure – High Viscous Oil (HVO)

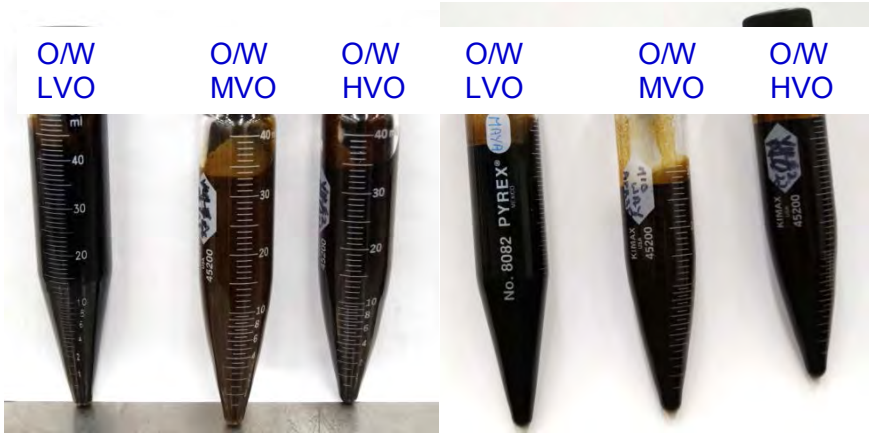


Figure 13: Emulsion Stability Check by Observation: Emulsion Photos Taken at 23 Days (Left) and 55 Days (Right) Post Emulsion Preparation

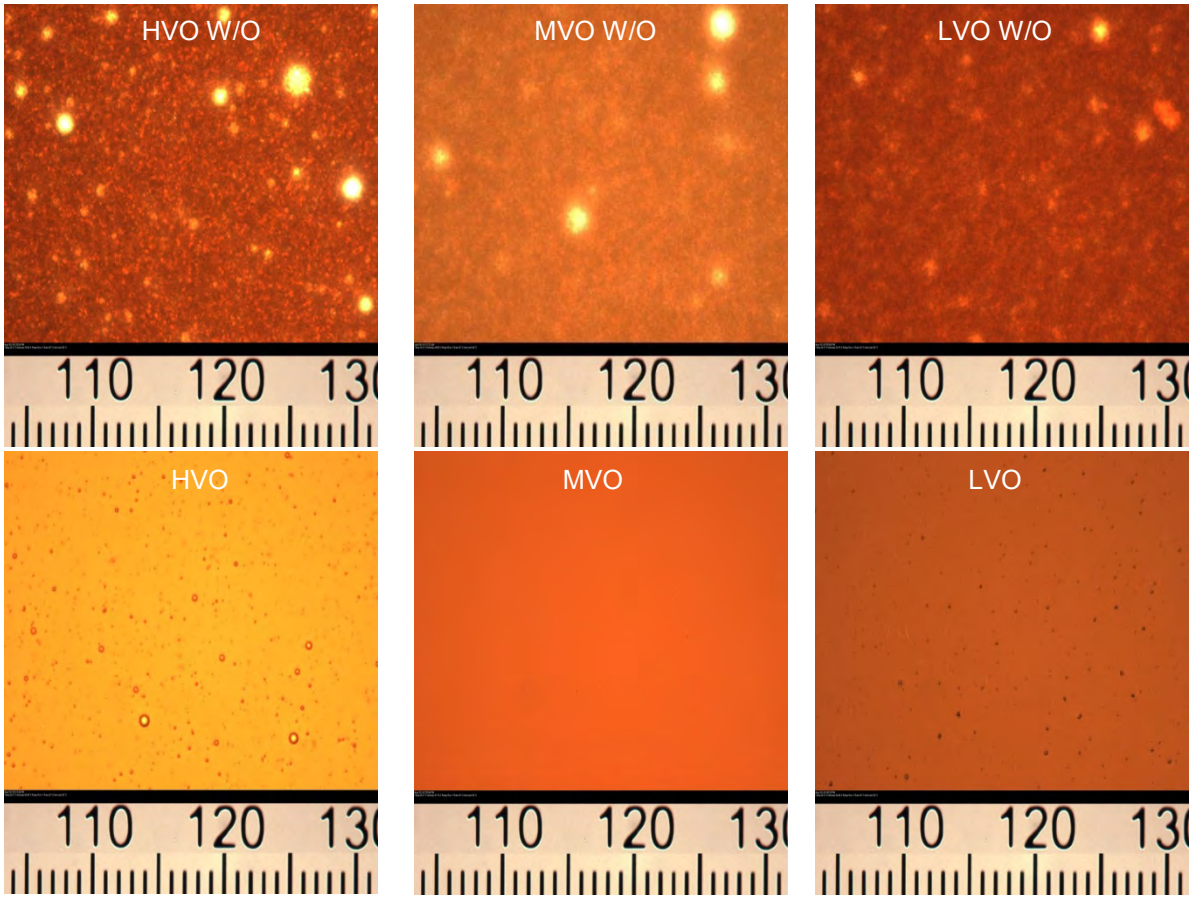


Figure 14: Emulsion Stability Check by Micro-Imaging: Images of Prepared Emulsions (Upper Row) and Images of Original Stock Tank Oils (Lower Row) **(Note: one small scale = 10 µm)**

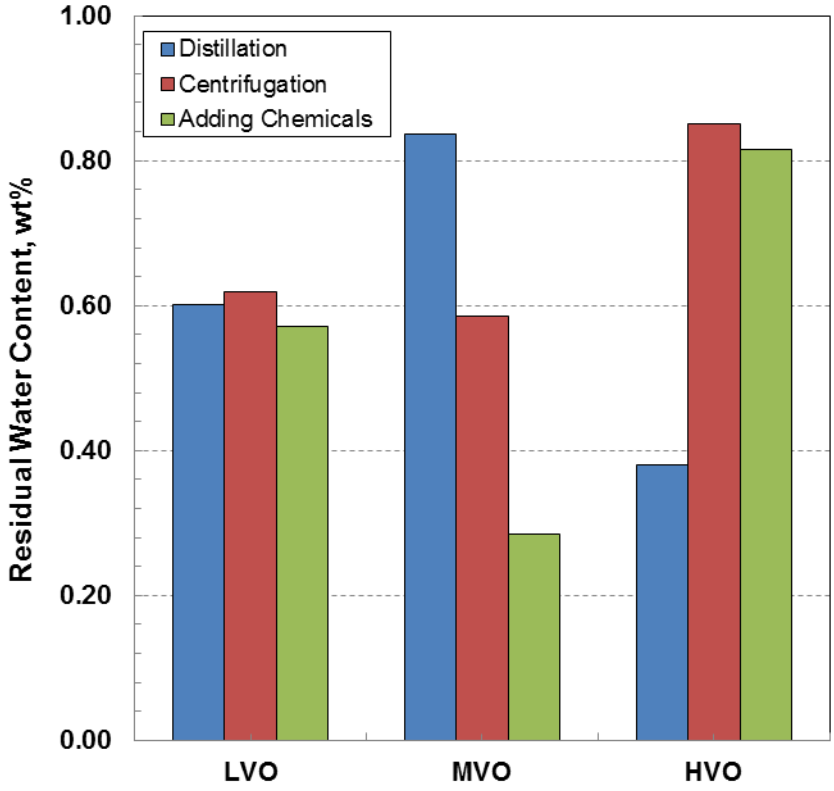


Figure 15: Residual Water Content of Dewatered Samples by Different Dewatering Methods: Post Viscosity and Density Measurement

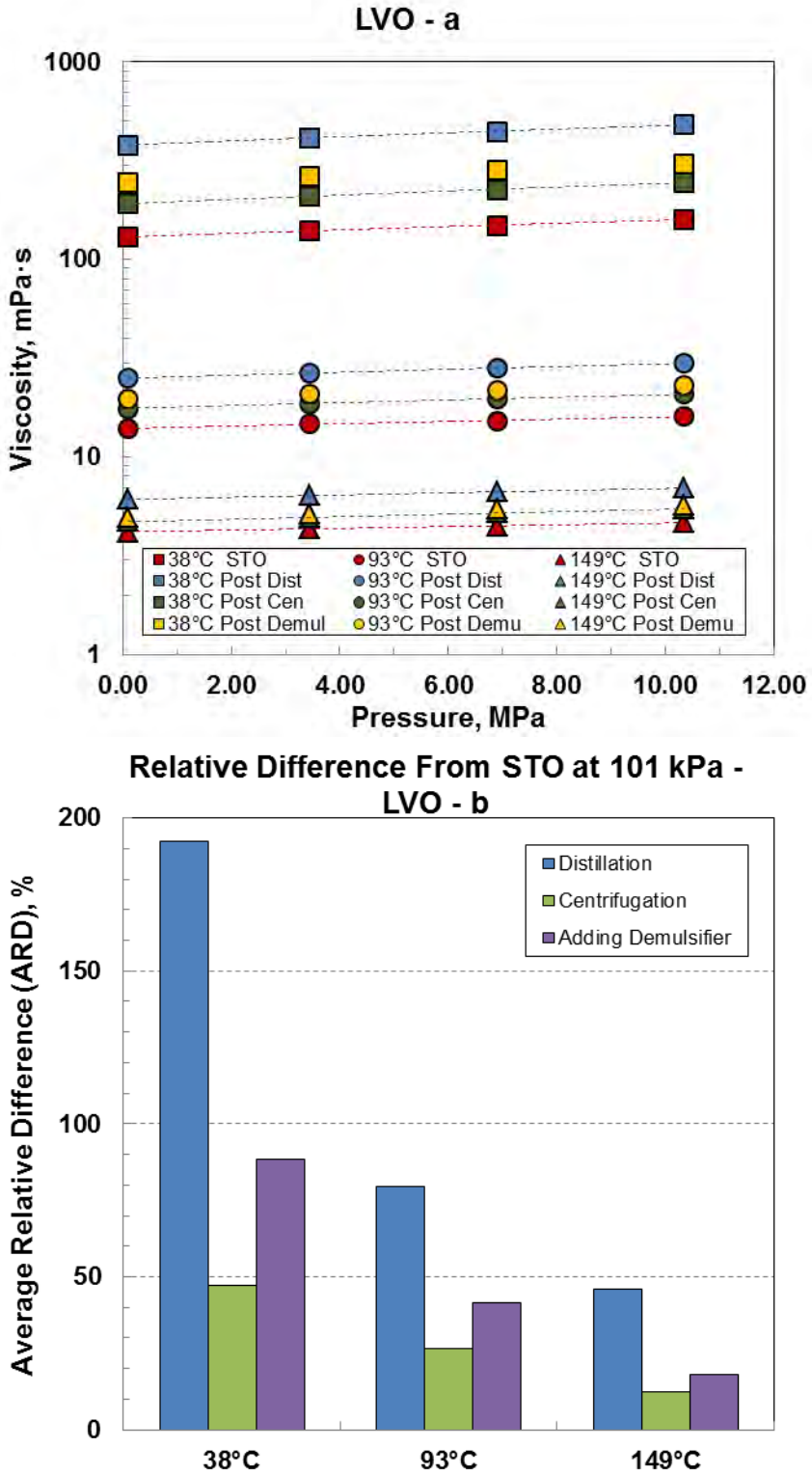
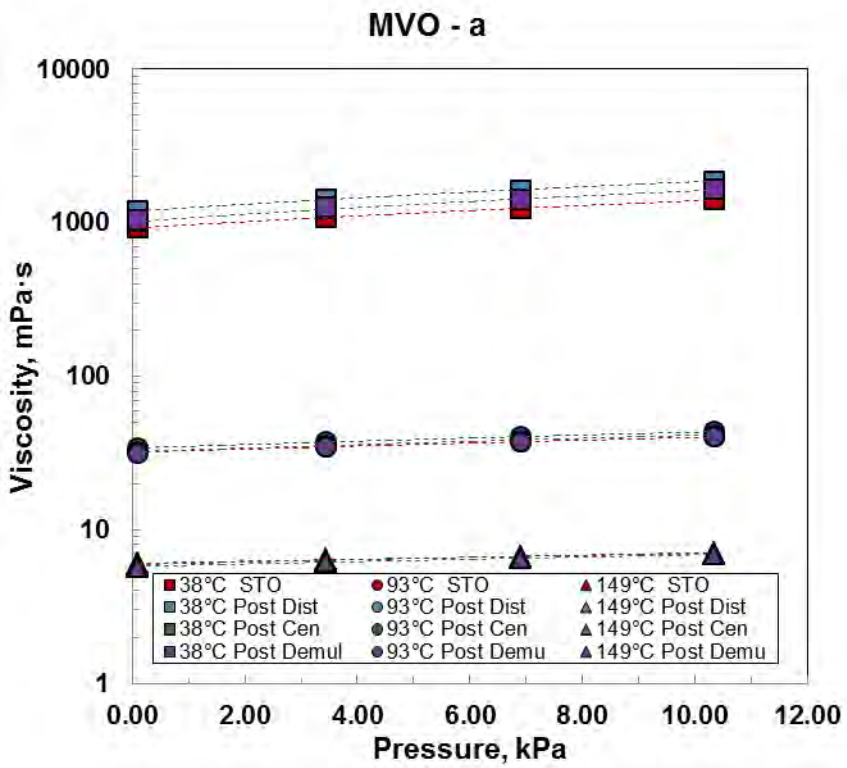


Figure 16: Viscosity Comparison between Dewatered Oils and the Original Oil ─ Low Viscous Oil (LVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Temperature



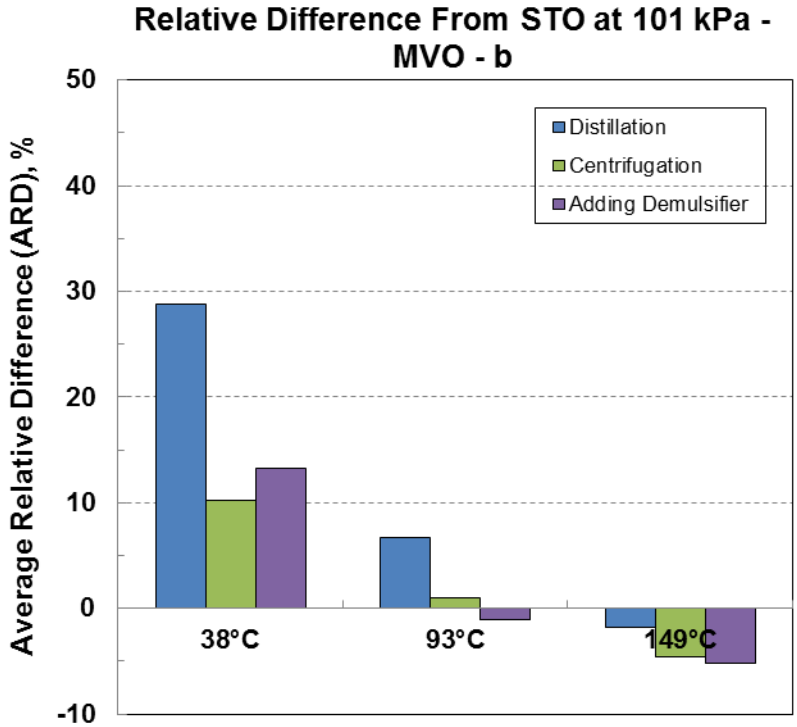


Figure 17: Viscosity Comparison between Dewatered Oils and the Original Oil ─ Medium Viscous Oil (MVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Temperature

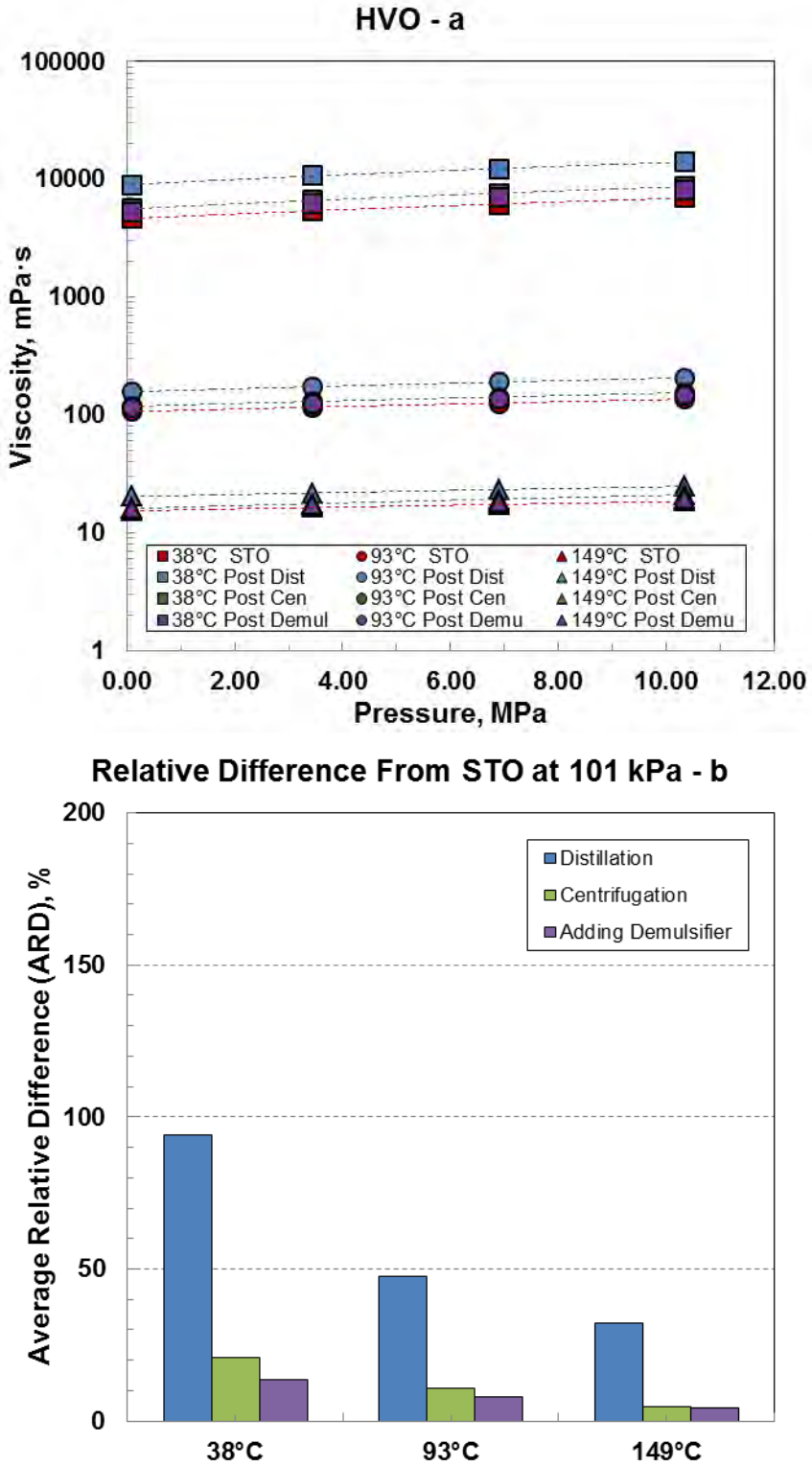


Figure 18: Viscosity Comparison between Dewatered Oils and the Original Oil ─ High Viscous Oil (HVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Temperature

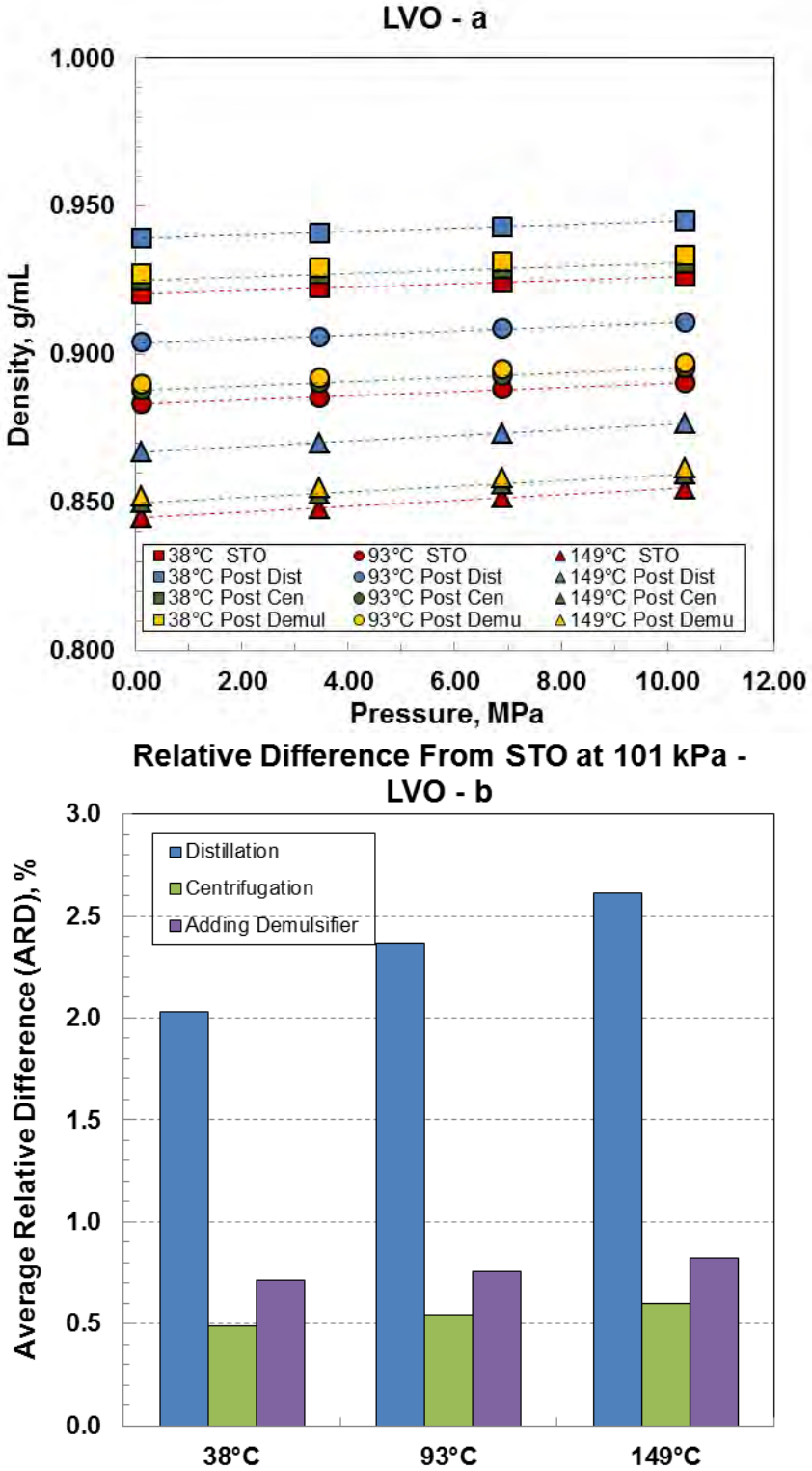
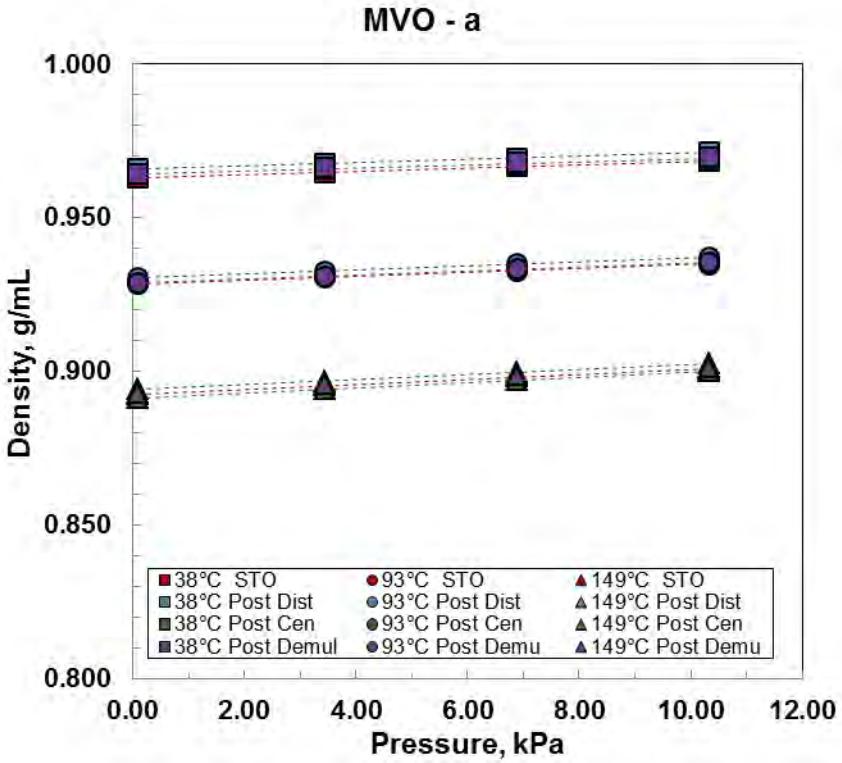


Figure 19: Density Comparison between Dewatered Oils and the Original Oil ─ Low Viscous Oil (LVO): a) Density vs. Pressure; b) Relative Difference vs. Temperature



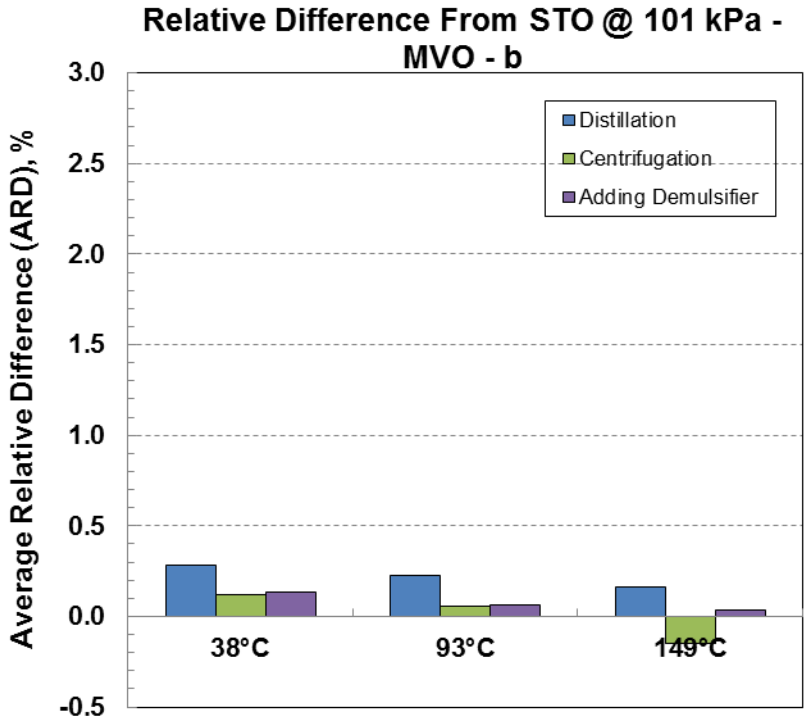


Figure 20: Density Comparison between Dewatered Oils and the Original Oil ─ Medium Viscous Oil (MVO): a) Density vs. Pressure; b) Relative Difference vs. Temperature

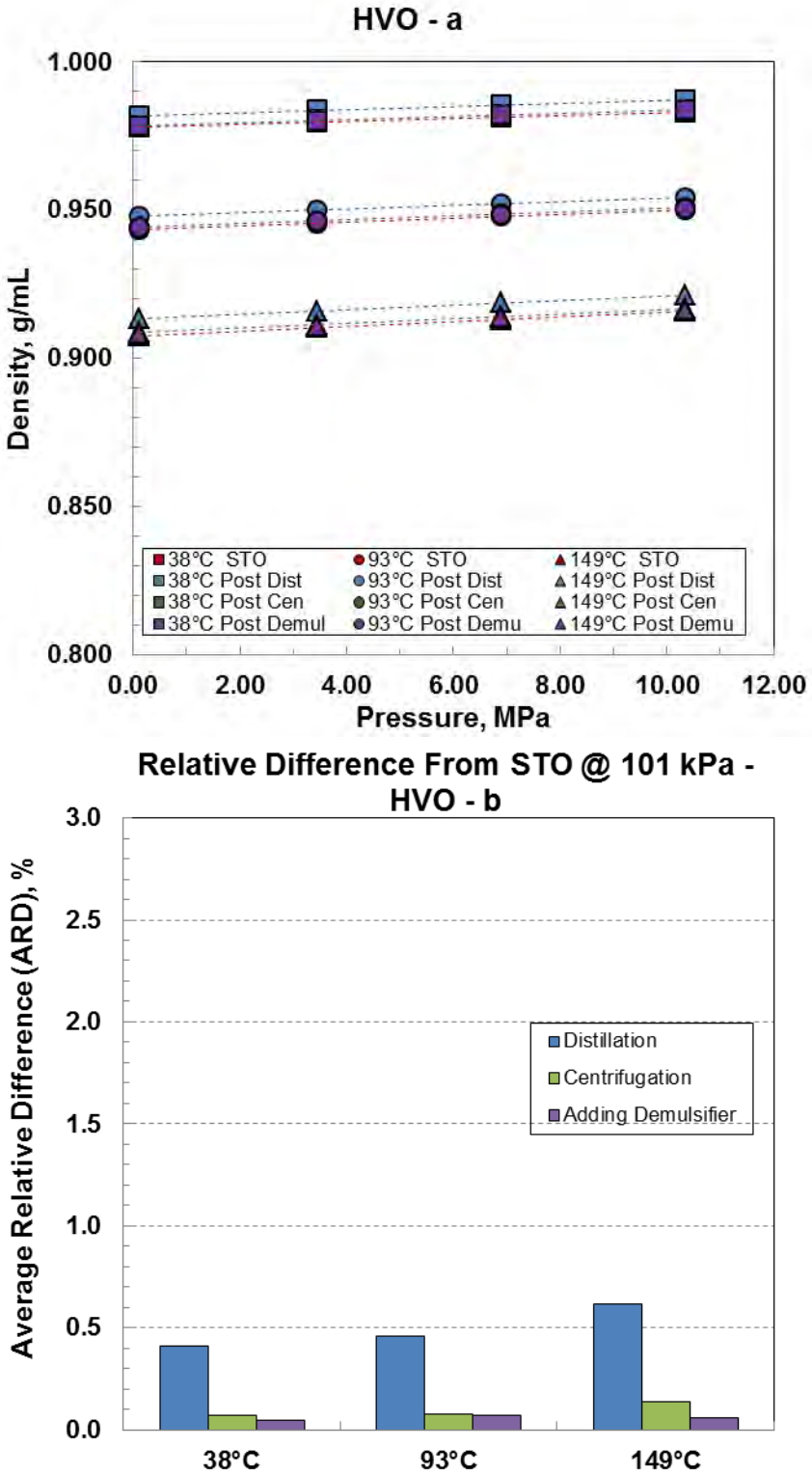
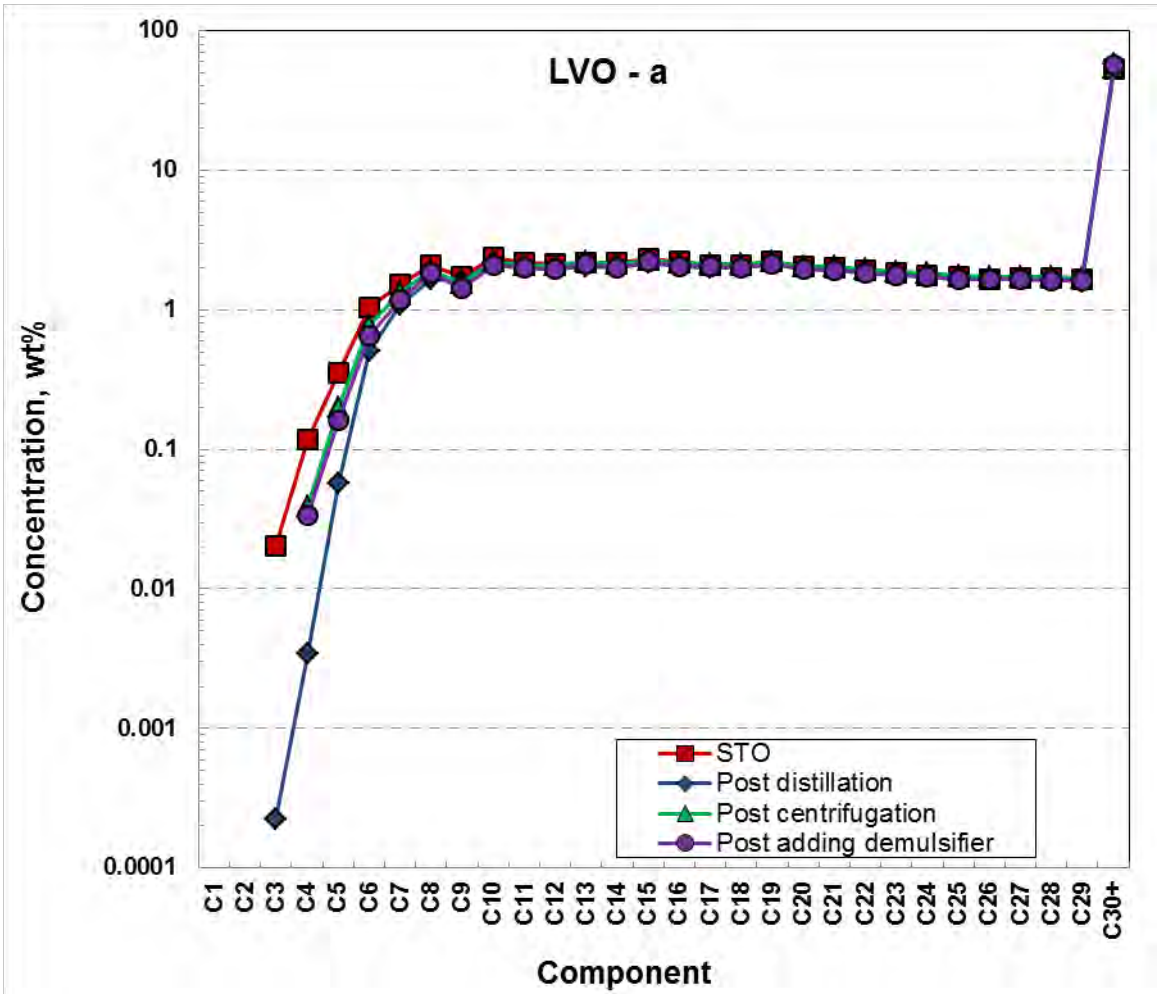


Figure 21: Density Comparison between Dewatered Oils and the Original Oil ─ High Viscous Oil (HVO): a) Density vs. Pressure; b) Relative Difference vs. Temperature


LVO - a
Concentration, wt%
100
10
1
0.1
0.01
0.001
0.0001
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30+
Component
STO
Post distillation
Post centrifugation
Post adding demulsifier

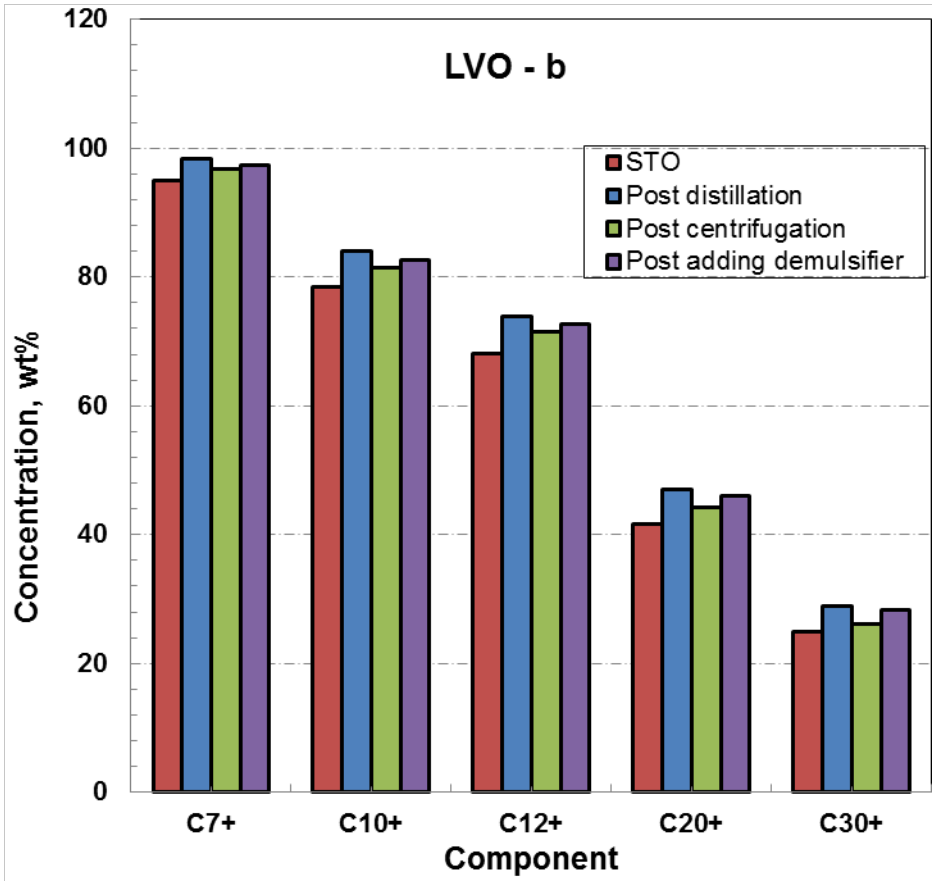
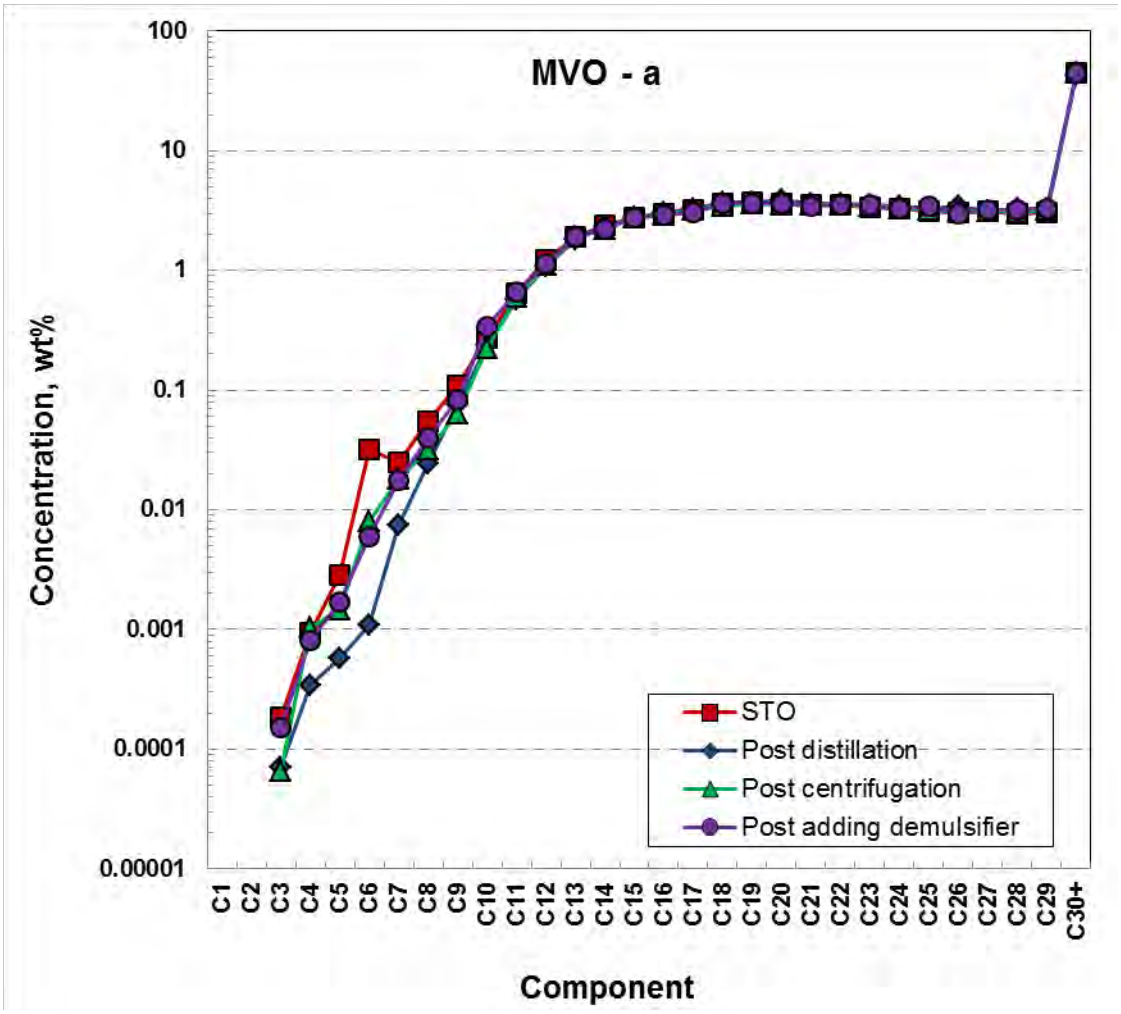


Figure 22: Impact of Dewatering Methods on O il Composition – Low Viscous Oil (LVO): a) Concentration vs. Component; and b) Concentration vs. Component Group


MVO - a
Concentration, wt%
100
10
1
0.1
0.01
0.001
0.0001
0.00001
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30+
Component
STO
Post distillation
Post centrifugation
Post adding demulsifier

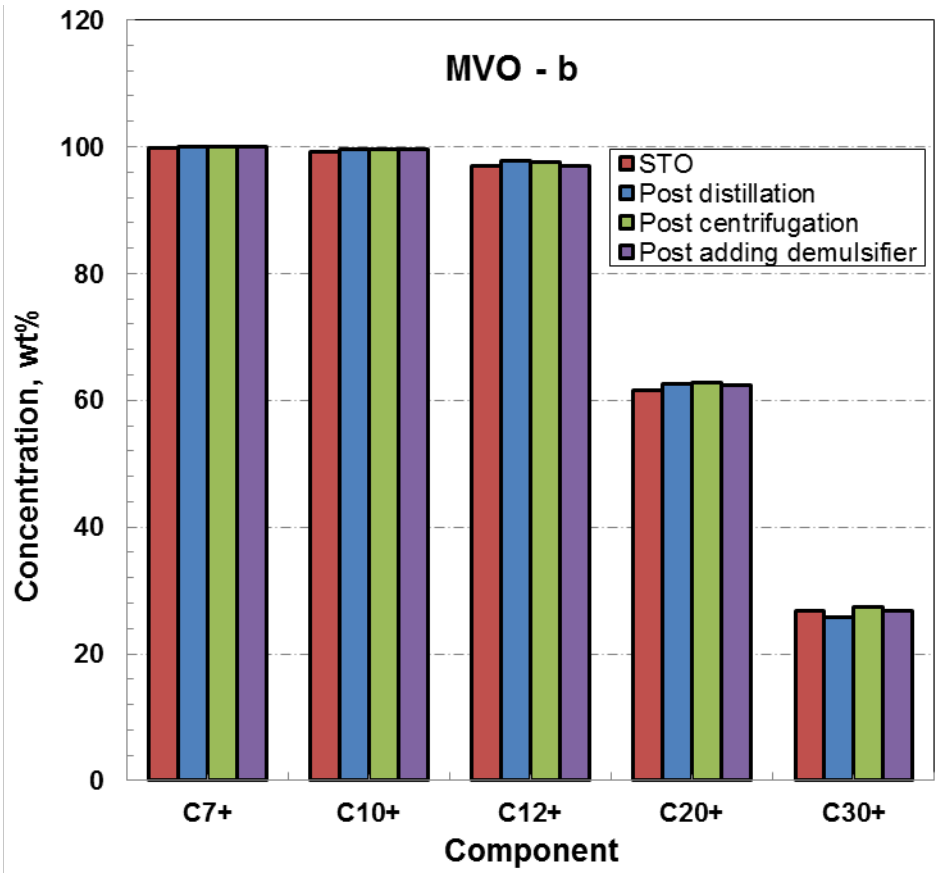
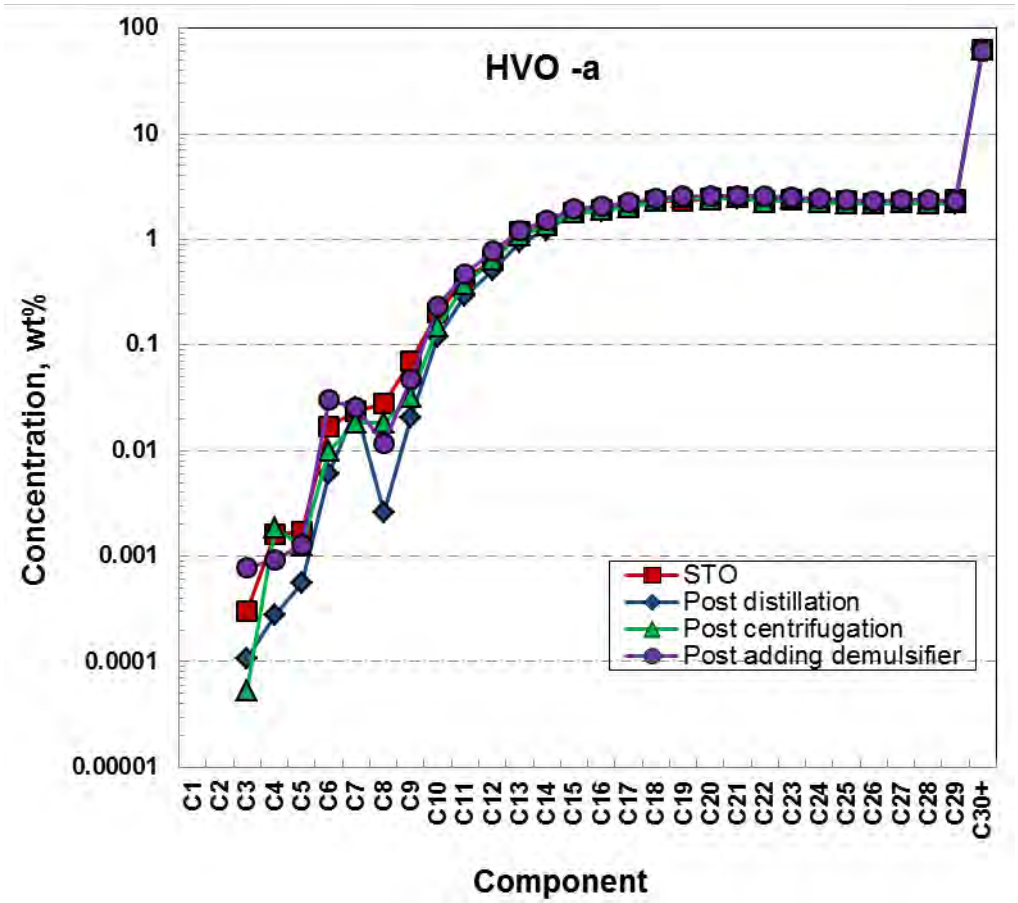


Figure 23: Impact of Dewatering Methods on Oil Composition ─ Medium Viscous Oil (MVO): a) Concentration vs. Component; and b) Concentration vs. Component Group


HVO -a
Concentration, wt%
100
10
1
0.1
0.01
0.001
0.0001
0.00001
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30+
Component
STO
Post distillation
Post centrifugation
Post adding demulsifier

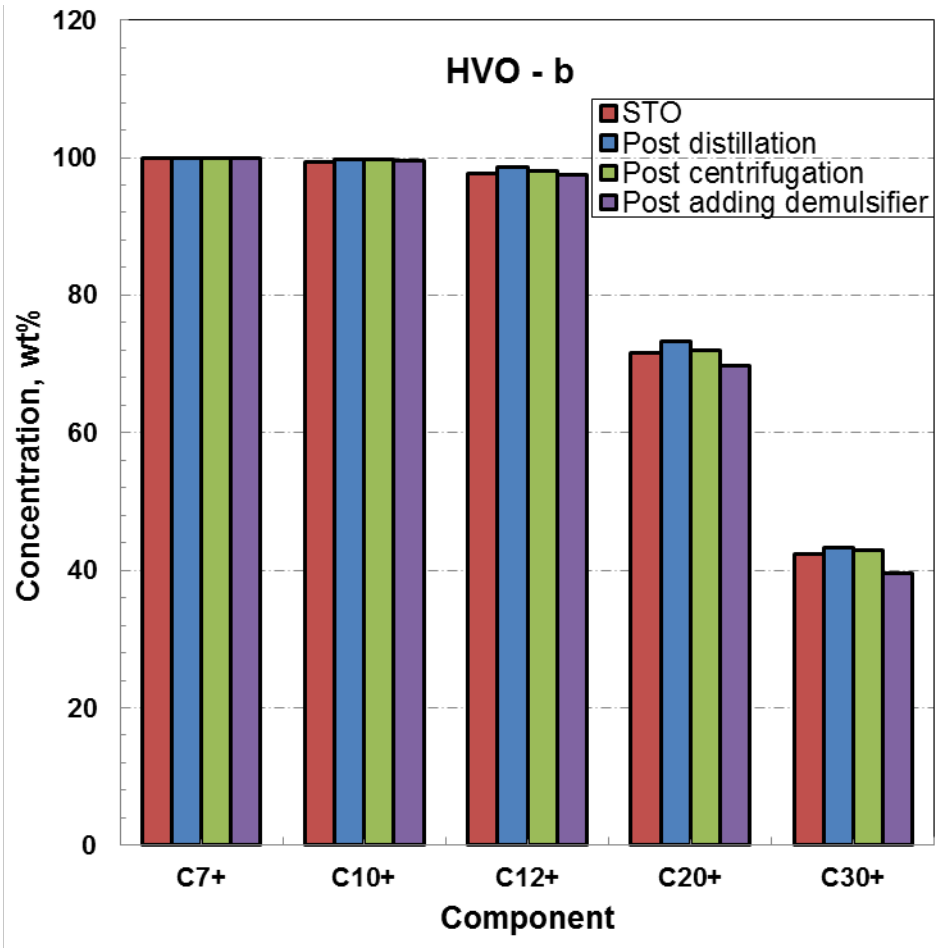
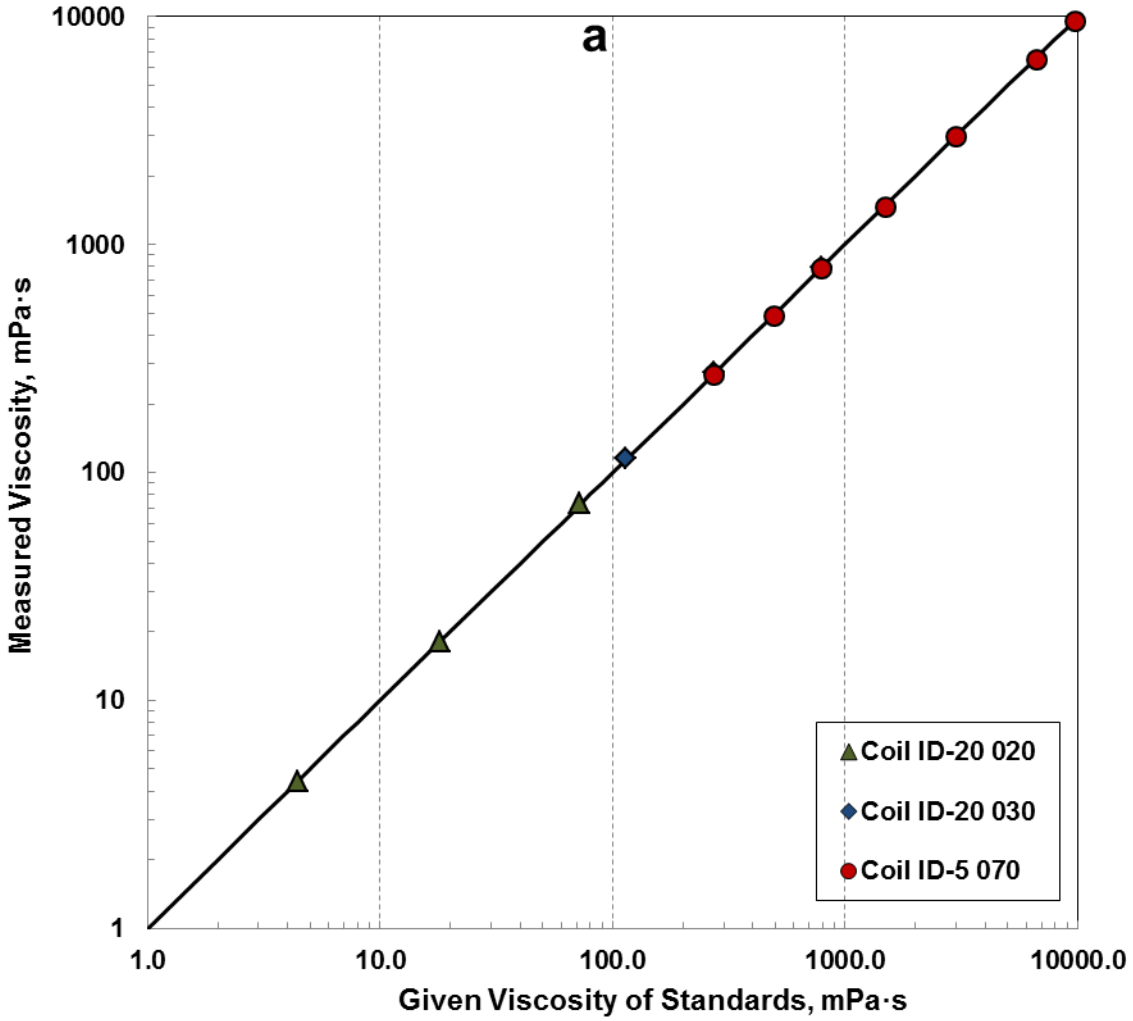


Figure 24: Impact of Dewatering Methods on Oil Composition ─ High Viscous Oil (HVO): a) Concentration vs. Component; and b) Concentration vs. Component Group


a
10000
1000
100
10
1
Measured Viscosity, mPa·s
1.0
10.0
100.0
1000.0
10000.0
Given Viscosity of Standards, mPa·s
Coil ID-20 020
Coil ID-20 030
Coil ID-5 070

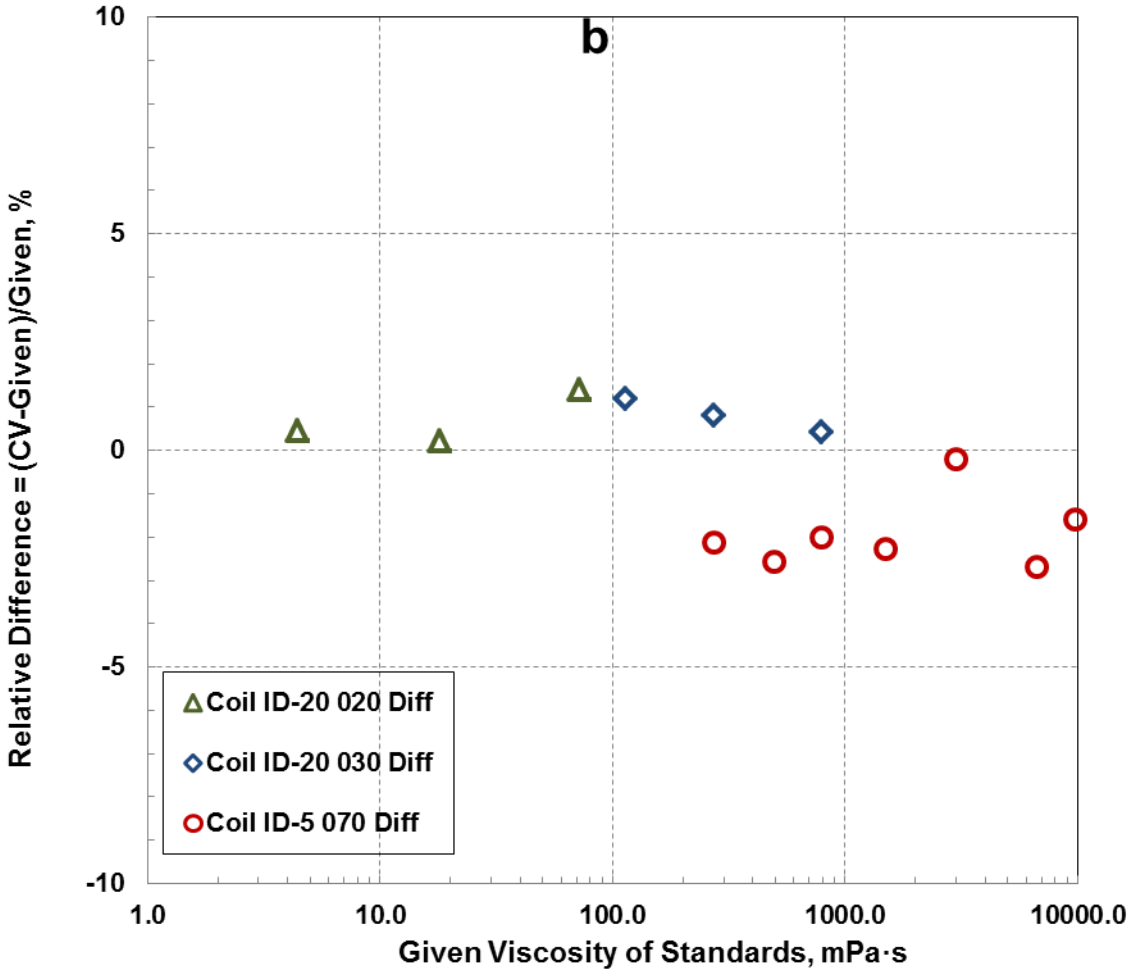
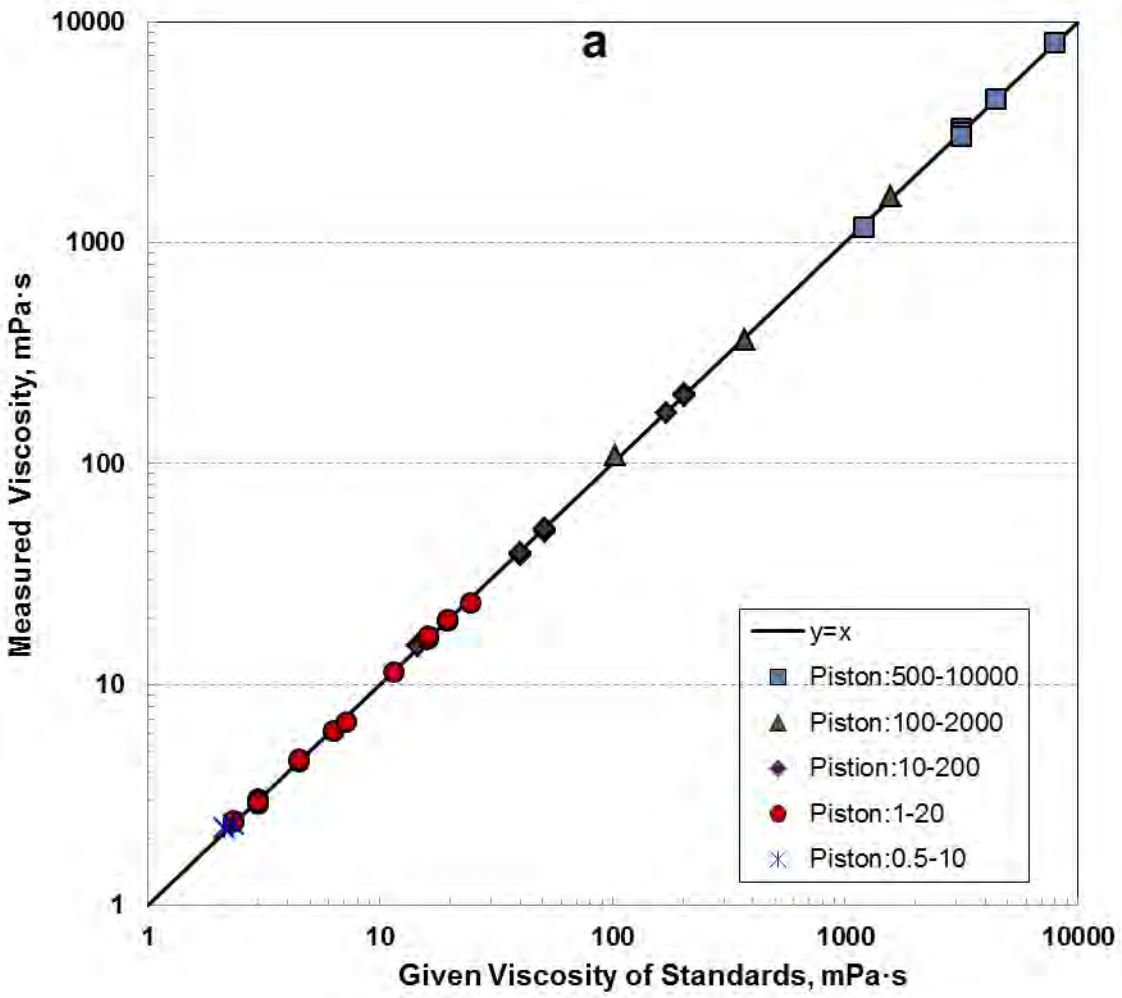


Figure 25: Results of Capillary Viscometer (CV) Validation Tests, for Different Coils, Using Viscosity Standards at Various Temperatures: a) Measured Viscosity vs. Given Viscosity; b) Relative Difference vs. Given Viscosity


a
10000
1000
100
10
1
Measured Viscosity, mPa·s
1
10
100
1000
10000
Given Viscosity of Standards, mPa·s
y=x
Piston:500-10000
Piston:100-2000
Pistion:10-200
Piston:1-20
Piston:0.5-10

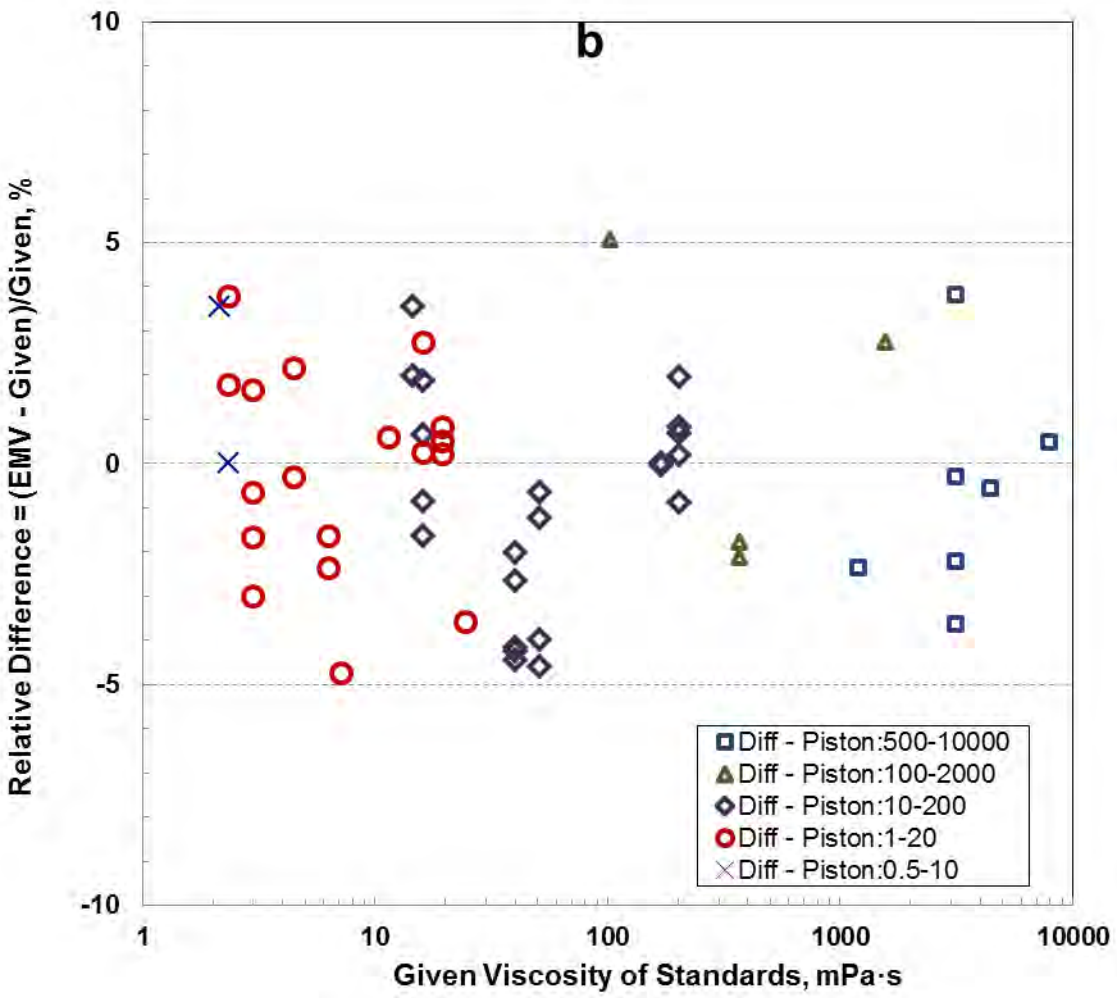
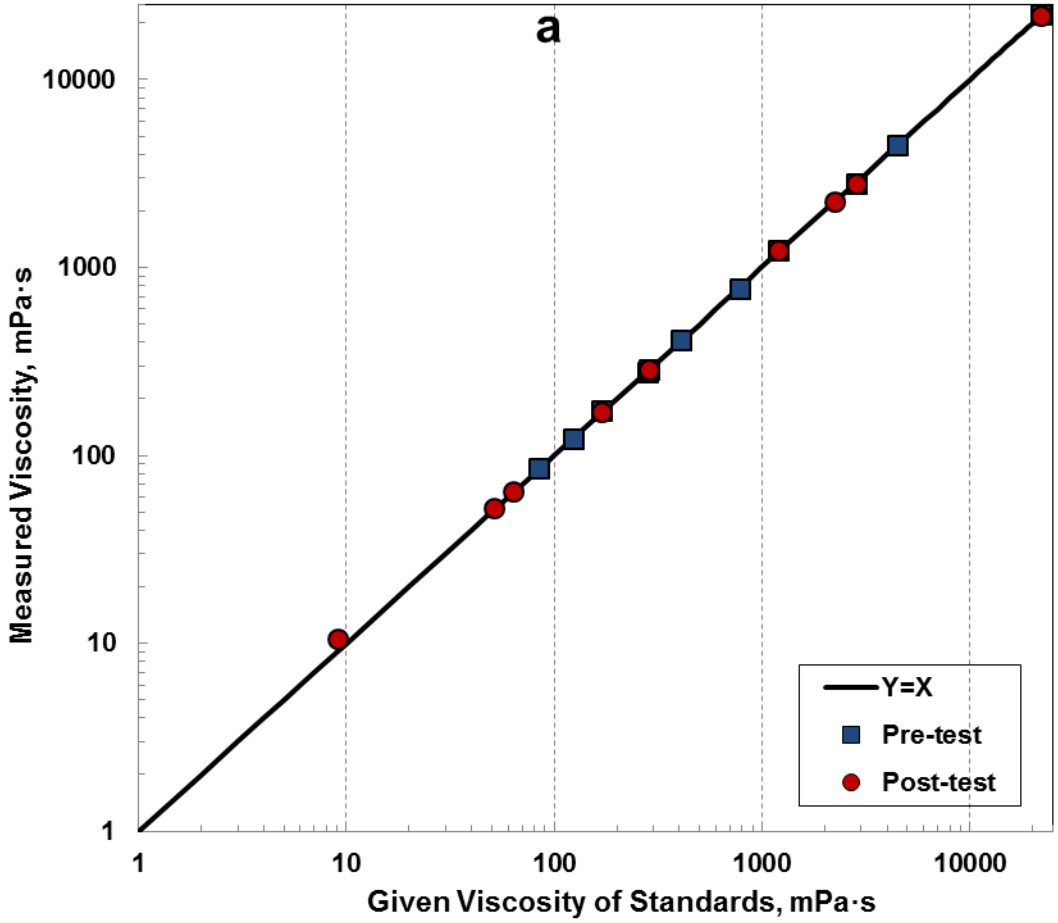


Figure 26: Results of Electromagnetic Viscometer (EMV) Validation Tests, for Different Pistons, Using Viscosity Standards at Various Temperatures: a) Measured Viscosity vs. Given Viscosity; b) Relative Difference vs. Given Viscosity


a
10000
1000
100
10
1
Measured Viscosity, mPa·s
1
10
100
1000
10000
Given Viscosity of Standards, mPa·s
Y=X
Pre-test
Post-test

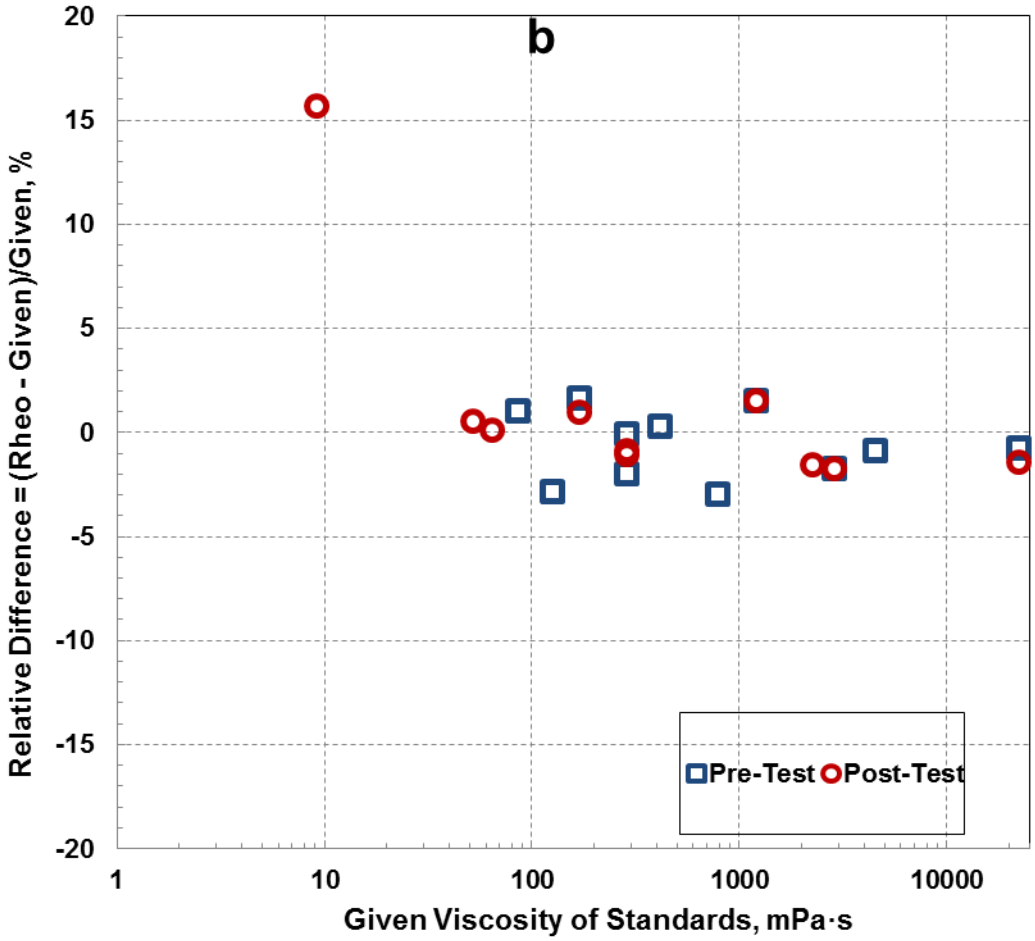
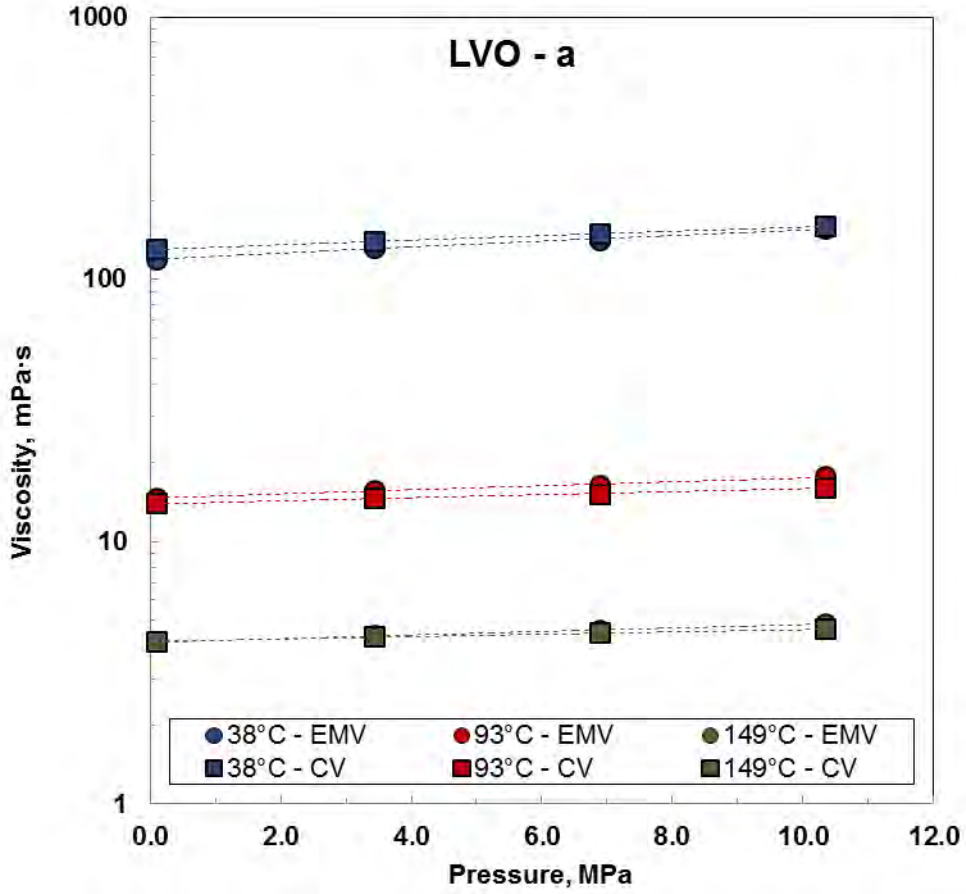


Figure 27: Results of Rheometer (Rheo) Validation Tests Using Viscosity Standards at Various Temperatures: a) Measured Viscosity vs. Given Viscosity; b) Relative Difference vs. Given Viscosity


LVO - a
1000
100
10
1
Viscosity, mPa·s
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Pressure, MPa
38°C - EMV
93°C - EMV
149°C - EMV
38°C - CV
93°C - CV
149°C - CV

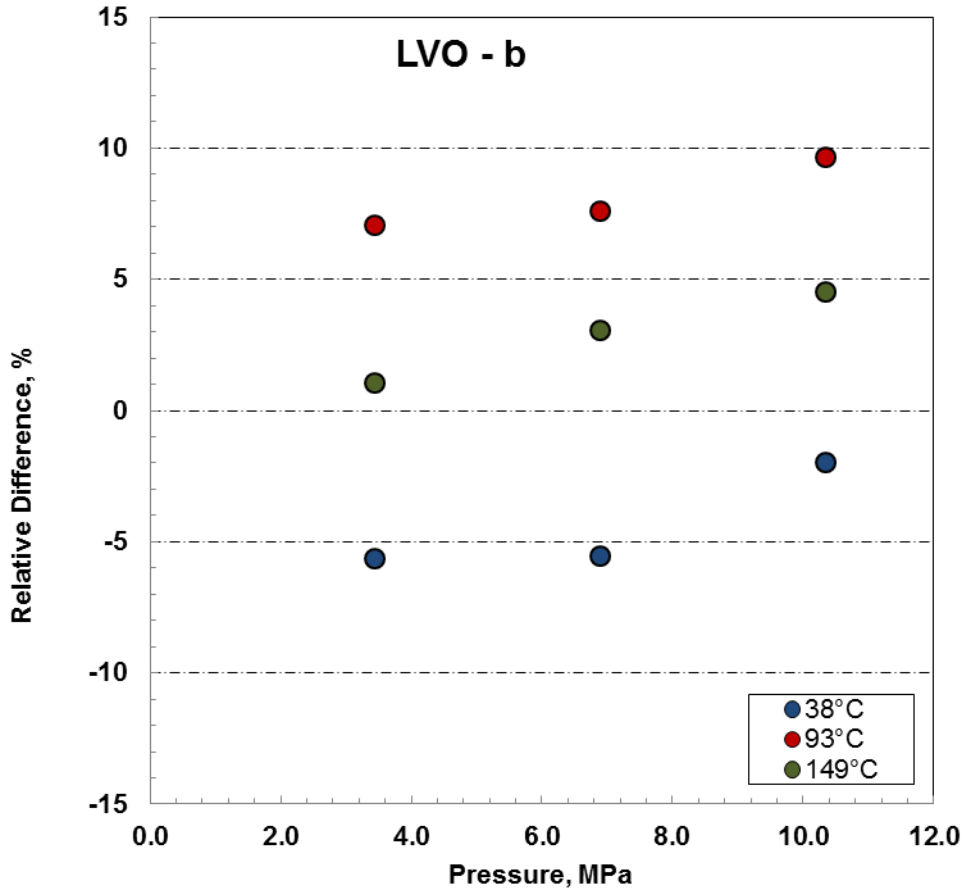
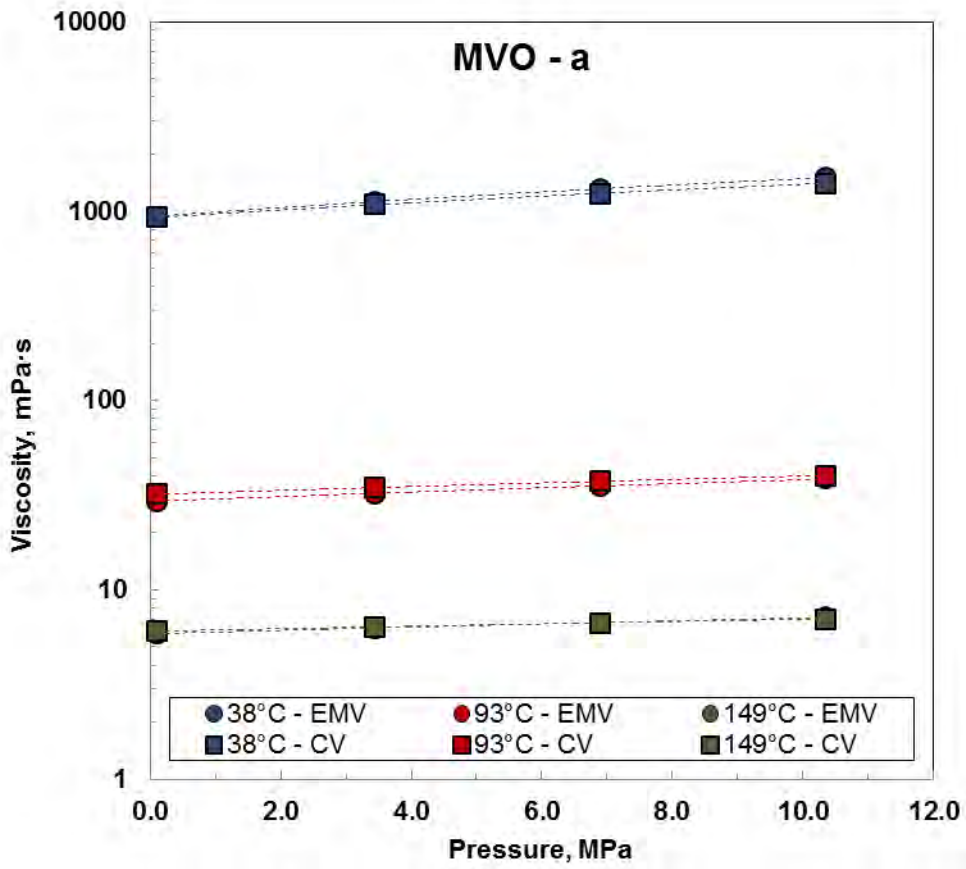


Figure 28: Comparison of Stock Tank Oil Viscosity Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) – Light Viscous Oil (LVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Pressure


MVO - a
10000
1000
100
10
1
Viscosity, mPa·s
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Pressure, MPa
38°C - EMV
93°C - EMV
149°C - EMV
38°C - CV
93°C - CV
149°C - CV

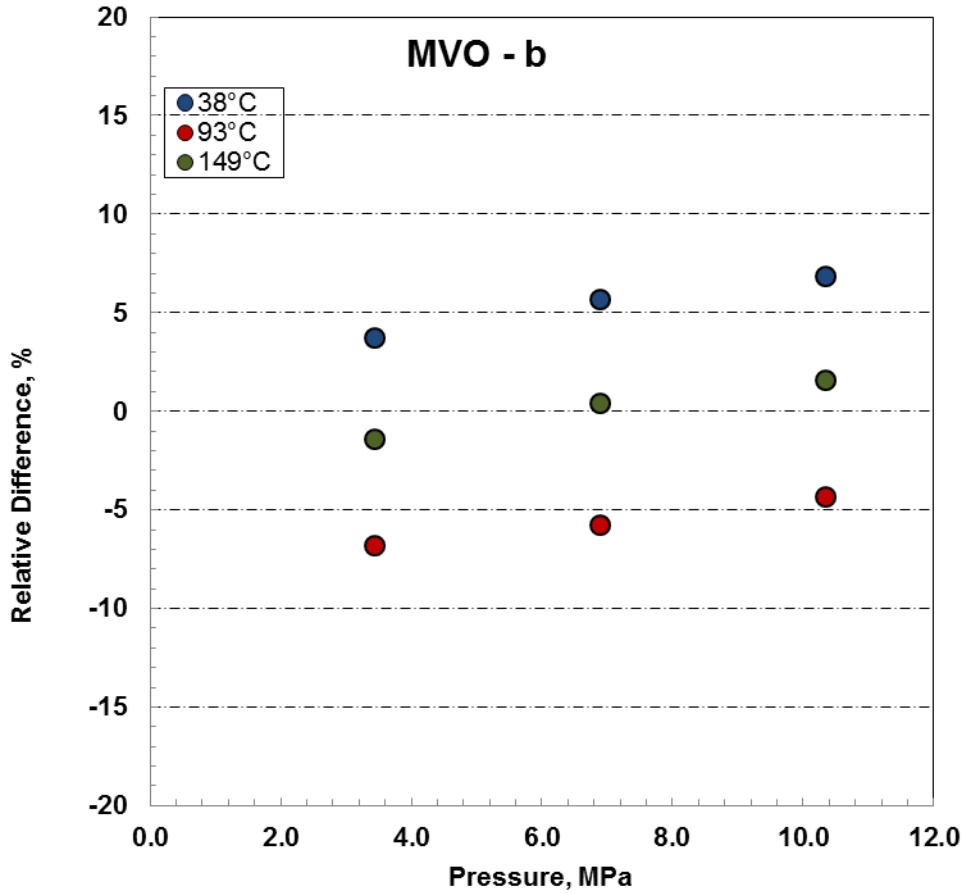
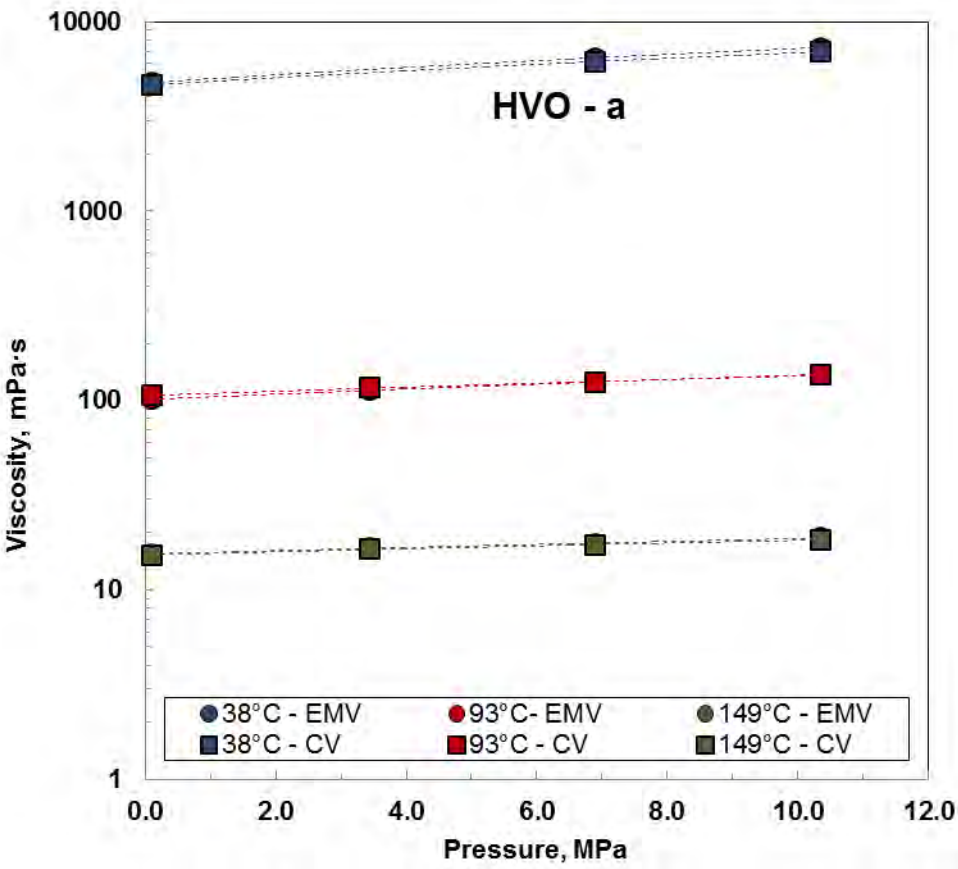


Figure 29: Comparison of Stock Tank Oil Viscosity Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) – Medium Viscous Oil (MVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Pressure


HVO - a
Viscosity, mPa·s
10000
1000
100
10
1
0.0
2.0
4.0
6.0
8.0
10.0
12.0
Pressure, MPa
38°C - EMV
93°C- EMV
149°C - EMV
38°C - CV
93°C - CV
149°C - CV

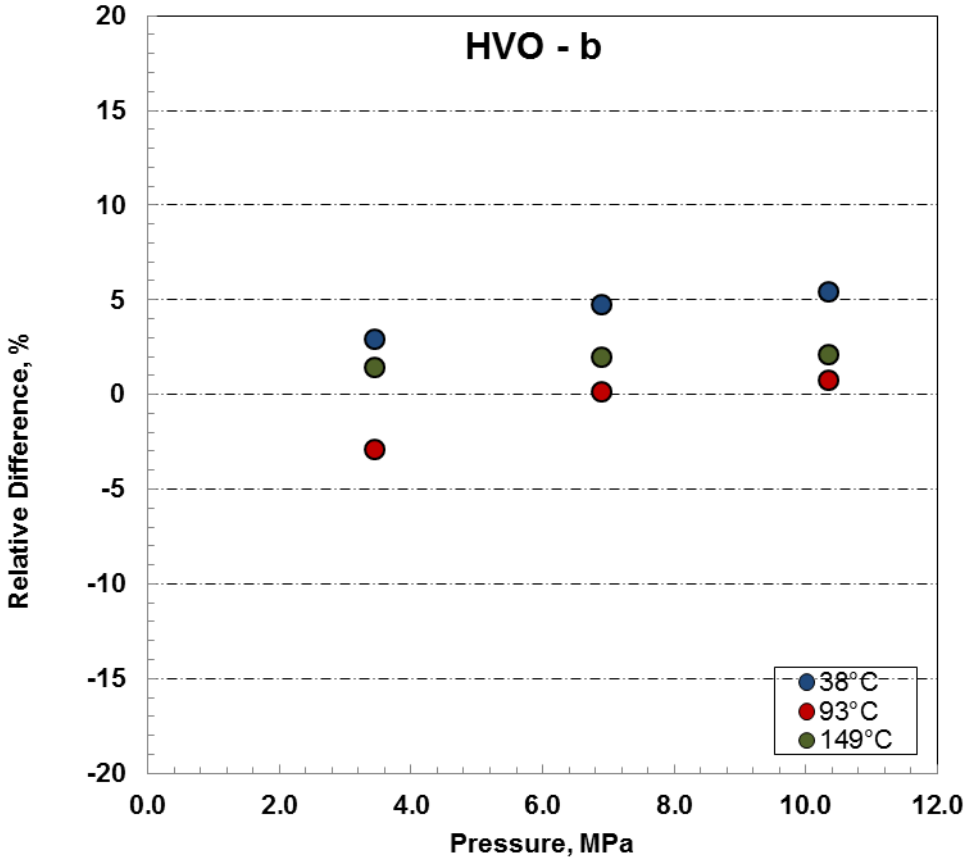


Figure 30: Comparison of Stock Tank Oil Viscosity Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) – High Viscous Oil (HVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Pressure

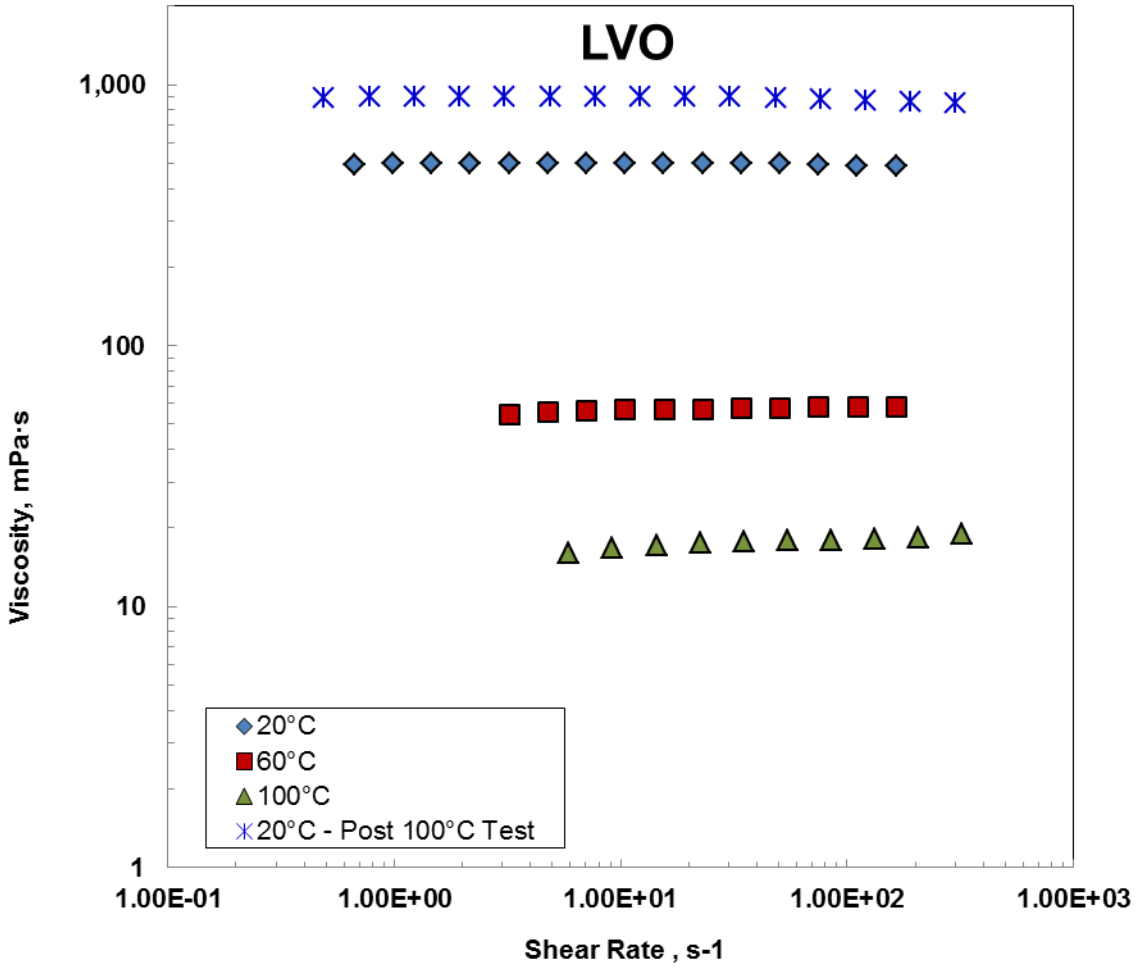


Figure 31: Viscosity of Stock Tank Oil Measured by Rheometer vs. Shear Rate – Low Viscous Oil (LVO)

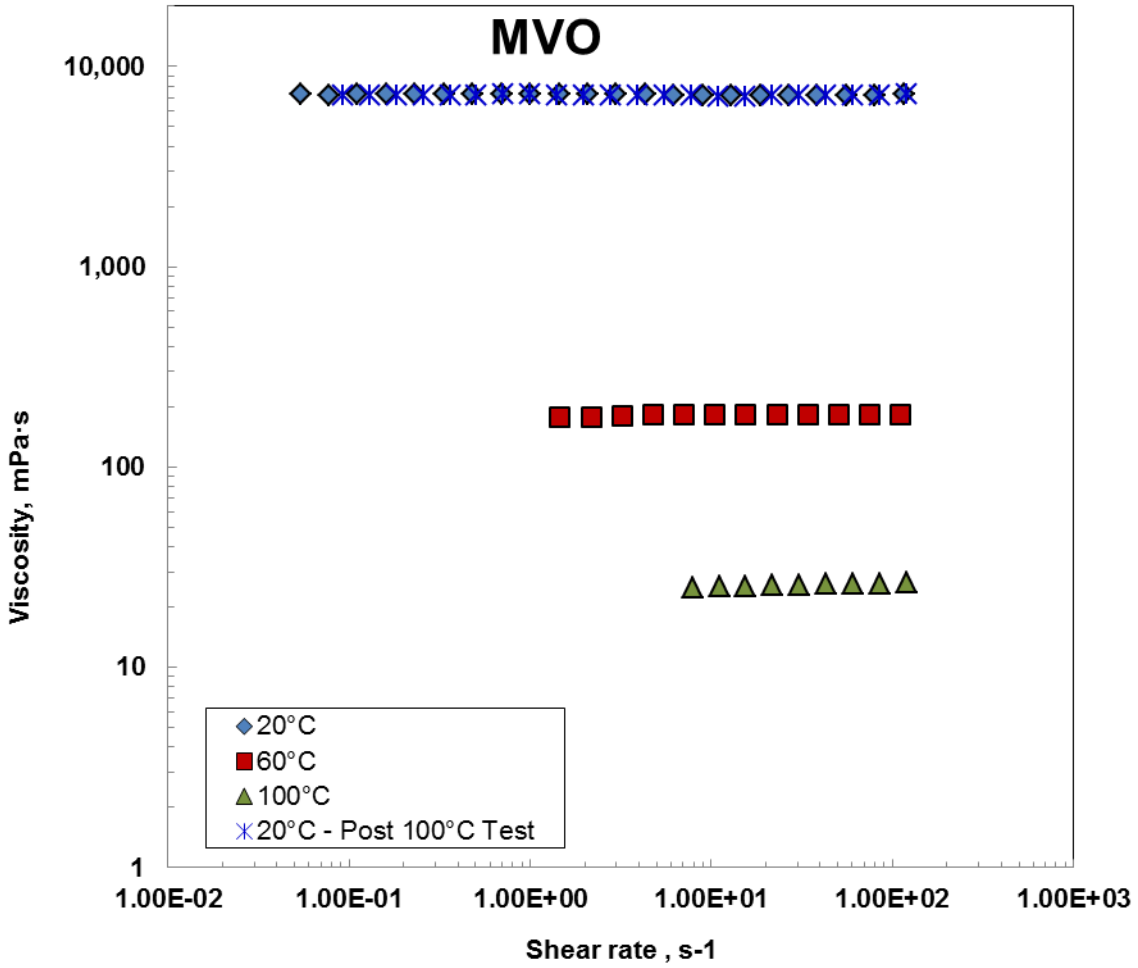


Figure 32: Viscosity of Stock Tank Oil Measured by Rheometer vs. Shear Rate – Medium Viscous Oil (MVO)

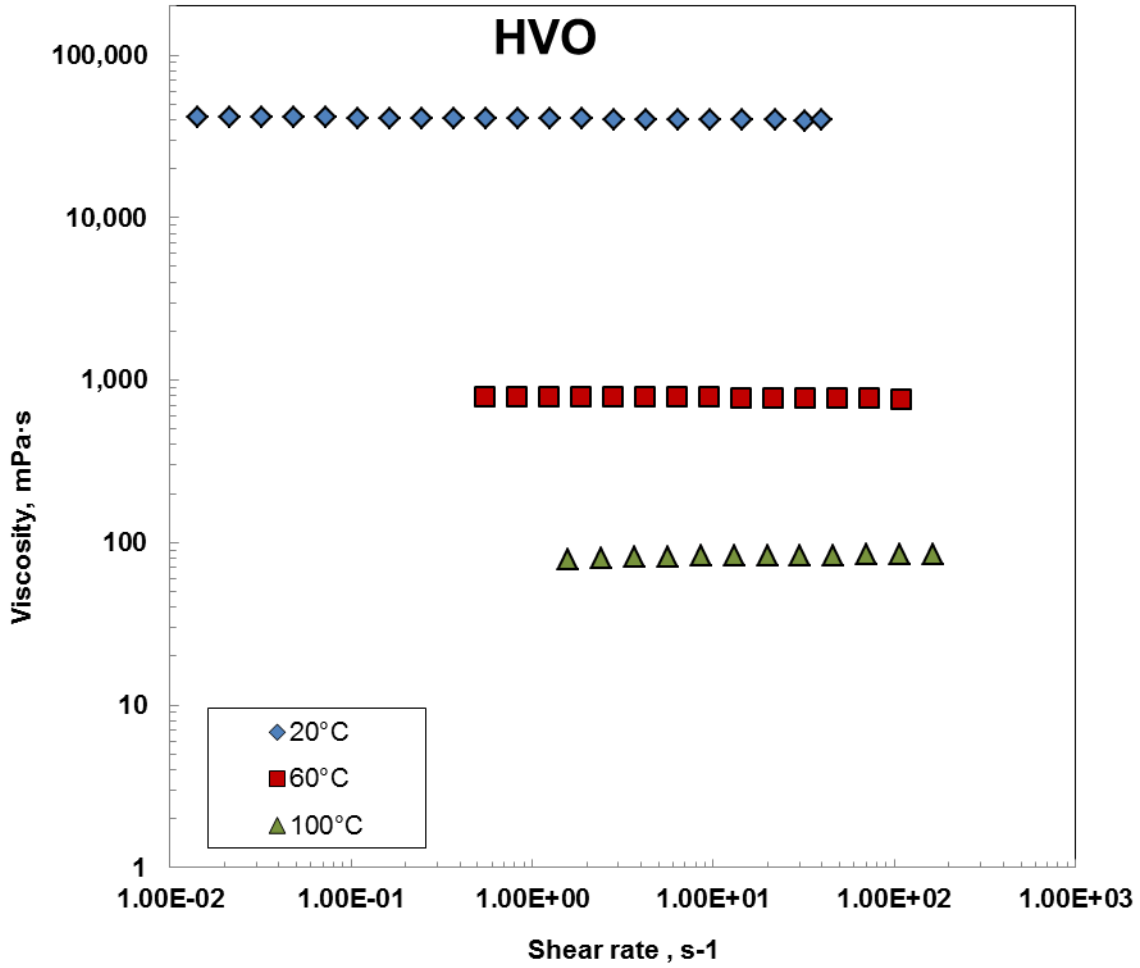
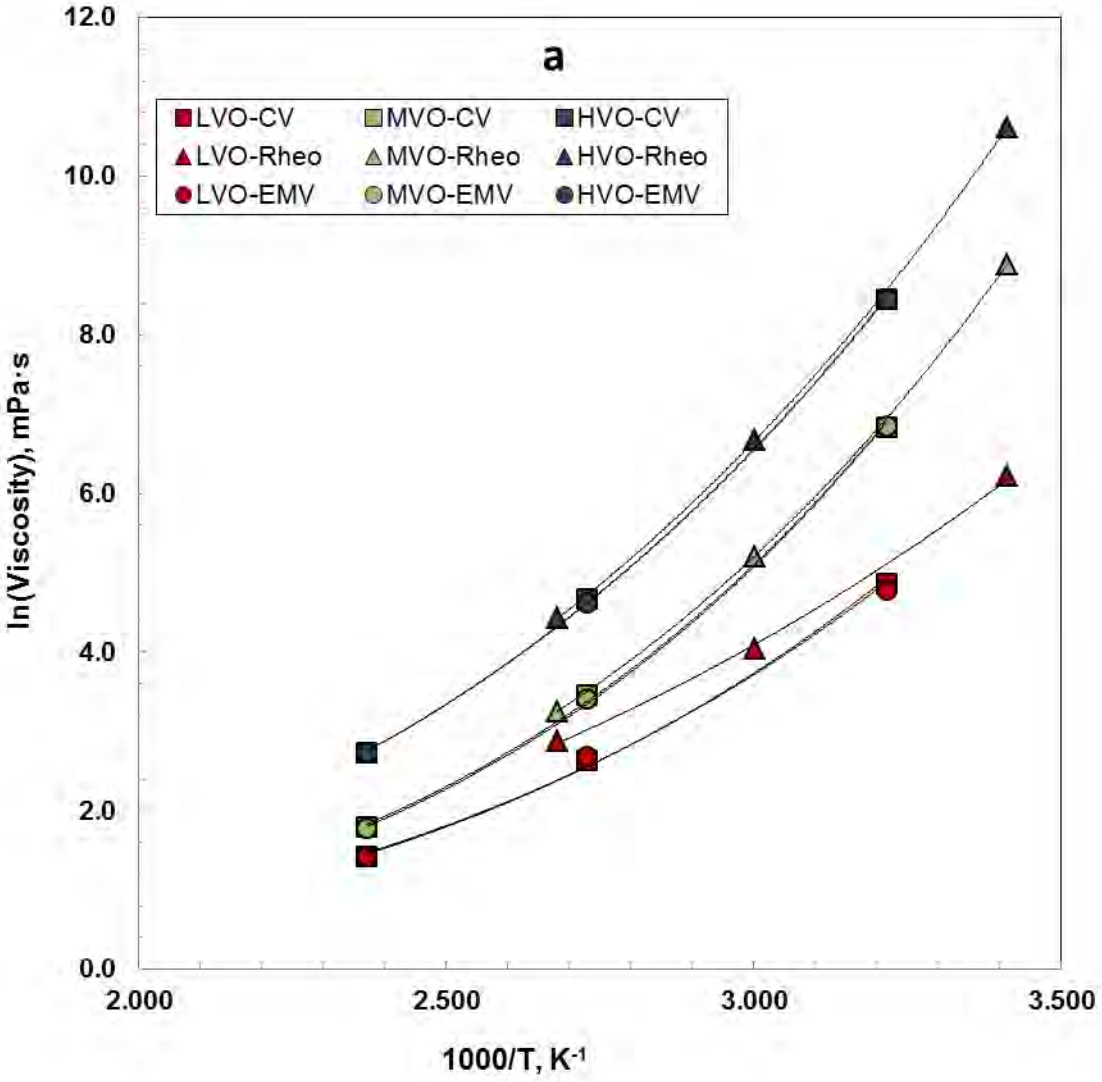


Figure 33: Viscosity of Stock Tank Oil Measured by Rheometer vs. Shear Rate – High Viscous Oil (HVO)


a
LVO-CV
MVO-CV
HVO-CV
LVO-Rheo
MVO-Rheo
HVO-Rheo
LVO-EMV
MVO-EMV
HVO-EMV
ln(Viscosity), mPa·s
1000/T, K-1
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2.000
2.500
3.000
3.500

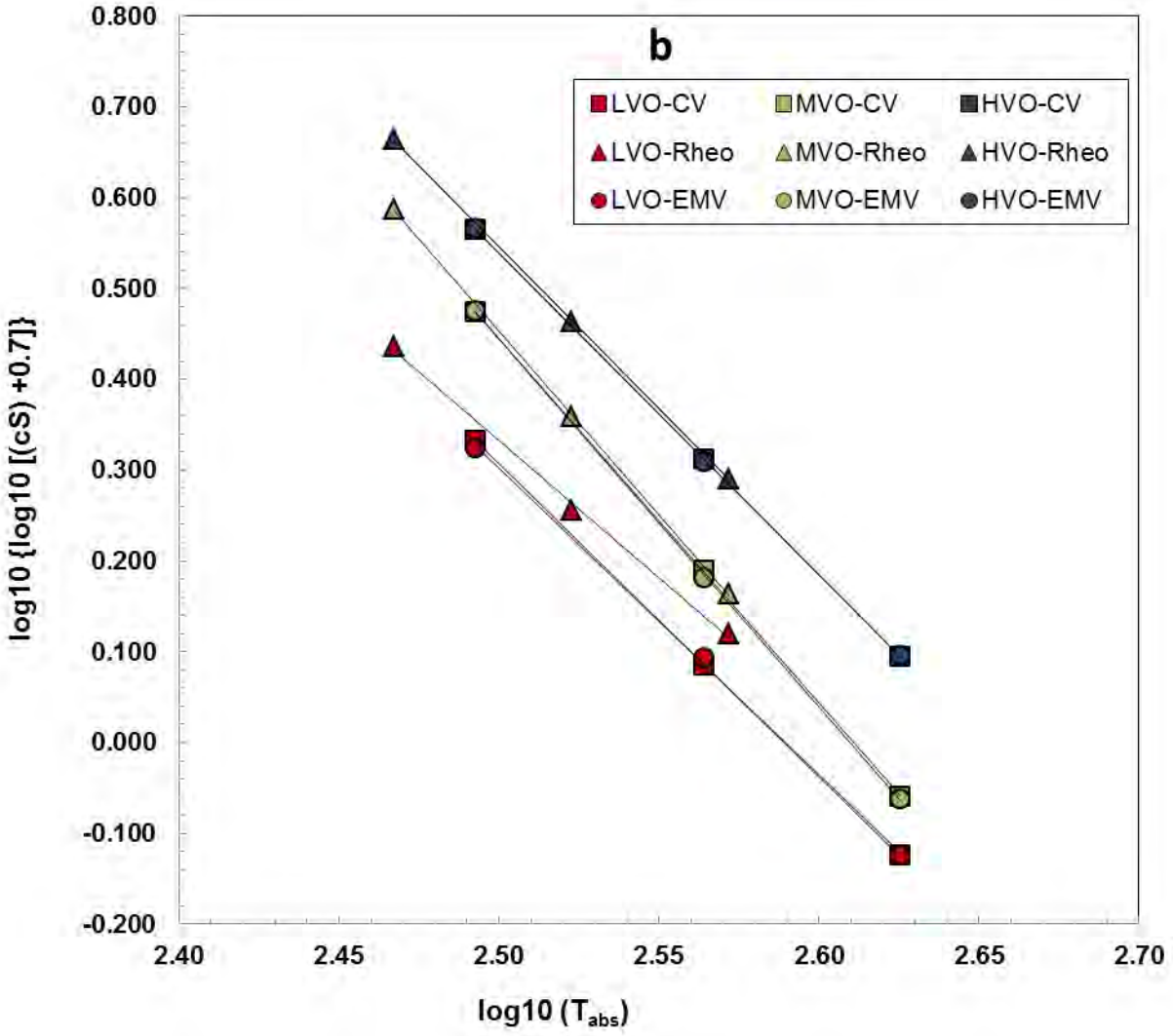


Figure 34: Comparison of Stock Tank Oil Viscosity Measured by Three Viscometers: a) ln (Viscosity) vs. 1000/T; b) log10 {log10 [(cS) +0.7]} vs. Log (T)

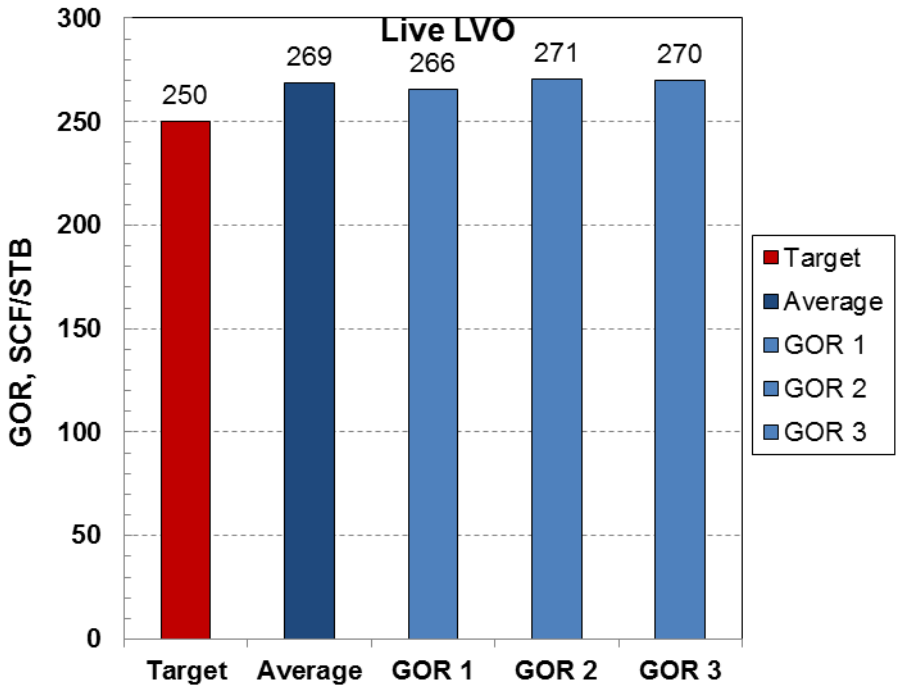


Figure 35: Comparison of Measured Gas-Oil-Ratio (GOR) with Target GOR for the Prepared Live Low Viscous Oil (Live LVO)

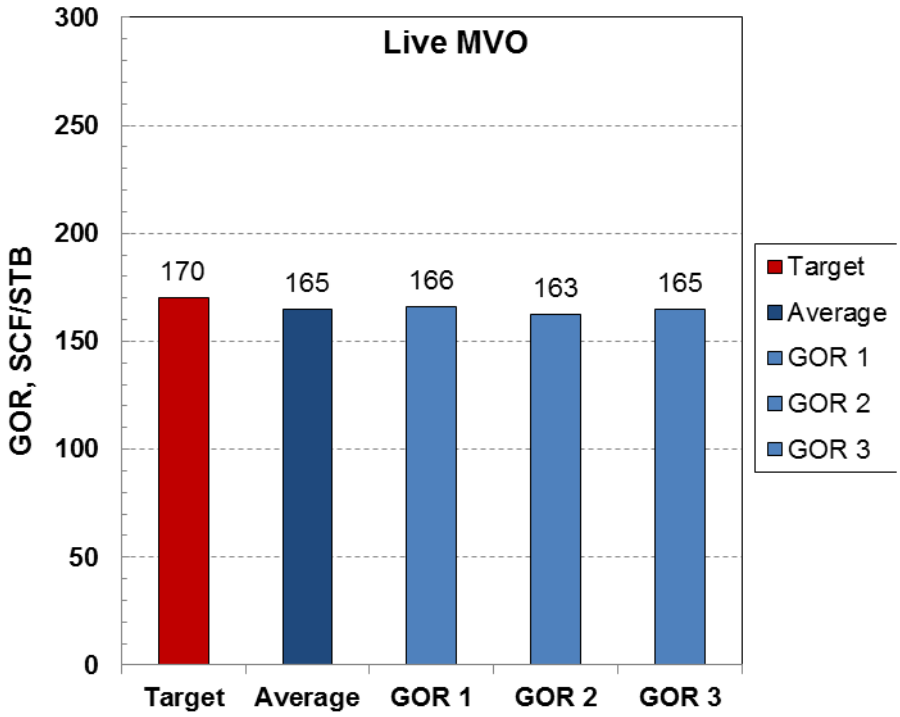


Figure 36: Comparison of Measured Gas-Oil-Ratio (GOR) with Target GOR for the Prepared Live Medium Viscous Oil (Live MVO)

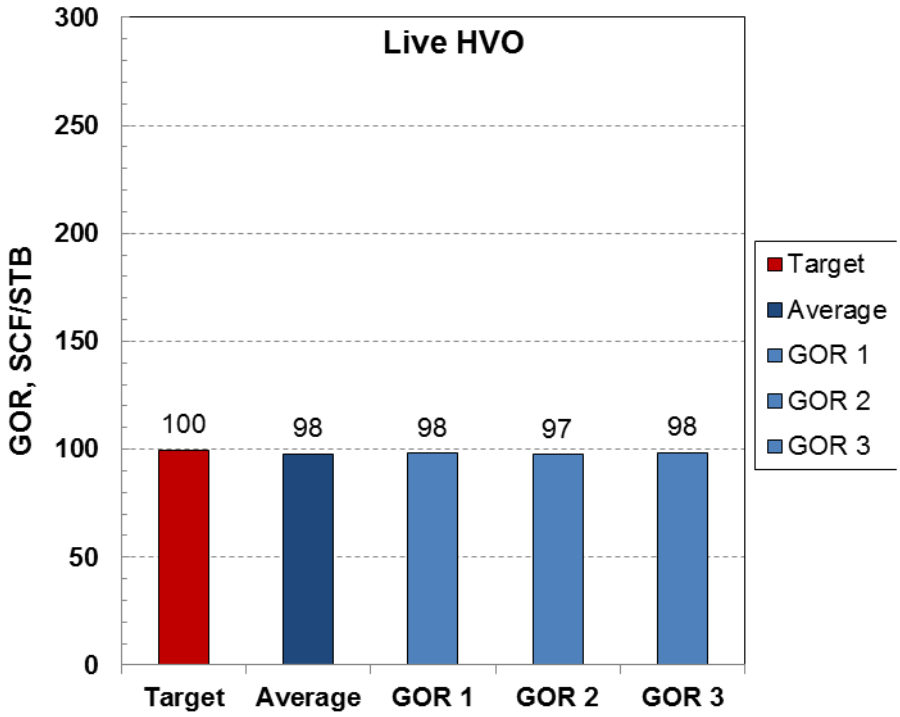


Figure 37: Comparison of Measured Gas-Oil-Ratio (GOR) with Target GOR for the Prepared Live High Viscous Oil (Live HVO)

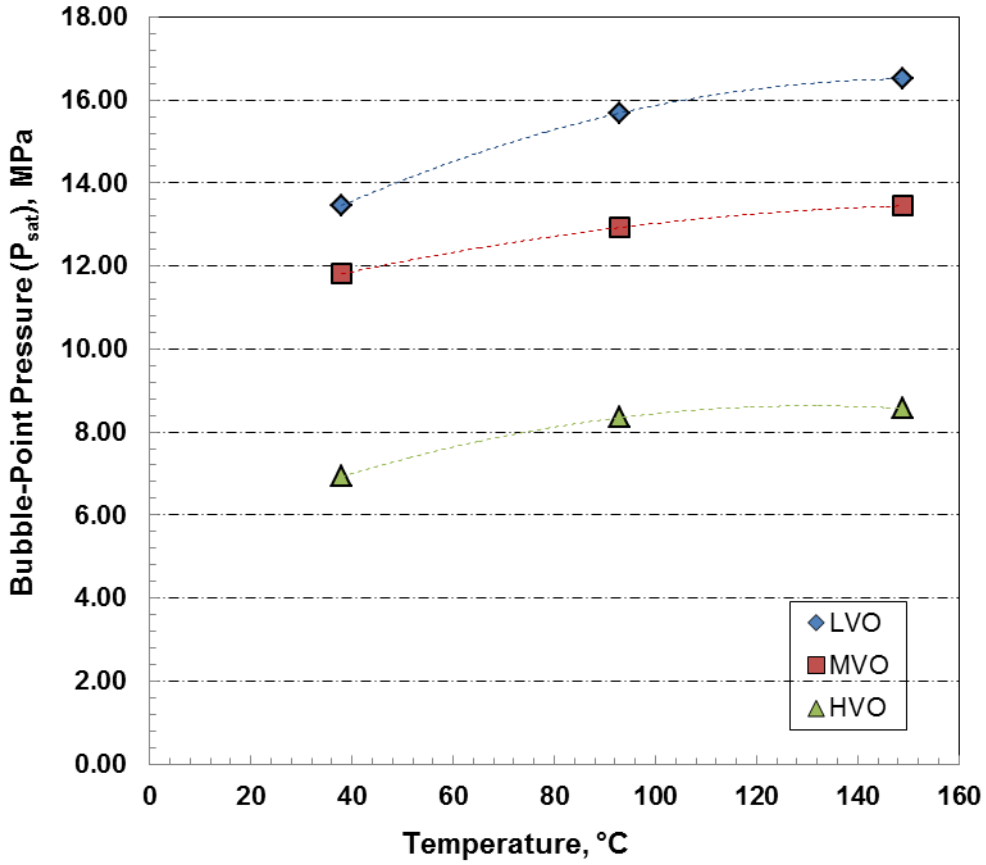


Figure 38: Plots of Saturation Pressure vs. Temperature for Three Live Oil Samples

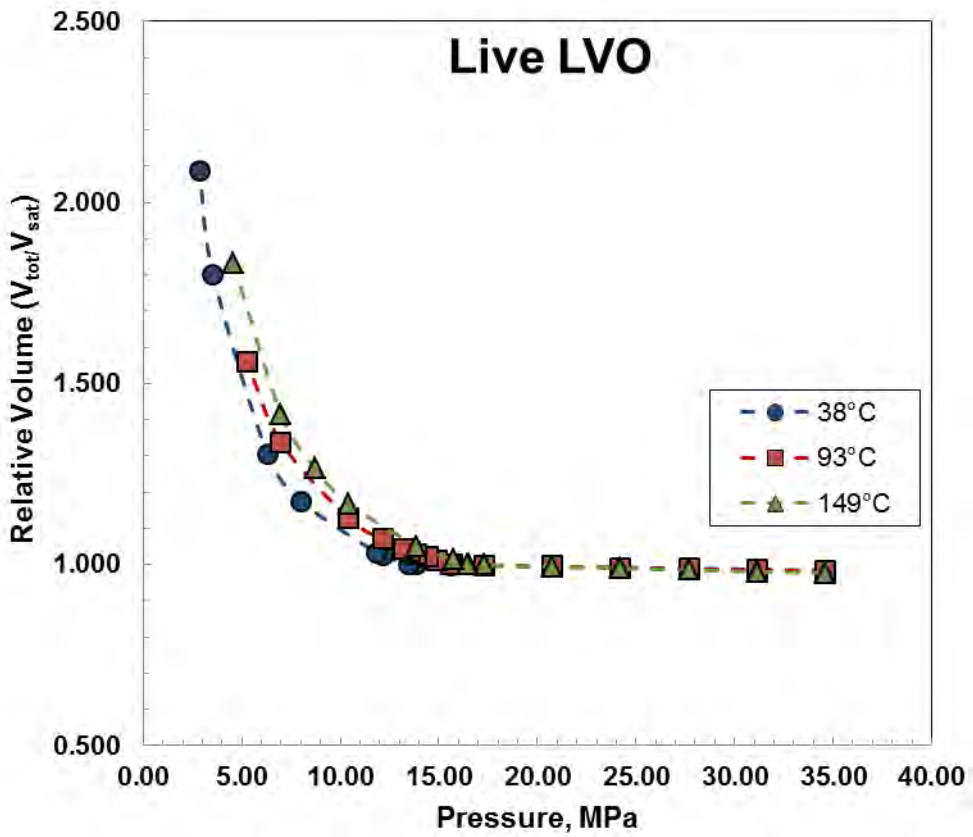


Figure 39: Plots of Relative Volume (V_{tot}/V_{sat}) vs. Pressure for the Live Low Viscous Oil (Live LVO)

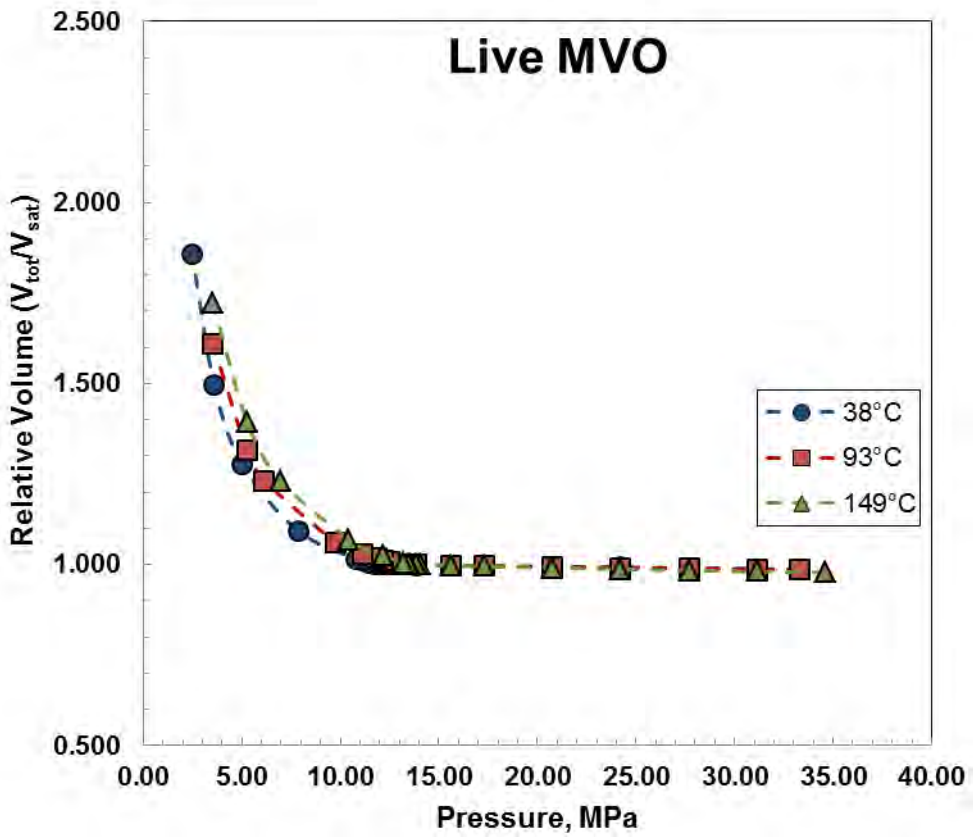


Figure 40: Plots of Relative Volume (V_{tot}/V_{sat}) vs. Pressure for the Live Medium Viscous Oil (Live MVO)

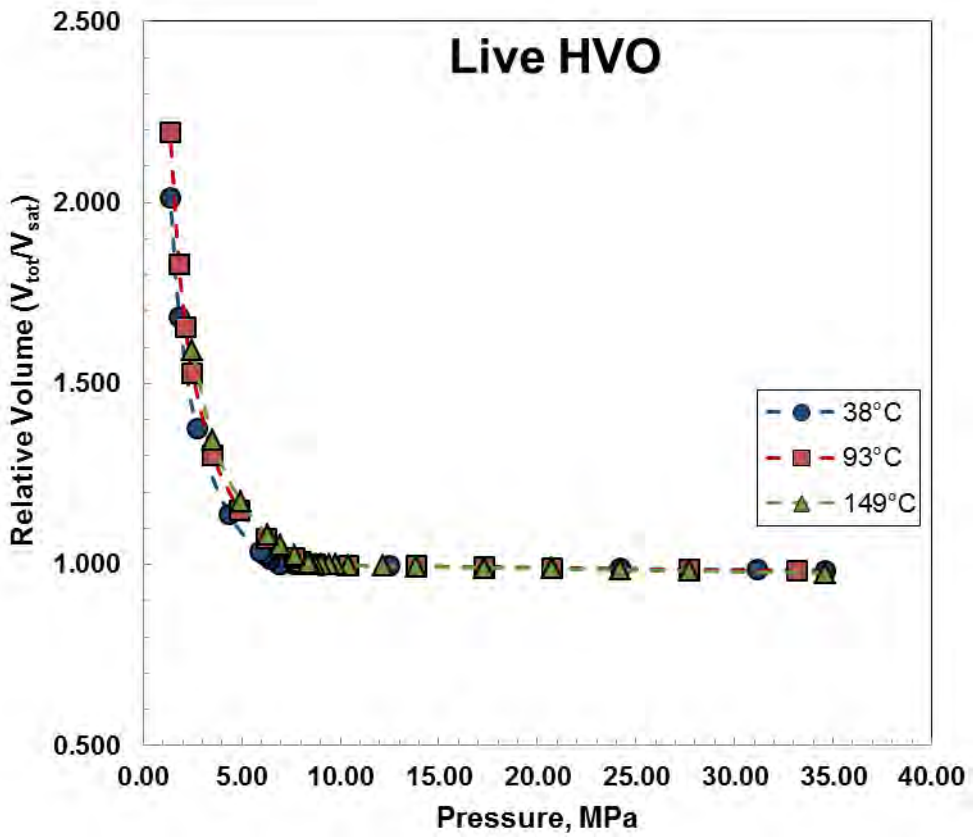


Figure 41: Plots of Relative Volume (V_{tot}/V_{sat}) vs. Pressure for the Live High Viscous Oil (Live HVO)

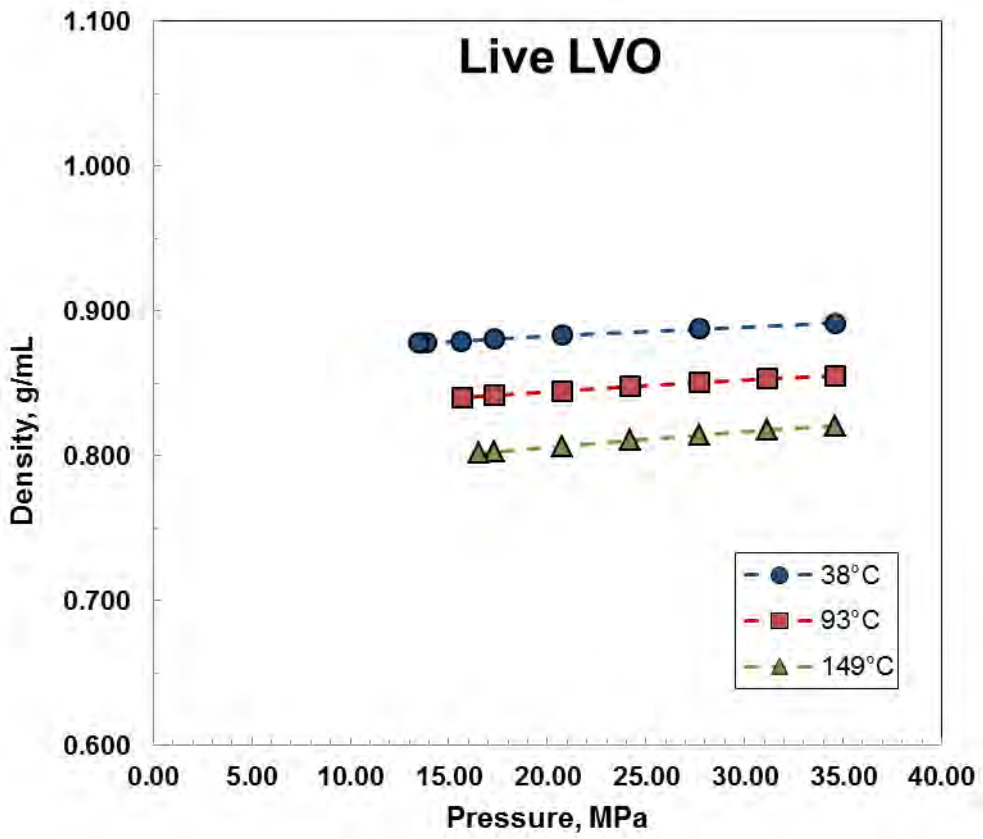


Figure 42: Plots of Single Phase Density vs. Pressure for the Live Low Viscous Oil (Live LVO)

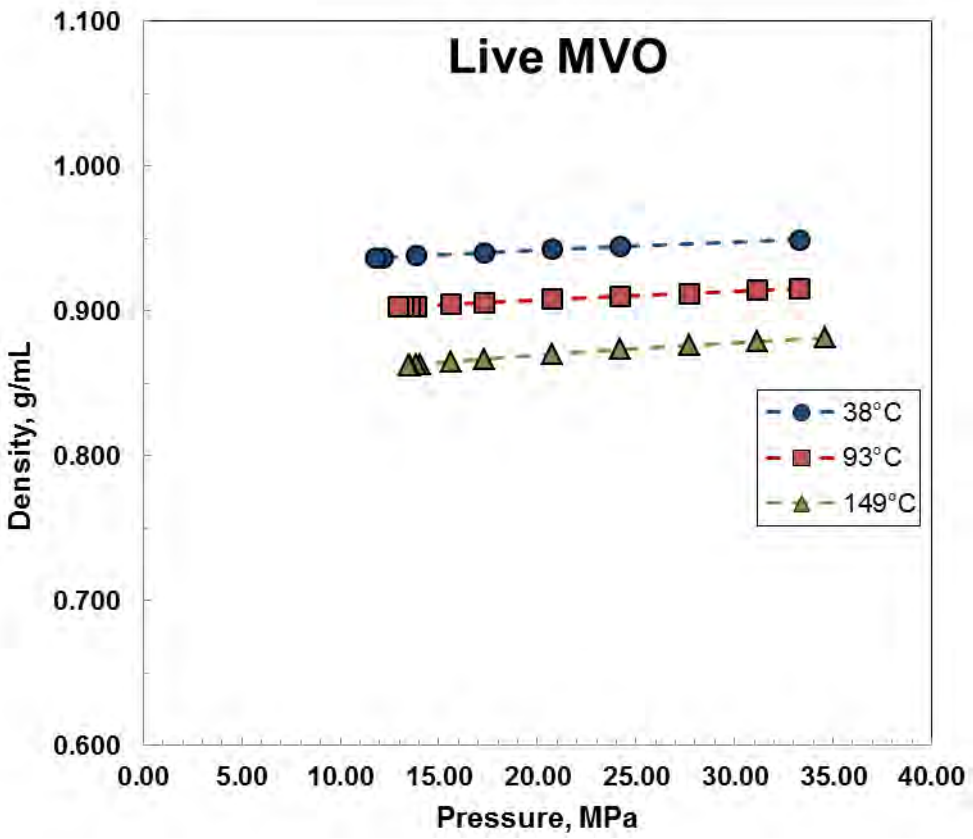


Figure 43: Plots of Single Phase Density vs. Pressure for the Live Medium Viscous Oil (Live MVO)

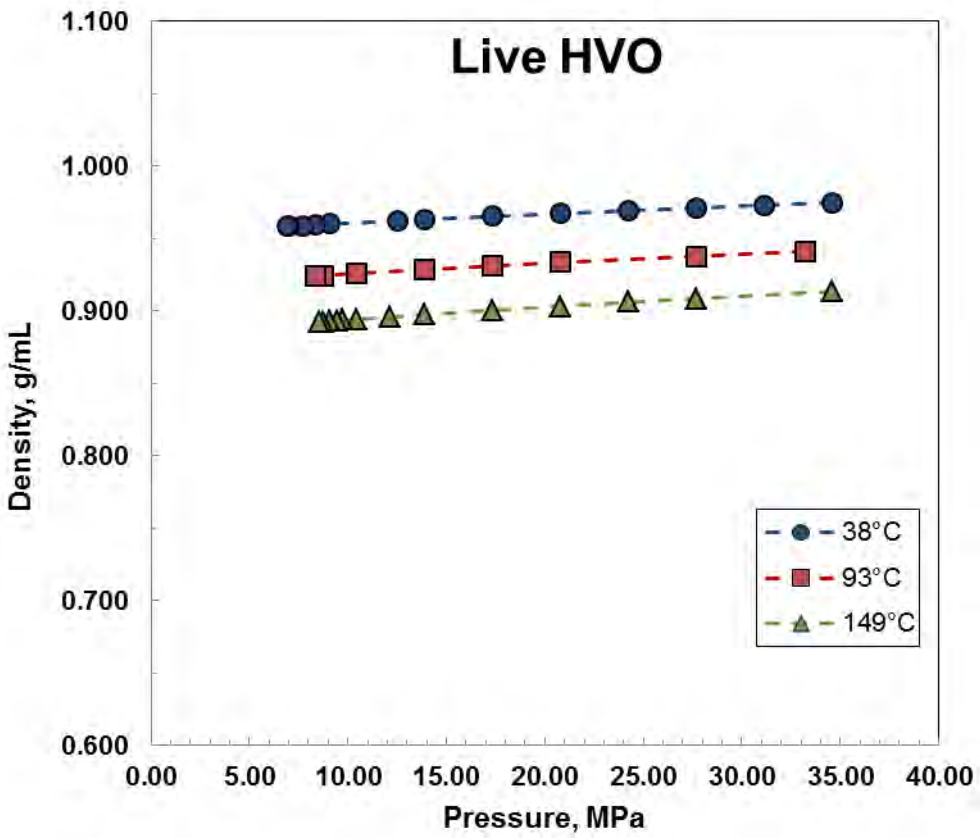


Figure 44: Plots of Single Phase Density vs. Pressure with Live High Viscous Oil (Live HVO)

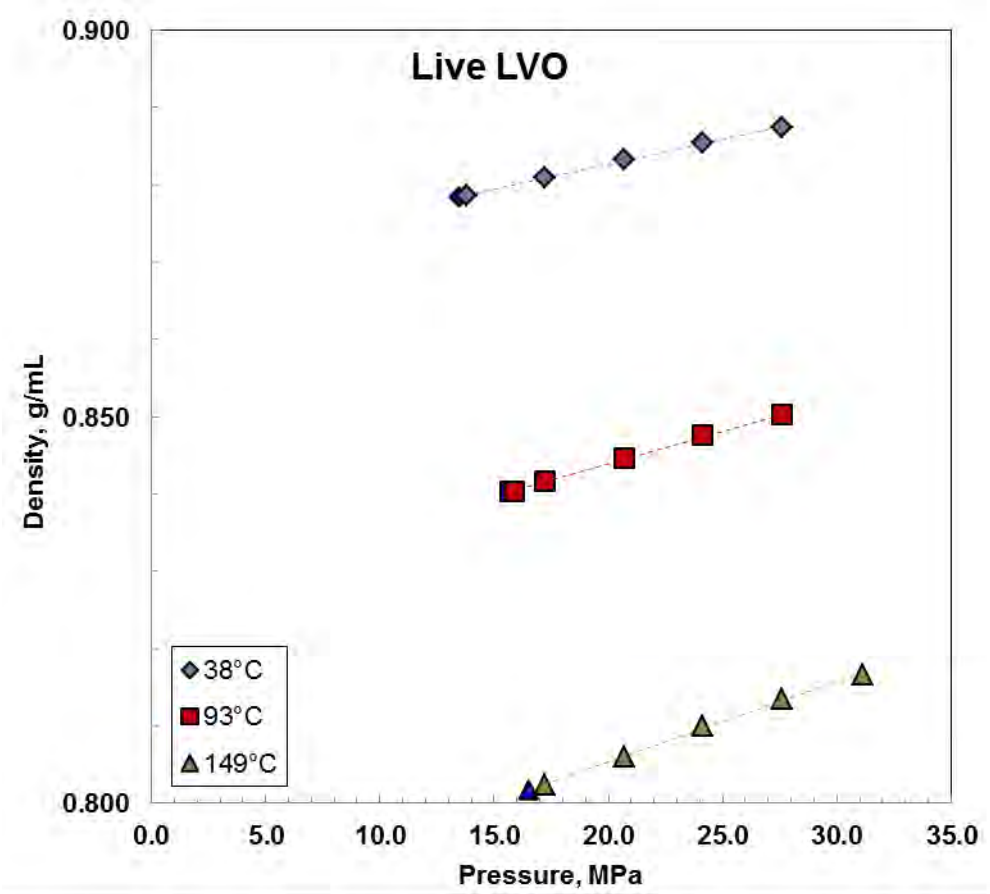


Figure 45: Live Oil Density vs. Pressure – Live Low Viscous Oil (Live LVO)

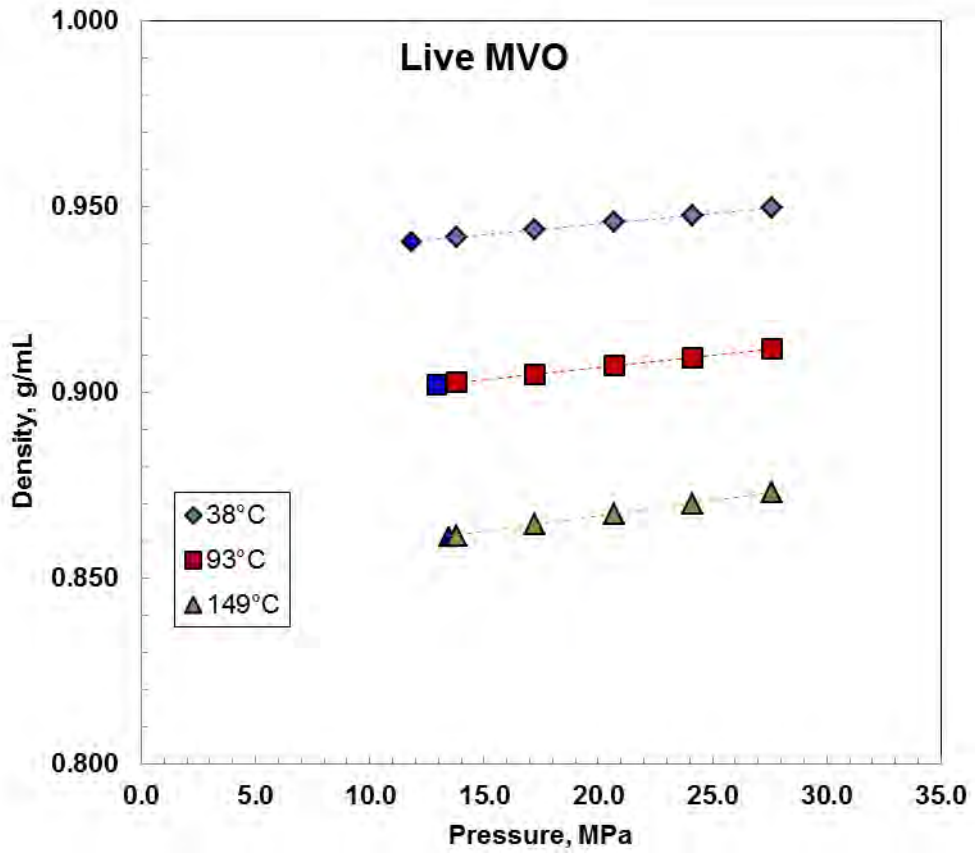


Figure 46: Live Oil Density vs. Pressure – Medium Viscous Oil (Live MVO)

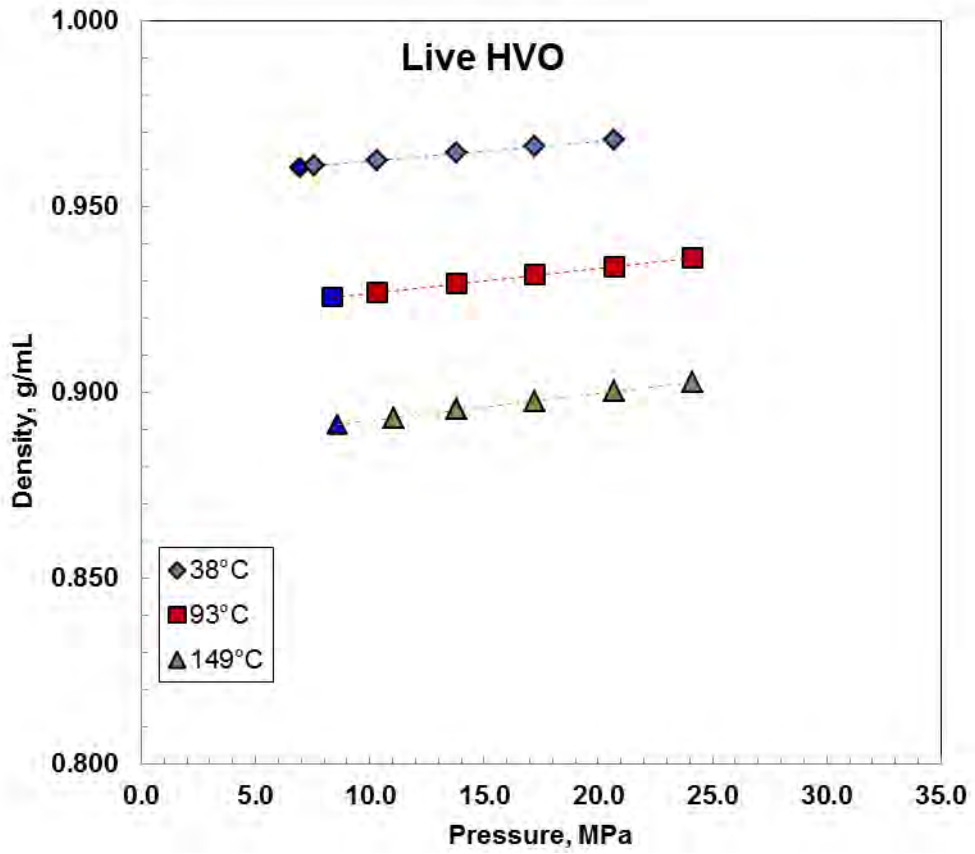
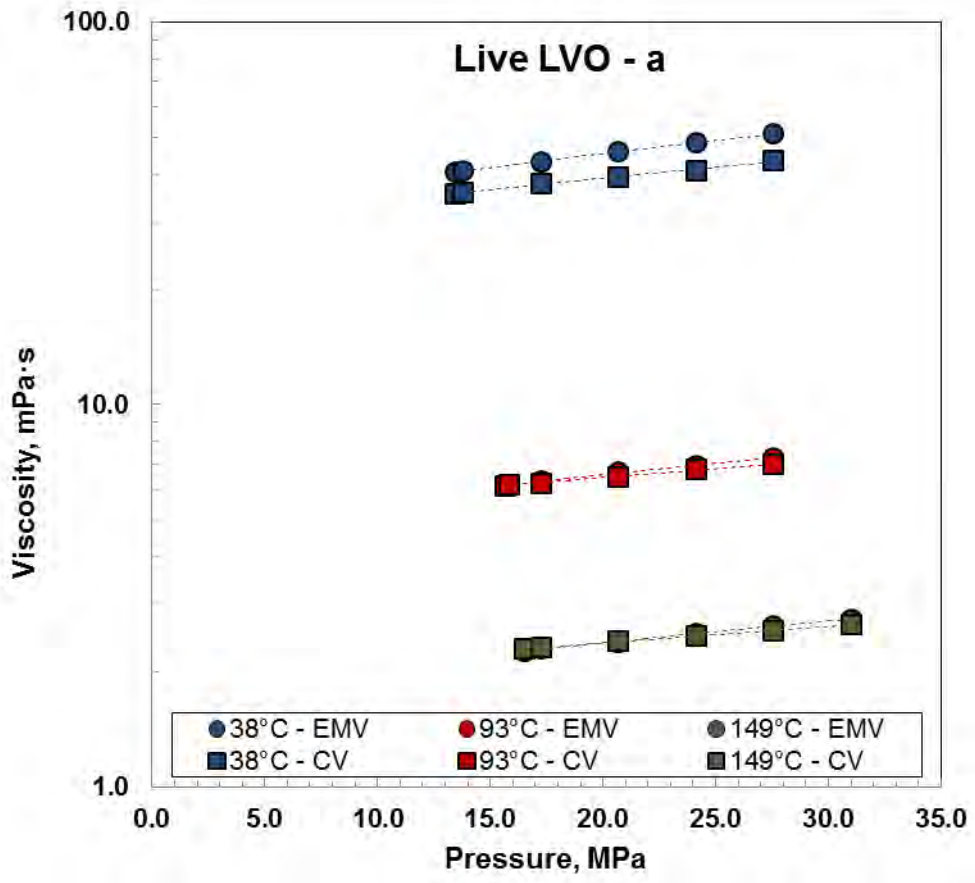


Figure 47: Live Oil Density vs. Pressure – Live High Viscous Oil (Live HVO)


Live LVO - a
100.0
10.0
1.0
Viscosity, mPa·s
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Pressure, MPa
38°C - EMV
93°C - EMV
149°C - EMV
38°C - CV
93°C - CV
149°C - CV

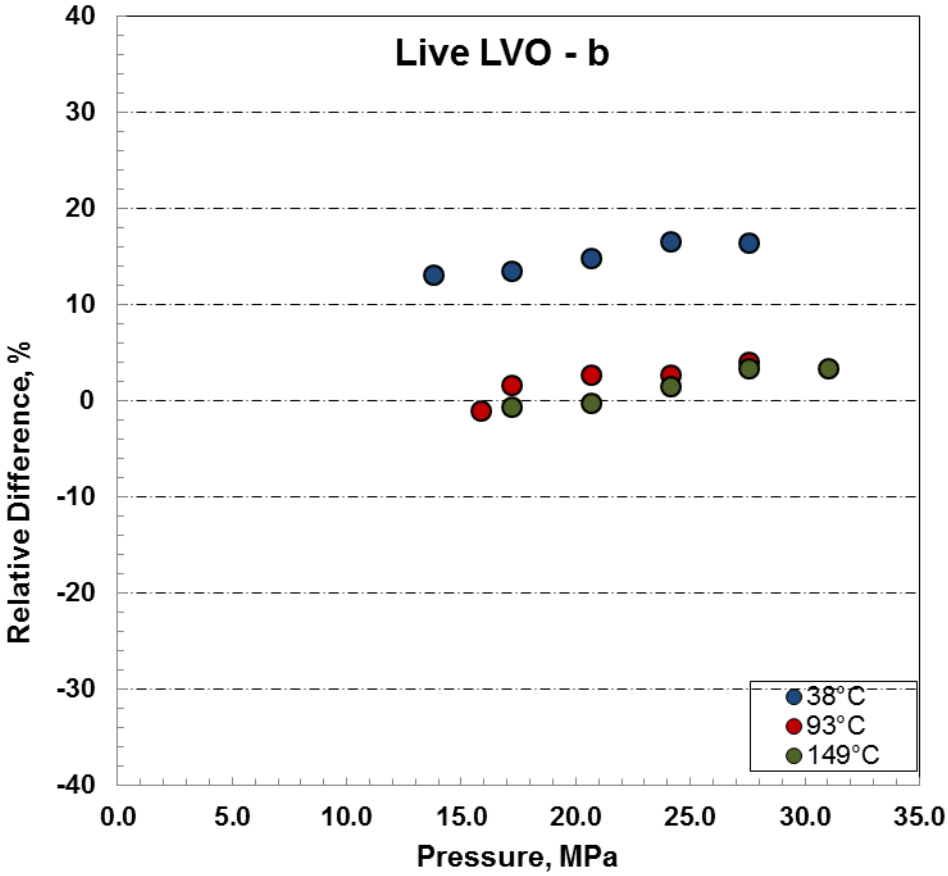
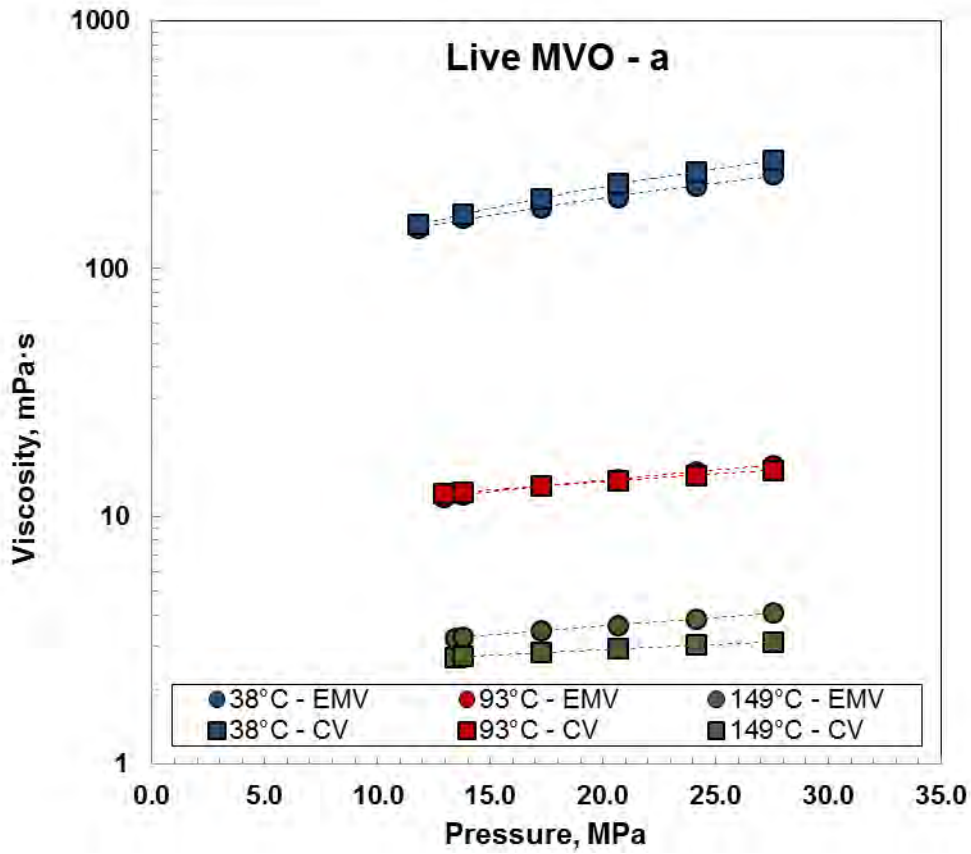


Figure 48: Live Oil Viscosity Comparison between Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) – Live Light Viscous Oil (Live LVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Pressure


Live MVO - a
Viscosity, mPa·s
1000
100
10
1
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Pressure, MPa
38°C - EMV
93°C - EMV
149°C - EMV
38°C - CV
93°C - CV
149°C - CV

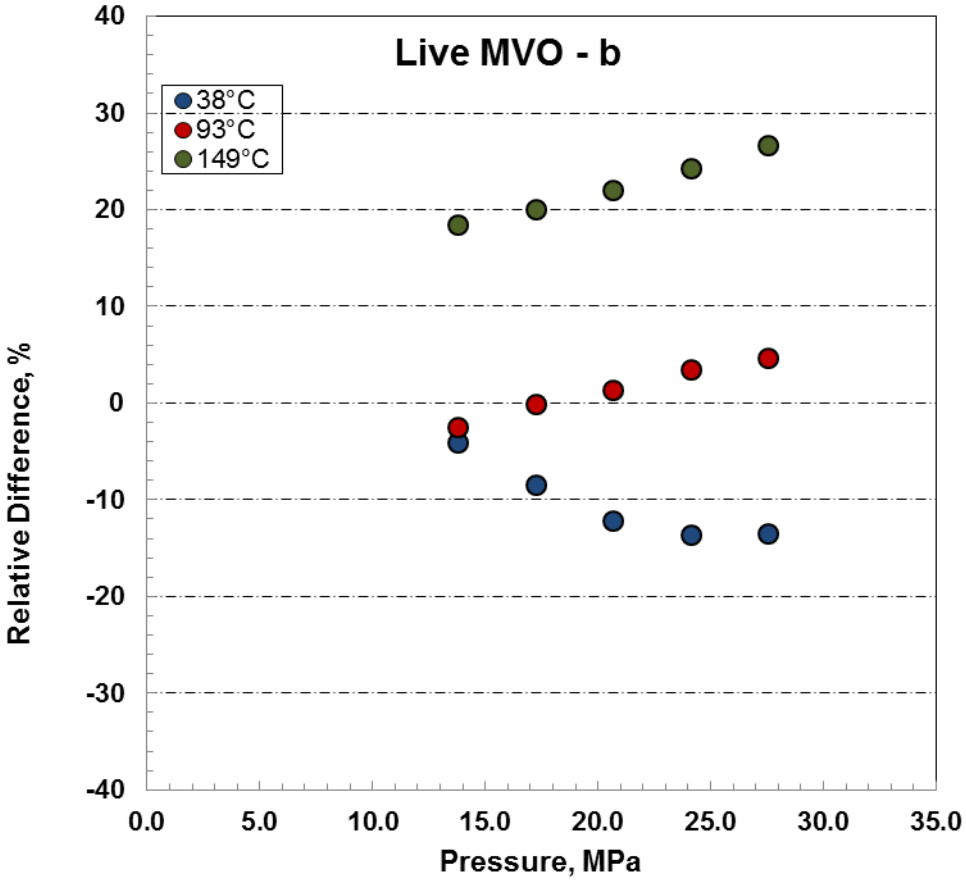
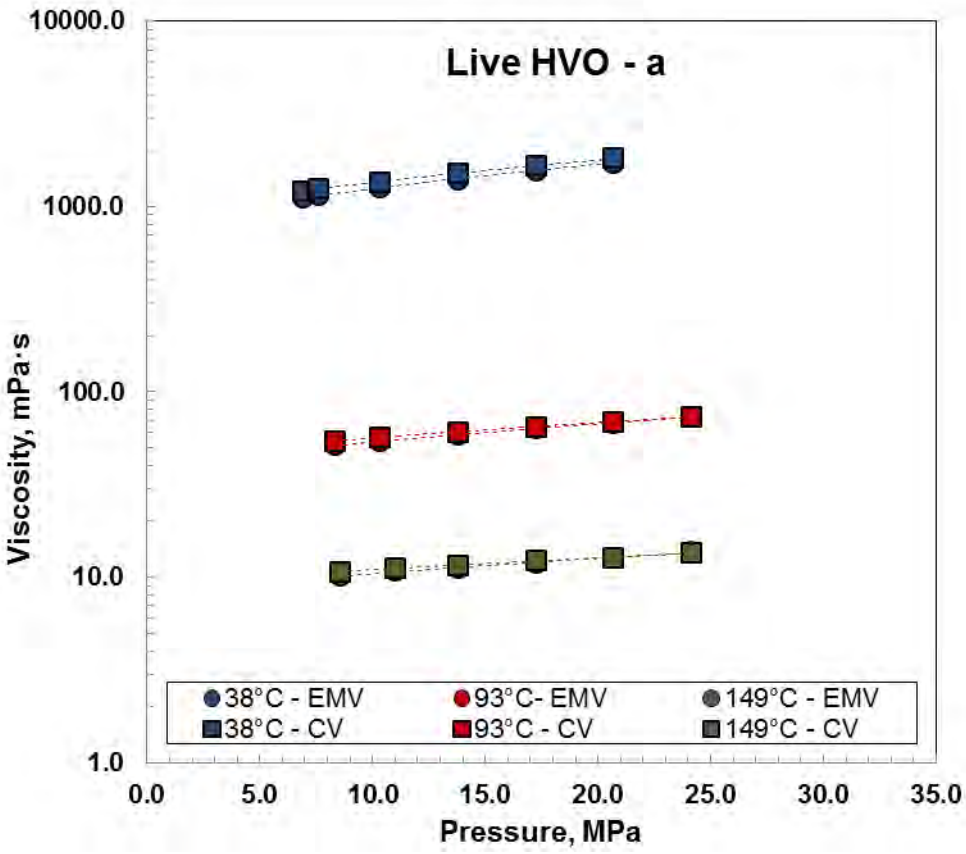


Figure 49: Live Oil Viscosity Comparison between Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) – Live Medium Viscous Oil (Live MVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Pressure


Live HVO - a
10000.0
1000.0
100.0
10.0
1.0
Viscosity, mPa·s
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Pressure, MPa
38°C - EMV
93°C- EMV
149°C - EMV
38°C - CV
93°C - CV
149°C - CV

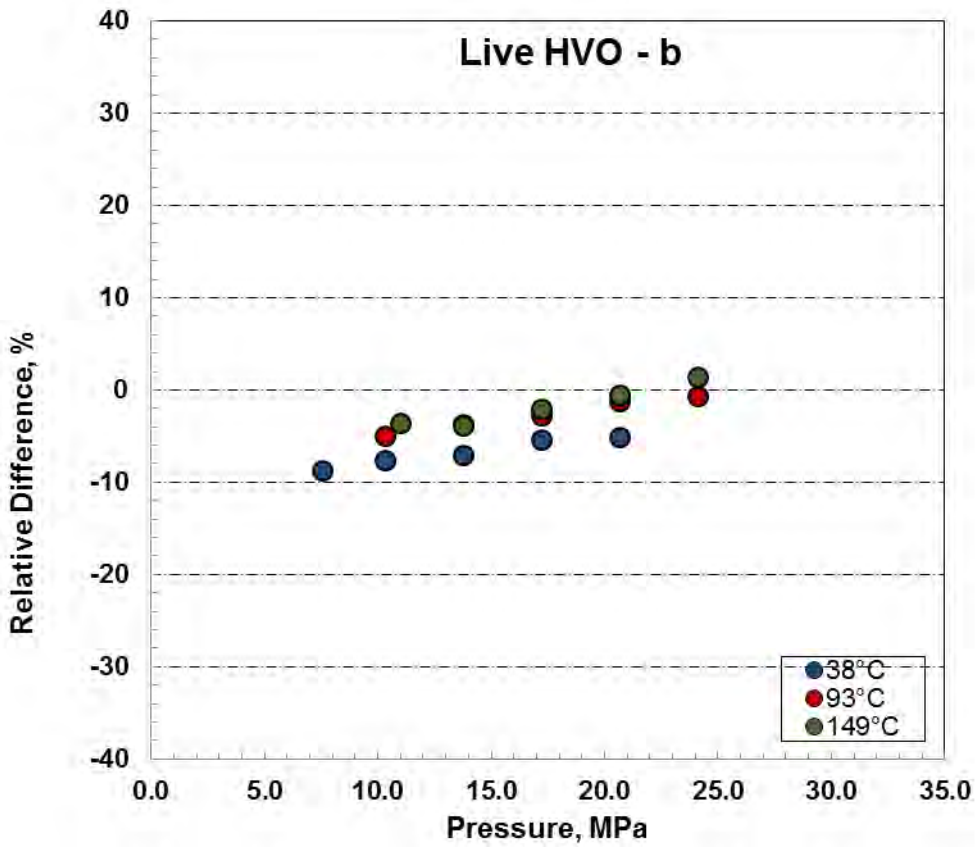


Figure 50: Live Oil Viscosity Comparison between Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) – Live High Viscous Oil (Live HVO): a) Viscosity vs. Pressure; b) Relative Difference vs. Pressure

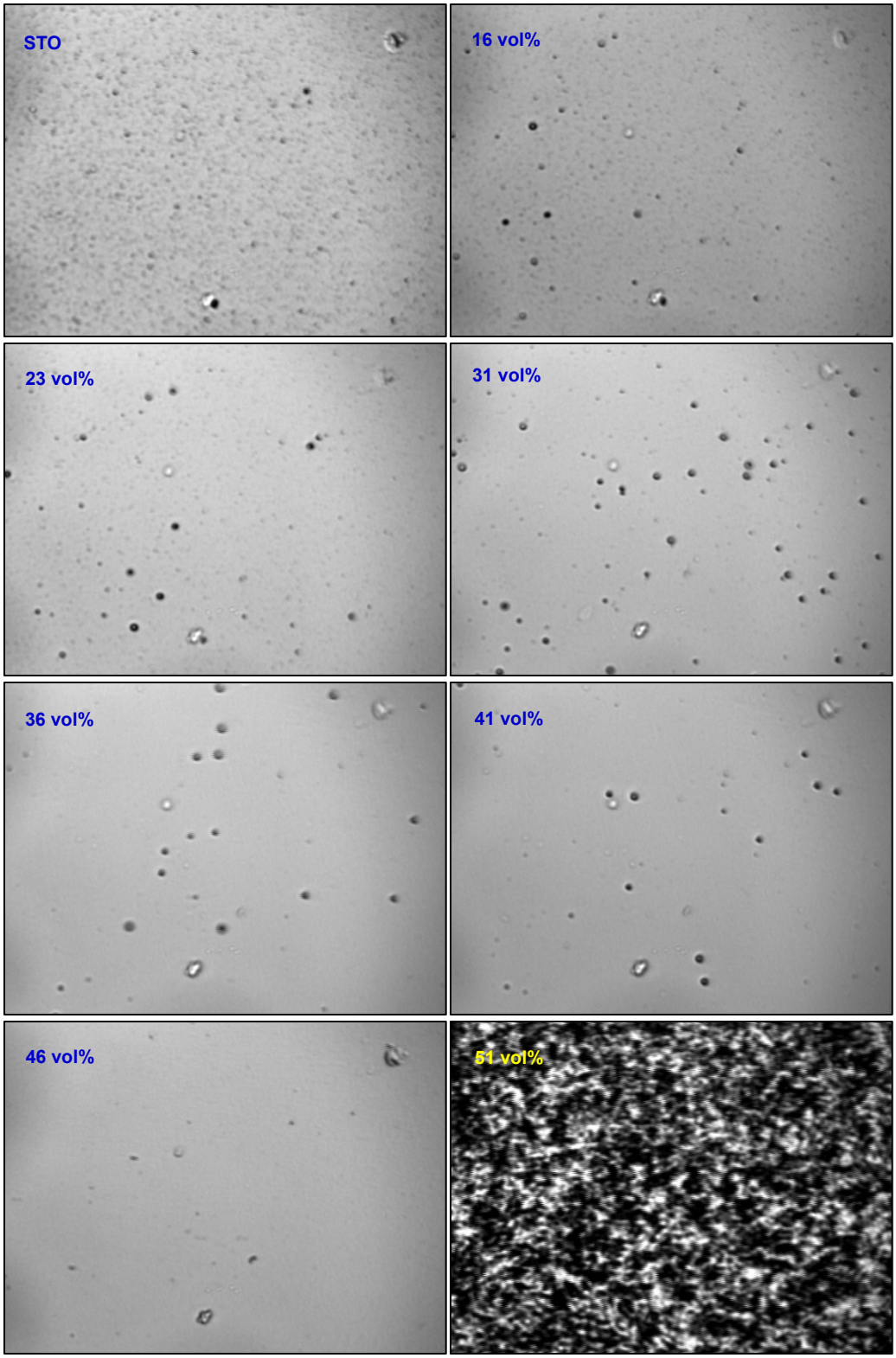


Figure 51: Results of Asphaltene Titration Tests Using Low Viscous Oil (LVO) and Heptane at 50°C and 3.45 MPa/500 psia: High Pressure Micro-images of Fluid with Heptane Additions

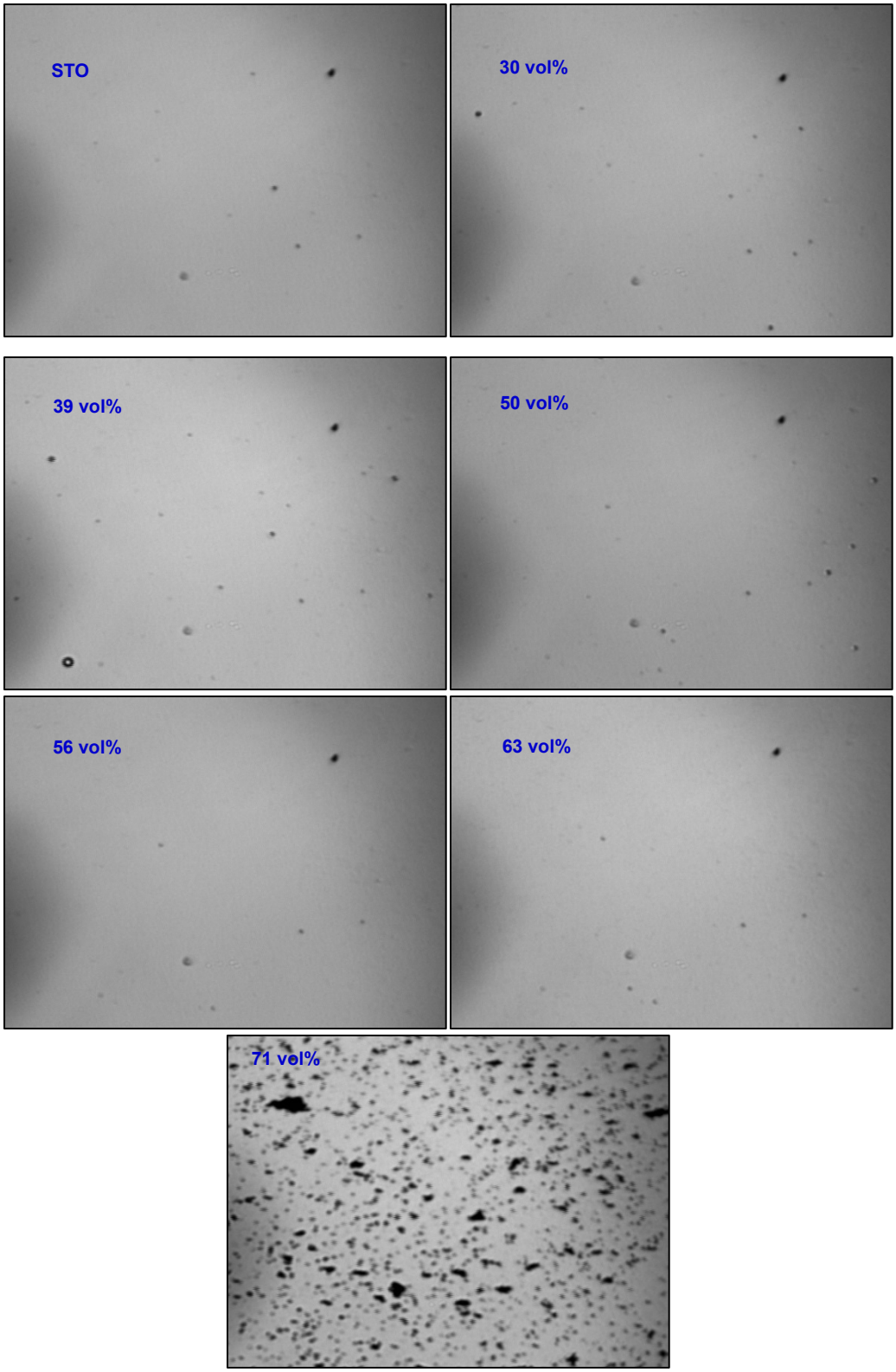


Figure 52: Results of Asphaltene Titration Tests Using Medium Viscous Oil (MVO) and Heptane at 50°C and 3.45 MPa/500 psia: High Pressure Micro-images of Fluid with Heptane Additions

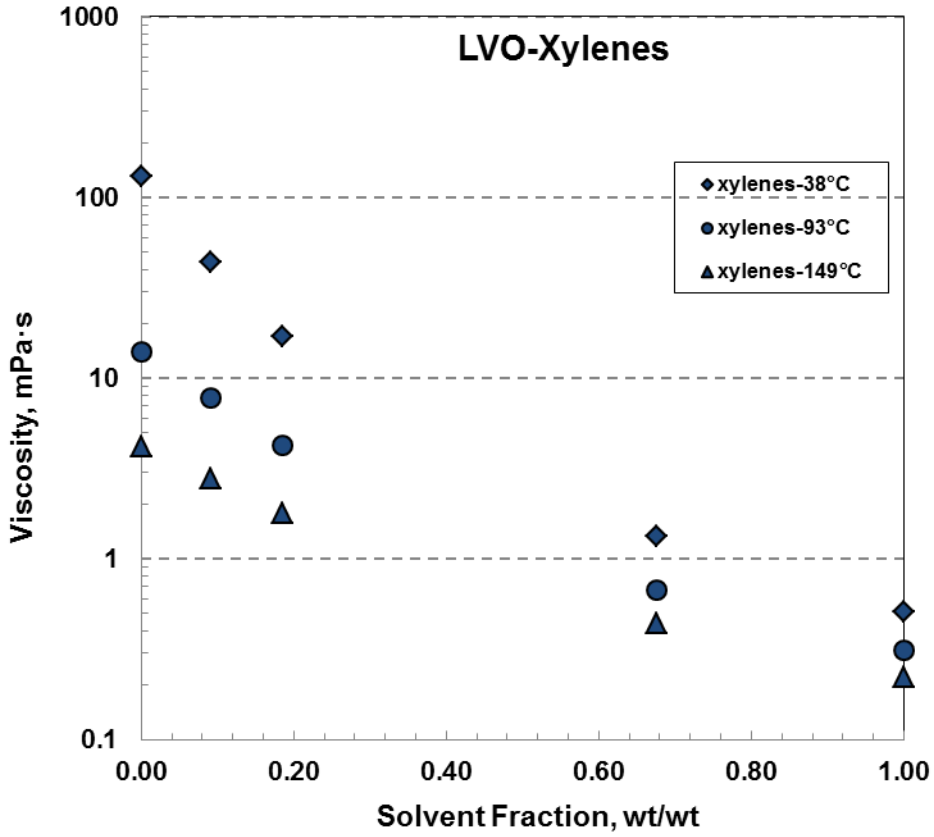


Figure 53: Mixture Viscosity vs. Solvent Fraction – Low Viscous Oil / Xylenes

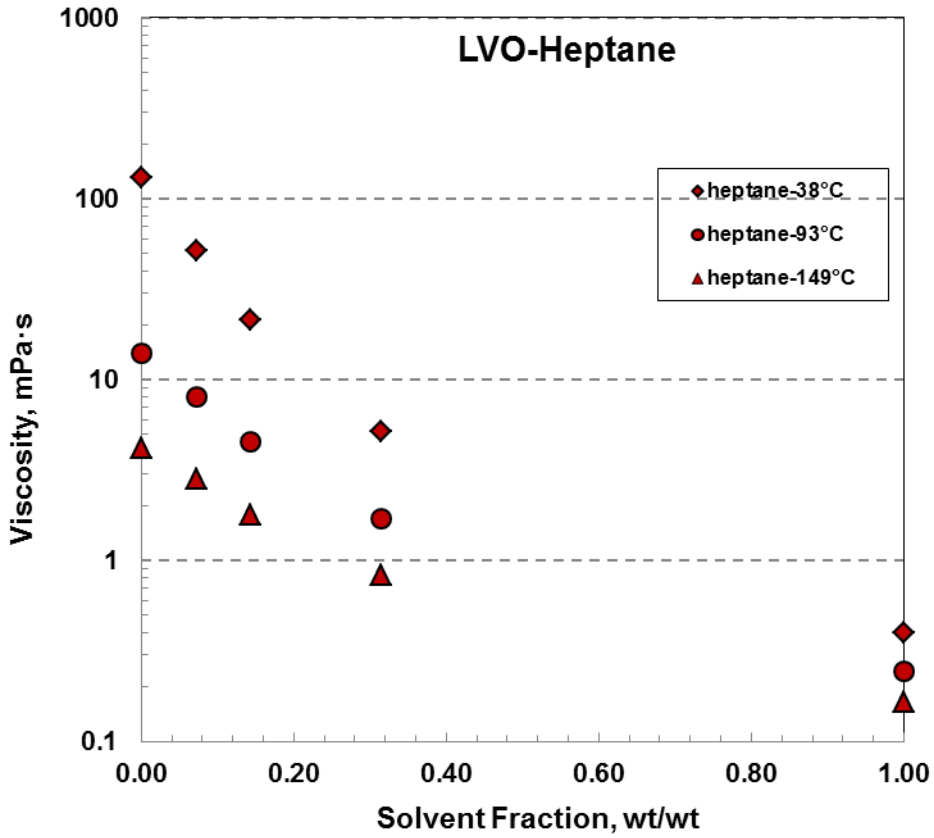


Figure 54: Mixture Viscosity vs. Solvent Fraction – Low Viscous Oil / Heptane

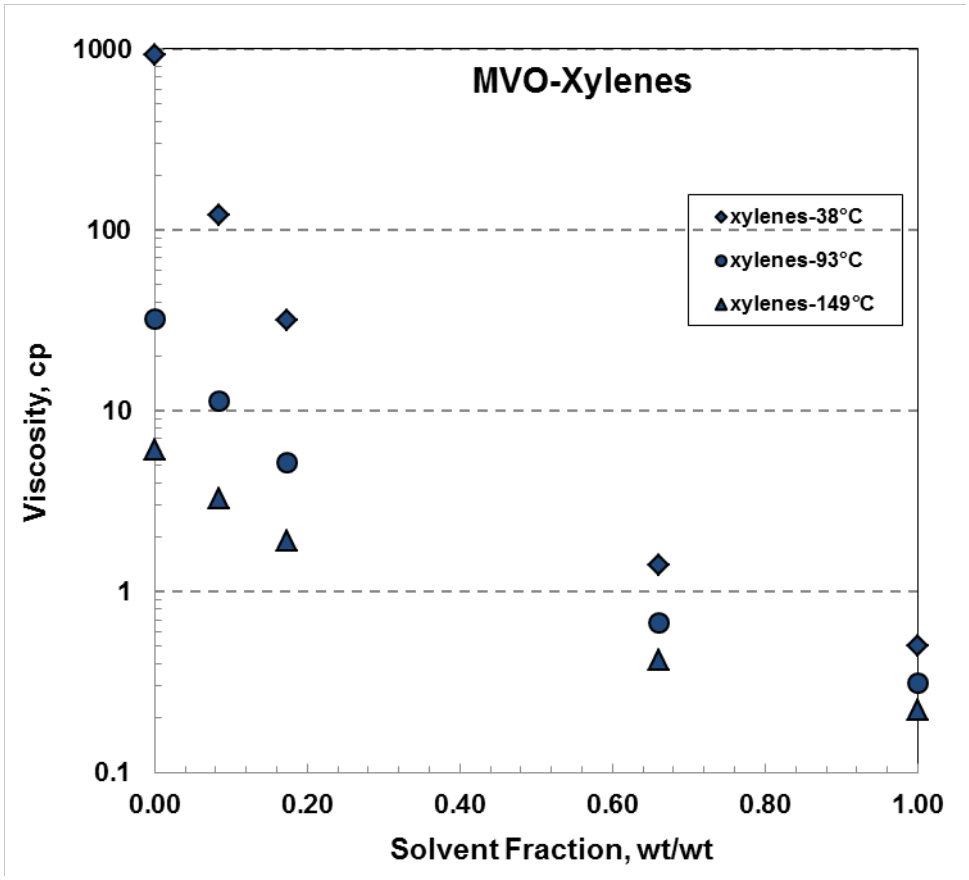


Figure 55: Mixture Viscosity vs. Solvent Fraction – Medium Viscous Oil / Xylenes

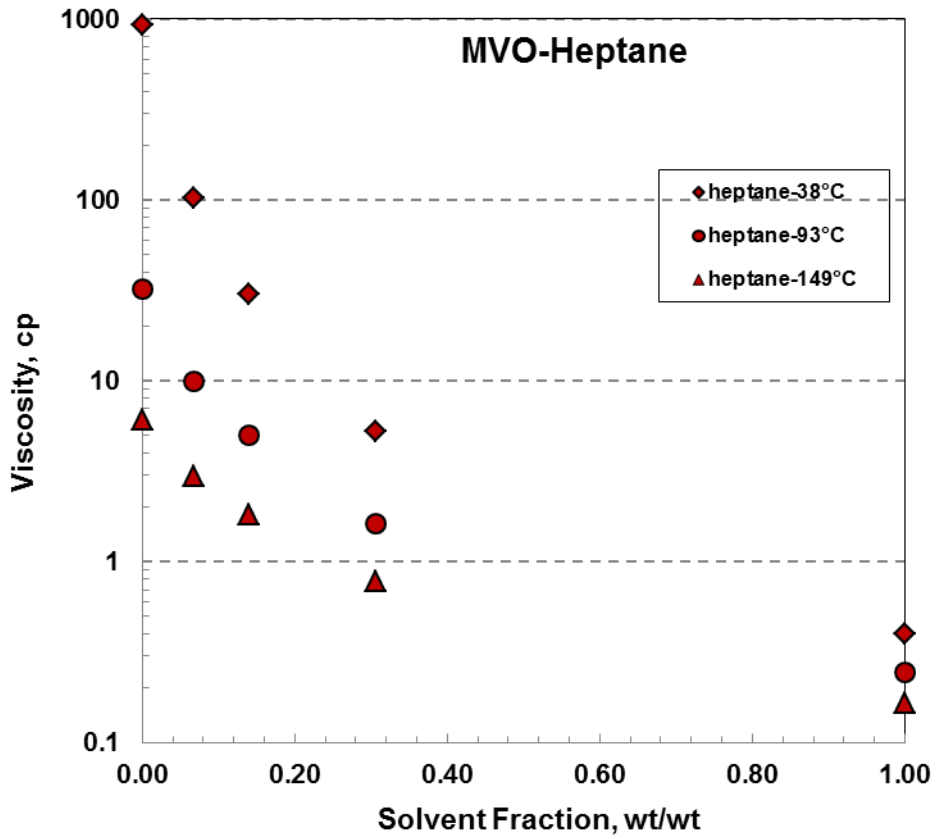


Figure 56: Mixture Viscosity vs. Solvent Fraction – Medium Viscous Oil / Heptane

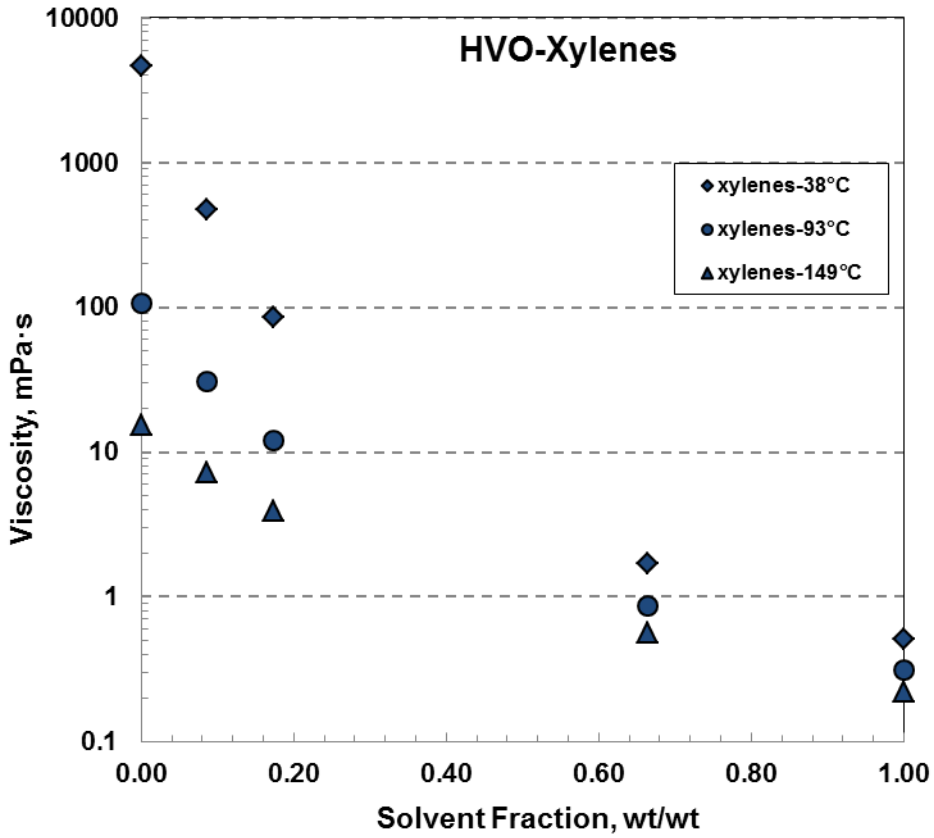


Figure 57: Mixture Viscosity vs. Solvent Fraction – High Viscous Oil / Xylenes

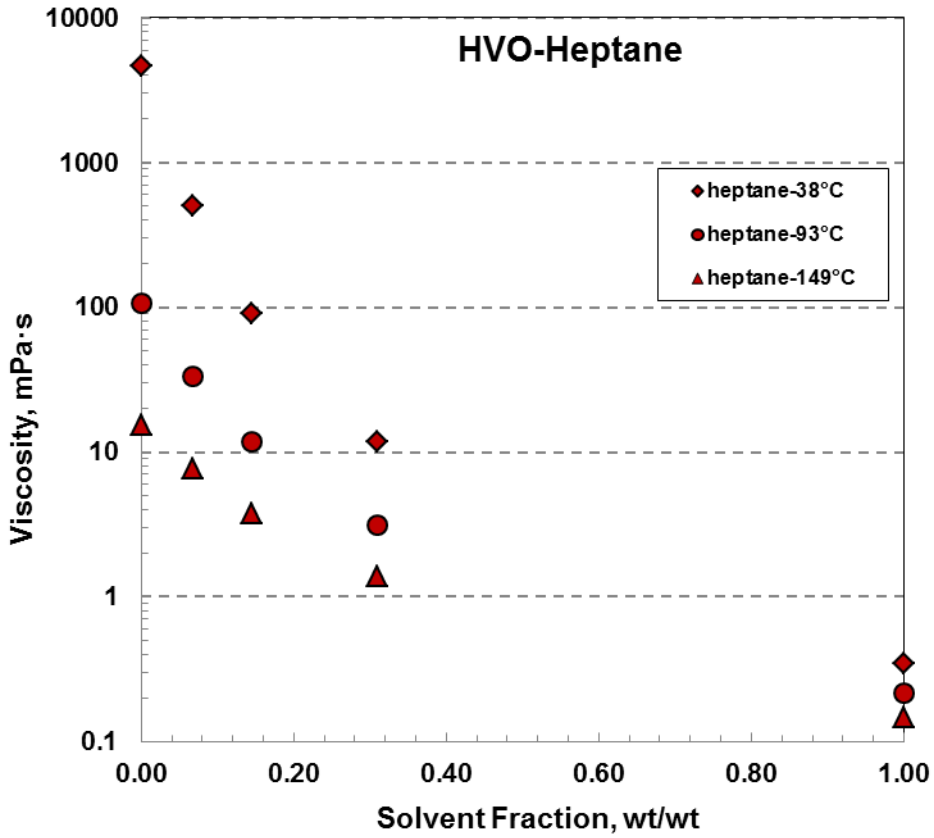


Figure 58: Mixture Viscosity vs. Solvent Fraction – High Viscous Oil / Heptane

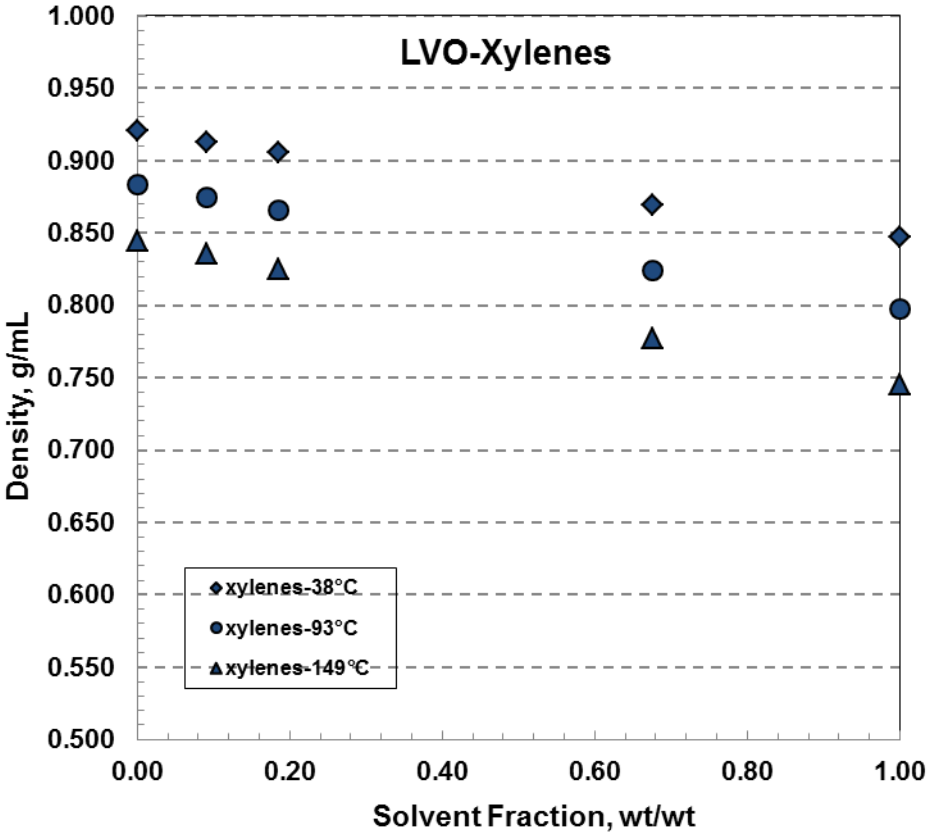


Figure 59: Mixture Density vs. Solvent Fraction – Low Viscous Oil / Xylenes

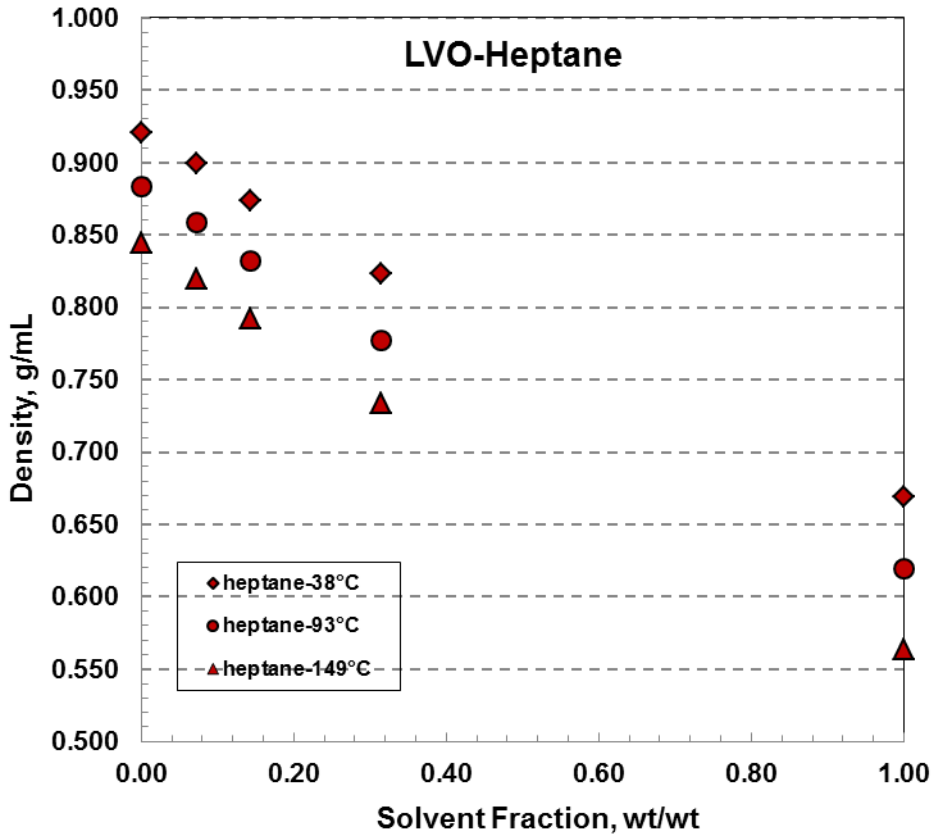


Figure 60: Mixture Density vs. Solvent Fraction – Low Viscous Oil / Heptane

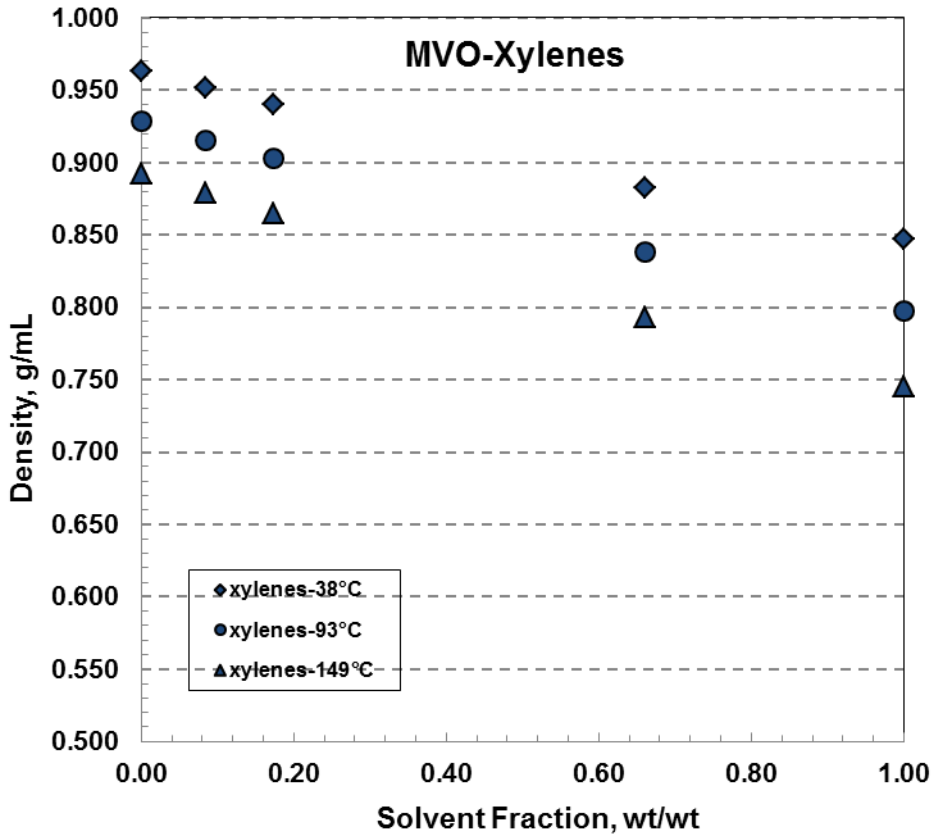


Figure 61: Mixture Density vs. Solvent Fraction – Medium Viscous Oil / Xylenes

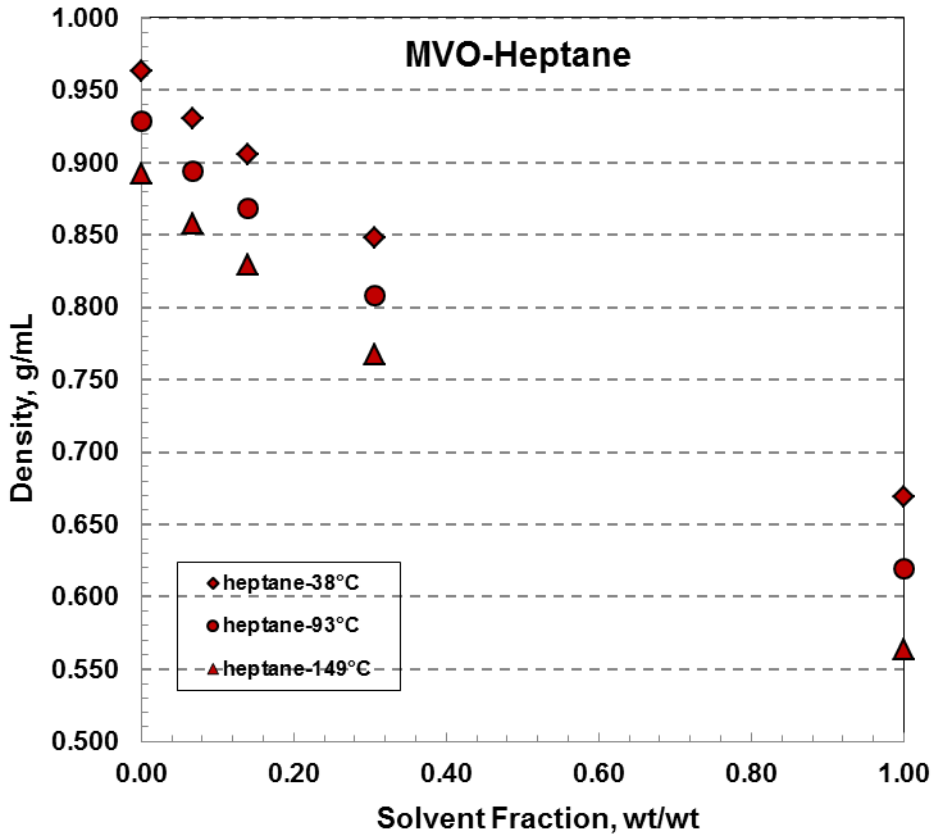


Figure 62: Mixture Density vs. Solvent Fraction – Medium Viscous Oil / Heptane

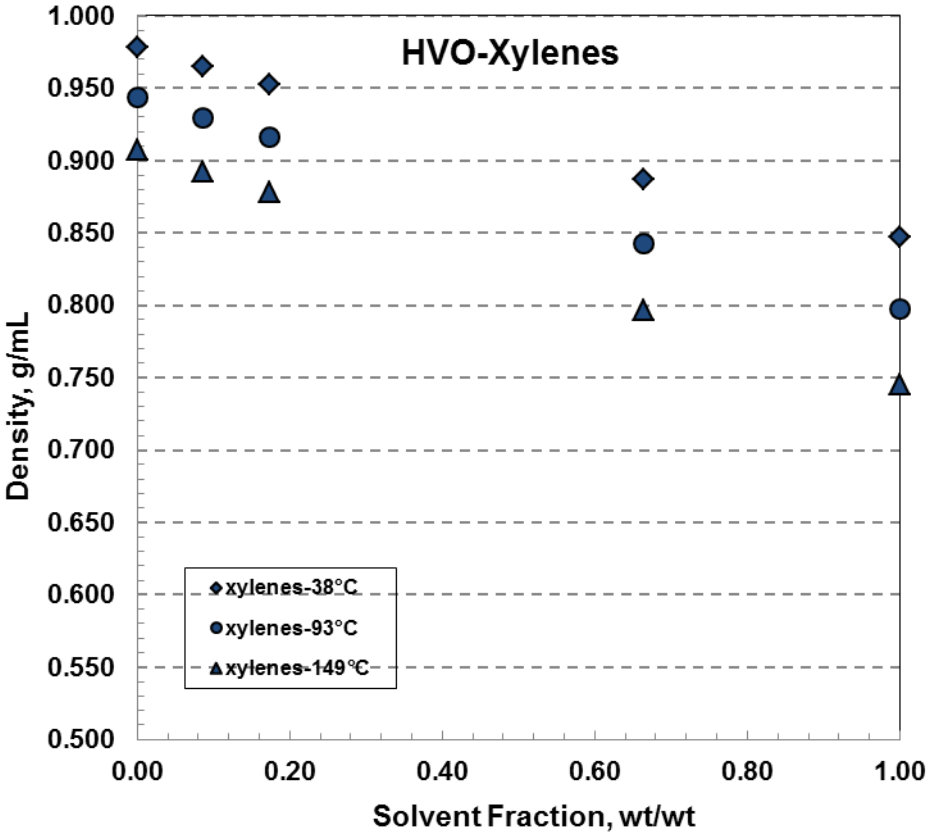


Figure 63: Mixture Density vs. Solvent Fraction – High Viscous Oil / Xylenes

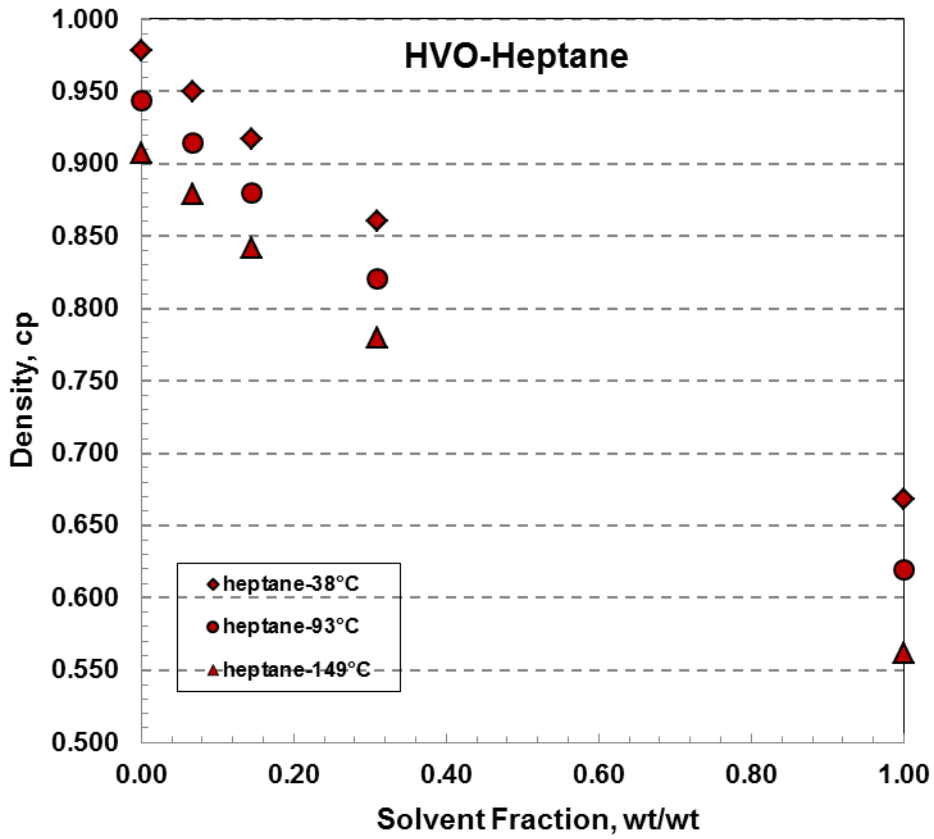


Figure 64: Mixture Density vs. Solvent Fraction – High Viscous Oil / Heptane

11. TABLES

Table 1: Summary of Stock Tank Oil Properties of Low Viscous Oil (LVO), Medium Viscous Oil (MVO) and High Viscous Oil (HVO)

Properties	Method	LVO	MVO	HVO
API	Anton-Paar Densitometer	19.6	13.1	11.0
Viscosity @100°F & 101 kPa	Capillary Viscometer	116	917	4660
C7+, mol%	GC	94.9	99.9	99.9
Water content, wt%	Karl-Fischer	0.14±0.02	0.01±0.00	0.68±0.02
BS&W, vol%	ASTM D 1796	0.20	0.04	0.10
MW, g/mol	Freezing-Point-Depression	315±2	354±1	420±4
TAN, mg KOH/g	ASTM WK26624	0.18	5.04	1.05
C30+, wt%	GC	52.8±2.5	44.5±2.5	64.1±2.5
C30+ density, g/mL	Match STO density to measured density based on composition	1.05	1.18	1.08
C30+ MW, g/mol	Match calculated MW based on composition to measured MW	678	588	598

Table 2: Compositions of Stock Tank Oils – Low Viscous Oil (LVO): Original Oil, Dewatered Oils, and Oil Post Viscosity Measurement by Rheometer

Component	MW	STO-1		STO-2		Dewatered by Distillation		Dewatered by Centrifugation		Dewatered by Chemical Demulsifier		Post Viscosity Measurement by Rheometer	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2	30.07	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C3	44.10	0.026	0.184	0.020	0.145	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.002
i-C4	58.12	0.022	0.118	0.019	0.102	0.000	0.002	0.002	0.012	0.002	0.013	0.009	0.051
n-C4	58.12	0.109	0.591	0.099	0.534	0.003	0.019	0.037	0.210	0.031	0.182	0.075	0.421
i-C5	72.15	0.128	0.561	0.124	0.540	0.015	0.072	0.067	0.304	0.056	0.261	0.093	0.420
n-C5	72.15	0.238	1.038	0.232	1.013	0.042	0.200	0.133	0.602	0.105	0.492	0.172	0.780
C6	84.00	0.717	2.689	0.718	2.690	0.331	1.350	0.530	2.061	0.446	1.794	0.565	2.199
Mcyclo-C5	84.16	0.135	0.504	0.149	0.556	0.074	0.302	0.106	0.412	0.092	0.370	0.107	0.415
Benzene	78.11	0.052	0.211	0.053	0.214	0.028	0.122	0.044	0.184	0.040	0.174	0.042	0.178
Cyclo-C6	84.16	0.108	0.403	0.108	0.403	0.070	0.285	0.084	0.327	0.074	0.298	0.088	0.344
C7	98.19	1.097	3.522	1.095	3.507	0.772	2.696	0.926	3.079	0.827	2.842	0.894	2.978
Mcyclo-C6	98.19	0.238	0.766	0.240	0.770	0.183	0.638	0.213	0.708	0.193	0.665	0.202	0.673
Toluene	92.14	0.169	0.580	0.174	0.593	0.123	0.459	0.187	0.661	0.170	0.624	0.143	0.508
C8	112.22	1.599	4.493	1.609	4.511	1.318	4.026	1.413	4.108	1.295	3.895	1.327	3.869
C2-Benzene	106.17	0.115	0.340	0.115	0.341	0.071	0.229	0.105	0.324	0.106	0.337	0.081	0.248
m&p-Xylene	106.17	0.278	0.826	0.280	0.829	0.175	0.565	0.299	0.918	0.320	1.018	0.193	0.594
o-Xylene	106.17	0.091	0.269	0.093	0.277	0.072	0.232	0.104	0.320	0.114	0.361	0.087	0.268
C9	118.00	1.717	4.587	1.721	4.589	1.613	4.686	1.539	4.256	1.423	4.069	1.579	4.376
C10	134.00	2.360	5.554	2.376	5.579	2.160	5.524	2.228	5.425	2.082	5.244	2.203	5.377
C11	147.00	2.204	4.727	2.178	4.662	2.004	4.673	2.101	4.663	2.007	4.608	2.163	4.813
C12	161.00	2.120	4.151	2.133	4.168	1.969	4.191	2.080	4.216	1.959	4.108	2.164	4.397
C13	175.00	2.187	3.939	2.162	3.887	2.037	3.989	2.203	4.107	2.120	4.090	2.266	4.237
C14	190.00	2.200	3.651	2.193	3.631	1.979	3.570	2.147	3.687	1.995	3.543	2.212	3.808
C15	206.00	2.308	3.533	2.306	3.521	2.191	3.645	2.283	3.617	2.217	3.632	2.370	3.764
C16	222.00	2.173	3.087	2.210	3.132	2.062	3.183	2.180	3.205	2.063	3.136	2.228	3.283
C17	237.00	2.088	2.777	2.085	2.768	2.006	2.901	2.111	2.907	2.024	2.883	2.083	2.874
C18	251.00	2.076	2.607	2.103	2.636	2.019	2.756	2.111	2.745	2.001	2.691	2.100	2.736
C19	263.00	2.161	2.591	2.207	2.641	2.121	2.764	2.233	2.771	2.114	2.713	2.180	2.712
C20	275.00	1.999	2.292	2.024	2.315	1.976	2.463	2.049	2.432	1.958	2.403	1.983	2.359
C21	291.00	1.967	2.131	2.009	2.173	1.916	2.257	2.043	2.291	1.907	2.211	1.959	2.203
C22	305.00	1.872	1.935	1.918	1.978	1.870	2.101	1.965	2.102	1.842	2.039	1.863	1.998
C23	318.00	1.789	1.774	1.853	1.834	1.791	1.931	1.872	1.921	1.768	1.877	1.783	1.834
C24	331.00	1.733	1.651	1.747	1.660	1.722	1.783	1.818	1.792	1.740	1.774	1.686	1.666
C25	345.00	1.653	1.510	1.726	1.574	1.659	1.648	1.767	1.672	1.646	1.610	1.636	1.551
C26	359.00	1.647	1.446	1.657	1.452	1.641	1.567	1.728	1.571	1.651	1.552	1.608	1.466
C27	374.00	1.645	1.386	1.683	1.416	1.650	1.512	1.739	1.517	1.636	1.476	1.597	1.397
C28	388.00	1.608	1.307	1.676	1.359	1.640	1.449	1.721	1.447	1.621	1.410	1.609	1.356
C29	402.00	1.625	1.274	1.638	1.282	1.572	1.340	1.686	1.368	1.629	1.368	1.551	1.262
C30+	678.00	53.750	24.995	53.267	24.718	57.122	28.873	54.145	26.060	56.725	28.238	55.099	26.584
MW			315.3		314.6		342.7		326.3		337.5		327.1

Table 3 Properties of Stock Tank Oils – Low Viscous Oil (LVO): Original Oil, Dewatered Oils, and Oil Post Viscosity Measurement by Rheometer

Properties	STO-1	STO-2	Dewatered by Distillation	Dewatered by Centrifugation	Dewatered by Chemical Demulsifier	Post Viscosity Measurement by Rheometer
Mole %						
C7+	94.82	94.98	98.36	96.81	97.26	96.13
C10+	78.32	78.39	84.12	81.52	82.60	81.68
C12+	68.04	68.15	73.92	71.43	72.75	71.49
C20+	41.70	41.76	46.92	44.17	45.96	43.68
C30+	24.99	24.72	28.87	26.06	28.24	26.58
Mass %						
C7+	98.76	98.79	99.61	99.23	99.36	99.09
C10+	93.16	93.15	95.11	94.21	94.70	94.34
C12+	88.60	88.60	90.94	89.88	90.62	89.98
C20+	71.29	71.20	74.56	72.53	74.12	72.38
C30+	53.75	53.27	57.12	54.15	56.72	55.10
Molar Mass						
C7+	328.40	327.25	347.06	334.47	344.80	337.19
C10+	375.05	373.88	387.48	377.14	386.95	377.85
C12+	410.57	409.04	421.62	410.63	420.38	411.73
C20+	538.97	536.39	544.56	535.82	544.35	542.06
C30+	678.00	678.00	678.00	678.00	678.00	678.00
Density (g/mL)						
C7+	0.941	0.940	0.949	0.943	0.949	0.945
C10+	0.953	0.952	0.959	0.954	0.959	0.955
C12+	0.964	0.963	0.969	0.964	0.968	0.965
C20+	1.003	1.002	1.005	1.001	1.005	1.004
C30+	1.050	1.050	1.050	1.050	1.050	1.050

Table 4: Compositions of Stock Tank Oils – Medium Viscous Oil (MVO): Original Oil, Dewatered Oils, and Oil Post Viscosity Measurement by Rheometer

Component	MW	STO-1		STO-2		Dewatered by Distillation		Dewatered by Centrifugation		Dewatered by Chemical Demulsifier		Post Viscosity Measurement by Rheometer	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2	30.07	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C3	44.10	0.000	0.002	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.001
i-C4	58.12	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.002
n-C4	58.12	0.001	0.004	0.001	0.004	0.000	0.002	0.001	0.003	0.001	0.003	0.000	0.003
i-C5	72.15	0.001	0.004	0.001	0.004	0.000	0.001	0.001	0.003	0.000	0.002	0.001	0.004
n-C5	72.15	0.002	0.010	0.002	0.009	0.000	0.002	0.001	0.004	0.001	0.006	0.002	0.011
C6	84.00	0.026	0.109	0.026	0.110	0.000	0.002	0.006	0.024	0.004	0.018	0.020	0.086
Mcyclo-C5	84.16	0.004	0.018	0.003	0.015	0.000	0.002	0.002	0.007	0.001	0.005	0.004	0.016
Benzene	78.11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.002	0.008	0.002	0.008	0.000	0.001	0.001	0.003	0.001	0.002	0.002	0.007
C7	98.19	0.021	0.077	0.021	0.077	0.007	0.024	0.016	0.058	0.015	0.055	0.021	0.077
Mcyclo-C6	98.19	0.003	0.013	0.003	0.012	0.001	0.003	0.002	0.008	0.002	0.007	0.003	0.010
Toluene	92.14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.000	0.000
C8	112.22	0.042	0.134	0.044	0.140	0.015	0.046	0.022	0.071	0.021	0.068	0.023	0.074
C2-Benzene	106.17	0.003	0.008	0.003	0.009	0.002	0.007	0.002	0.007	0.003	0.010	0.002	0.005
m&p-Xylene	106.17	0.006	0.021	0.006	0.020	0.005	0.016	0.005	0.018	0.010	0.032	0.003	0.012
o-Xylene	106.17	0.003	0.009	0.003	0.009	0.003	0.009	0.002	0.006	0.006	0.019	0.002	0.006
C9	118.00	0.112	0.335	0.108	0.325	0.075	0.225	0.063	0.191	0.084	0.252	0.054	0.163
C10	134.00	0.269	0.710	0.271	0.715	0.233	0.617	0.224	0.598	0.337	0.893	0.227	0.600
C11	147.00	0.647	1.557	0.656	1.581	0.565	1.359	0.594	1.445	0.656	1.587	0.622	1.499
C12	161.00	1.217	2.675	1.233	2.712	1.084	2.383	1.104	2.454	1.137	2.510	1.216	2.675
C13	175.00	1.874	3.789	1.898	3.842	1.803	3.646	1.885	3.855	1.900	3.859	1.989	4.025
C14	190.00	2.389	4.450	2.416	4.503	2.349	4.377	2.219	4.179	2.225	4.161	2.288	4.265
C15	206.00	2.709	4.654	2.789	4.795	2.784	4.784	2.793	4.850	2.786	4.807	2.941	5.056
C16	222.00	3.017	4.808	2.997	4.781	3.023	4.819	2.891	4.660	2.903	4.648	3.071	4.899
C17	237.00	3.213	4.797	3.201	4.783	3.244	4.845	3.185	4.808	3.019	4.527	3.245	4.849
C18	251.00	3.556	5.013	3.624	5.113	3.699	5.216	3.477	4.956	3.643	5.158	3.535	4.987
C19	263.00	3.686	4.959	3.667	4.937	3.668	4.937	3.612	4.913	3.615	4.885	3.544	4.772
C20	275.00	3.721	4.787	3.575	4.604	3.905	5.027	3.543	4.610	3.648	4.714	3.845	4.951
C21	291.00	3.571	4.342	3.533	4.299	3.647	4.436	3.492	4.293	3.442	4.203	3.729	4.538
C22	305.00	3.545	4.113	3.560	4.133	3.646	4.231	3.568	4.186	3.519	4.100	3.452	4.008
C23	318.00	3.400	3.783	3.267	3.638	3.573	3.977	3.423	3.851	3.493	3.904	3.423	3.812
C24	331.00	3.285	3.511	3.323	3.555	3.451	3.690	3.271	3.535	3.265	3.506	3.376	3.612
C25	345.00	3.138	3.218	3.066	3.147	3.253	3.338	3.170	3.287	3.426	3.529	3.041	3.121
C26	359.00	3.102	3.057	3.053	3.011	3.414	3.366	3.161	3.151	2.986	2.956	2.956	2.916
C27	374.00	3.135	2.966	3.076	2.913	3.095	2.929	3.104	2.969	3.206	3.046	3.046	2.884
C28	388.00	3.034	2.767	2.879	2.628	3.241	2.957	3.066	2.827	3.178	2.911	2.960	2.701
C29	402.00	3.051	2.686	3.013	2.654	3.261	2.871	3.180	2.830	3.290	2.909	3.011	2.652
C30+	588.00	44.216	26.607	44.681	26.911	42.954	25.856	44.918	27.334	44.177	26.702	44.344	26.705
MW			353.8		354.1		354.0		357.8		355.4		354.1

Table 5: Properties of Stock Tank Oils – Medium Viscous Oil (MVO): Original Oil, Dewatered Oils, and Oil Post Viscosity Measurement by Rheometer

Properties	STO-1	STO-2	Dewatered by Distillation	Dewatered by Centrifugation	Dewatered by Chemical Demulsifier	Post Viscosity Measurement by Rheometer
Mole %						
C7+	99.87	99.87	99.99	99.96	99.97	99.89
C10+	99.25	99.26	99.66	99.59	99.52	99.52
C12+	96.98	96.96	97.68	97.55	97.04	97.42
C20+	61.84	61.49	62.68	62.87	62.48	61.90
C30+	26.61	26.91	25.86	27.33	26.70	26.70
Mass %						
C7+	99.97	99.97	100.00	99.99	99.99	99.98
C10+	99.77	99.78	99.89	99.88	99.85	99.86
C12+	98.86	98.85	99.09	99.06	98.86	99.01
C20+	77.20	77.02	77.44	77.89	77.63	77.18
C30+	44.22	44.68	42.95	44.92	44.18	44.34
Molar Mass						
C7+	354.19	354.50	353.97	357.92	355.49	354.39
C10+	355.71	356.00	354.78	358.83	356.60	355.31
C12+	360.68	361.05	359.06	363.35	362.07	359.87
C20+	441.72	443.59	437.32	443.29	441.57	441.54
C30+	588.00	588.00	588.00	588.00	588.00	588.00
Density (g/mL)						
C7+	0.977	0.978	0.974	0.979	0.977	0.977
C10+	0.977	0.979	0.974	0.980	0.978	0.977
C12+	0.980	0.981	0.976	0.982	0.980	0.980
C20+	1.028	1.031	1.023	1.030	1.028	1.029
C30+	1.175	1.175	1.175	1.175	1.175	1.175

Table 6: Compositions of Stock Tank Oils – High Viscous Oil (HVO): Original Oil and Dewatered Oils

Component	MW	STO-1		STO-2		Dewatered by Distillation		Dewatered by Centrifugation		Dewatered by Chemical Demulsifier	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2	30.07	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C3	44.10	0.001	0.006	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.007
i-C4	58.12	0.001	0.006	0.000	0.003	0.000	0.001	0.000	0.004	0.000	0.002
n-C4	58.12	0.001	0.007	0.001	0.007	0.000	0.001	0.001	0.010	0.001	0.004
i-C5	72.15	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.000	0.001
n-C5	72.15	0.002	0.011	0.002	0.009	0.000	0.002	0.001	0.005	0.001	0.006
C6	84.00	0.009	0.048	0.010	0.049	0.006	0.029	0.008	0.042	0.024	0.116
Mcyclo-C5	84.16	0.004	0.022	0.004	0.019	0.000	0.000	0.001	0.004	0.005	0.026
Benzene	78.11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.006
Cyclo-C6	84.16	0.003	0.016	0.003	0.015	0.000	0.001	0.001	0.005	0.001	0.003
C7	98.19	0.018	0.077	0.019	0.079	0.025	0.108	0.015	0.066	0.022	0.093
Mcyclo-C6	98.19	0.006	0.024	0.006	0.024	0.000	0.002	0.003	0.013	0.003	0.011
Toluene	92.14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005
C8	112.22	0.020	0.076	0.019	0.071	0.001	0.005	0.013	0.049	0.006	0.022
C2-Benzene	106.17	0.002	0.007	0.002	0.007	0.000	0.002	0.001	0.005	0.001	0.003
m&p-Xylene	106.17	0.001	0.005	0.001	0.005	0.000	0.002	0.001	0.004	0.001	0.004
o-Xylene	106.17	0.006	0.023	0.004	0.018	0.001	0.002	0.003	0.012	0.004	0.016
C9	118.00	0.069	0.246	0.072	0.253	0.020	0.074	0.032	0.116	0.048	0.165
C10	134.00	0.196	0.619	0.205	0.637	0.119	0.380	0.149	0.471	0.234	0.717
C11	147.00	0.417	1.198	0.434	1.232	0.291	0.845	0.374	1.076	0.467	1.302
C12	161.00	0.628	1.650	0.653	1.693	0.512	1.355	0.643	1.690	0.770	1.960
C13	175.00	1.147	2.773	1.198	2.856	0.932	2.270	1.076	2.601	1.206	2.826
C14	190.00	1.366	3.039	1.428	3.137	1.210	2.714	1.353	3.010	1.531	3.302
C15	206.00	1.768	3.630	1.848	3.744	1.785	3.693	1.807	3.709	1.978	3.936
C16	222.00	1.841	3.507	1.930	3.628	1.865	3.581	1.897	3.613	2.090	3.858
C17	237.00	1.987	3.546	2.128	3.747	2.047	3.681	2.025	3.614	2.246	3.884
C18	251.00	2.289	3.856	2.339	3.889	2.336	3.967	2.288	3.855	2.467	4.029
C19	263.00	2.234	3.591	2.353	3.734	2.513	4.073	2.495	4.011	2.567	4.001
C20	275.00	2.384	3.666	2.513	3.813	2.499	3.873	2.376	3.654	2.609	3.889
C21	291.00	2.470	3.589	2.495	3.578	2.441	3.576	2.514	3.653	2.560	3.605
C22	305.00	2.259	3.132	2.400	3.284	2.452	3.427	2.268	3.145	2.552	3.430
C23	318.00	2.342	3.115	2.448	3.212	2.422	3.246	2.446	3.253	2.506	3.230
C24	331.00	2.216	2.831	2.277	2.870	2.302	2.964	2.235	2.855	2.440	3.022
C25	345.00	2.248	2.755	2.323	2.810	2.273	2.808	2.210	2.709	2.373	2.819
C26	359.00	2.141	2.522	2.174	2.527	2.205	2.618	2.184	2.572	2.282	2.605
C27	374.00	2.142	2.422	2.370	2.644	2.258	2.574	2.234	2.526	2.376	2.604
C28	388.00	2.224	2.424	2.176	2.340	2.257	2.479	2.170	2.365	2.402	2.537
C29	402.00	2.309	2.429	2.427	2.520	2.187	2.319	2.276	2.394	2.302	2.348
C30+	620.14	63.250	43.131	61.740	41.547	63.039	43.328	62.897	42.888	59.924	39.608
MW			422.9		417.3		426.2		422.9		409.9

Table 7: Properties of Stock Tank Oils – High Viscous Oil (HVO): Original Oil and Dewatered Oils

Properties	STO-1	STO-2	Dewatered by Distillation	Dewatered by Centrifugation	Dewatered by Chemical Demulsifier
Mole %					
C7+	99.92	99.93	99.96	99.94	99.86
C10+	99.43	99.44	99.77	99.66	99.51
C12+	97.61	97.57	98.55	98.12	97.49
C20+	72.02	71.15	73.21	72.01	69.70
C30+	43.13	41.55	43.33	42.89	39.61
Mass %					
C7+	99.99	99.99	99.99	99.99	99.97
C10+	99.86	99.86	99.94	99.92	99.88
C12+	99.24	99.22	99.53	99.39	99.18
C20+	85.99	85.34	86.33	85.81	84.33
C30+	63.25	61.74	63.04	62.90	59.92
Molar Mass					
C7+	423.15	417.54	426.36	423.08	410.35
C10+	424.72	419.06	426.98	423.94	411.42
C12+	429.97	424.35	430.51	428.37	416.99
C20+	504.91	500.58	502.64	503.87	495.93
C30+	620.14	620.14	620.14	620.14	620.14
Density (g/mL)					
C7+	0.994	0.991	0.995	0.994	0.986
C10+	0.995	0.991	0.995	0.994	0.987
C12+	0.996	0.993	0.996	0.995	0.988
C20+	1.026	1.023	1.025	1.026	1.021
C30+	1.091	1.091	1.091	1.091	1.091

Table 8: Density of Low Viscous Oil (LVO) Measured by High-Pressure Anton-Paar Densitometer at Various Temperature and Pressure Conditions

T °C	T °F	P psia	P MPa	Density g/mL
38	100	15	0.1	0.920
		500	3.4	0.922
		1000	6.9	0.924
		1500	10.3	0.926
93	200	15	0.1	0.883
		500	3.4	0.885
		1000	6.9	0.888
		1500	10.3	0.890
149	300	15	0.1	0.845
		500	3.4	0.848
		1000	6.9	0.852
		1500	10.3	0.855

Table 9: Density of Medium Viscous Oil (MVO) Measured by High-Pressure Anton-Paar Densitometer at Various Temperature and Pressure Conditions

T °C	T °F	P psia	P MPa	Density g/mL
38	100	15	0.1	0.963
		500	3.4	0.965
		1000	6.9	0.967
		1500	10.3	0.968
93	200	15	0.1	0.928
		500	3.4	0.930
		1000	6.9	0.933
		1500	10.3	0.935
149	300	15	0.1	0.893
		500	3.4	0.895
		1000	6.9	0.898
		1500	10.3	0.901

Table 10: Density of High Viscous Oil (HVO) Measured by High-Pressure Anton-Paar Densitometer at Various Temperature and Pressure Conditions

T °C	T °F	P psia	P MPa	Density g/mL
38	100	15	0.1	0.978
		500	3.4	0.980
		1000	6.9	0.981
		1500	10.3	0.983
93	200	15	0.1	0.943
		500	3.4	0.946
		1000	6.9	0.948
		1500	10.3	0.950
149	300	15	0.1	0.908
		500	3.4	0.910
		1000	6.9	0.913
		1500	10.3	0.916

Table 11: Brine Solution Formula for Each Oil Emulsion Prepared

Name	HVO	MVO	LVO
Brine	meq/L	meq/L	meq/L
$NaHCO_3$	1.6	20.1	
NaCl	1121.0	30.1	59.9
Na_2SO_4	0.2	1.5	
$MgCl_2$	116.0	1.0	
$CaCl_2$	134.0	2.2	
$BaCl_2$	1.0	0.5	
Sum	1373.8	55.4	59.9

Table 12: Summary of Dewatering by Centrifugation Method

	RPM	RCF	Period, hr	Residue Water Content, wt%	
				Tube 1	Tube 2
H_2O/LVO	10000	10956	4	1.88±0.01	na
	15000	24652	4	0.86±0.09	0.96±0.04
H_2O/MVO	20000	40695	4	8.83±2.03	11.31±2.03
	20000	40695	8	7.35±0.90	6.60±0.71
	20000	40695	12	1.33±0.44	2.27±0.01
	20000	40695	20	0.95±0.12	1.37±0.18
H_2O/HVO	20000	40695	8	5.31±0.27	5.92±0.34
	20000	40695	12	2.22±0.55	2.62±0.32
	20000	40695	20	1.70±0.54	2.21±0.43
	20000	40695	28	2.08±0.05	2.04±0.00

Table 13: Summary of Dewatering by Distillation Method

Emulsion ID	Feed		Recovered							Time and Temperature		
	Sample Mass g	Initial Water wt %	Bulk Oil g	Light Oil g	Water g	Total g	Mass Loss(+) Gain(-) g	Total Recovery wt%	Residue Water wt %	Dist Time hr	Post Mixing hr	Dist T °C
H_2O/HVO	49.93	27.75	35.44	1.00	11.78	48.22	1.71	96.58	0.22±0.00	5	2	105-125
H_2O/MVO	68.77	28.28	49.18	0.78	18.19	68.15	0.62	99.11	0.84±0.01	5	2	105-115
H_2O/LVO	62.40	28.00	38.98	6.20	15.94	61.12	1.28	97.95	0.39±0.01	11	2	105-115

Table 14: Summary of Dewatering by Adding Chemical Demulsifiers

Sample	Chemical Demulsifier		Gravity Settling					Centrifugation		
	Name	Concentration ppm	T °C	Time hr	T °C	Time hr	Residual Water wt%	Speed RCF	Time hr	Residual Water wt%
H_2O/HVO	DMO4348[a]	659	90	2	20	15	4.42±0.19	5478	1	1.28±0.09
H_2O/MVO	DMO7050[a]	1125	90	2	20	15	3.63±0.44	5478	1	0.32±0.03
H_2O/LVO	EB8834[b]	849	90	2	20	15	4.94±0.06	5478	1	0.37±0.02

Note:[a]Supplied by Baker Hughes; [b]Supplied by MI-SWACO, Schlumberger

Table 15: Viscosity Comparison of Dewatered Oils – Low Viscous Oil

Name	P, psia	P, MPa	Viscosity, mPa•s			ARD* From STO, %		
			38°C	93°C	149°C	38°C	93°C	149°C
STO	1500	10.34	159	16.0	4.64	-	-	-
	1000	6.89	149	15.2	4.47	-	-	-
	500	3.45	141	14.6	4.33	-	-	-
	14.7	0.10	131	13.9	4.17	-	-	-
Dewatered by Distillation	1500	10.34	479	29.7	6.93	201	85	49
	1000	6.89	445	28.2	6.66	199	85	49
	500	3.45	412	26.5	6.36	195	81	47
	14.7	0.10	379	25.0	6.08	192	80	46
Dewatered by Centrifugation	1500	10.34	245	20.7	5.44	54	29	17
	1000	6.89	225	19.7	5.19	51	30	16
	500	3.45	209	18.6	4.93	50	27	14
	14.7	0.10	191	17.6	4.68	47	26	12
Dewatered by Adding Demulsifier	1500	10.34	305	23.0	5.69	92	44	23
	1000	6.89	284	21.9	5.43	91	44	22
	500	3.45	265	20.8	5.17	90	42	19
	14.7	0.10	245	19.7	4.92	89	41	18

Note: All the viscosities in the above table were measured by capillary viscometer.

*ARD, average relative difference = (Dewatered – Original)/Original×100.

Table 16: Viscosity Comparison of Dewatered Oils – Medium Viscous Oil

Name	P, psia	P, MPa	Viscosity, mPa·s			ARD* From STO, %		
			38°C	93°C	149°C	38°C	93°C	149°C
STO	1500	10.34	1404	40.2	7.03	-	-	-
	1000	6.89	1233	37.3	6.68	-	-	-
	500	3.45	1084	34.7	6.38	-	-	-
	14.7	0.10	924	32.0	6.05	-	-	-
Dewatered by Distillation	1500	10.34	1870	43.6	7.11	33	8	1
	1000	6.89	1631	40.2	6.70	32	8	0
	500	3.45	1415	37.3	6.33	31	7	-1
	14.7	0.10	1190	34.1	5.94	29	7	-2
Dewatered by Centrifugation	1500	10.34	1639	41.5	6.90	17	3	-2
	1000	6.89	1407	38.4	6.52	14	3	-2
	500	3.45	1227	35.3	6.14	13	2	-4
	14.7	0.10	1019	32.3	5.78	10	1	-5
Dewatered by Adding Demulsifier	1500	10.34	1656	40.7	6.92	18	1	-2
	1000	6.89	1426	37.5	6.49	16	0	-3
	500	3.45	1252	34.6	6.14	15	0	-4
	14.7	0.10	1046	31.6	5.74	13	-1	-5

Note: All the viscosities in the above table were measured by capillary viscometer.

*ARD, average relative difference = (Dewatered – Original)/Original×100.

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Table 17: Viscosity Comparison of Dewatered Oils – High Viscous Oil

Name	P, psia	P, MPa	Viscosity, mPa·s			ARD* From STO, %		
			38°C	93°C	149°C	38°C	93°C	149°C
STO	1500	10.34	6930	136	18.4	-	-	-
	1000	6.89	6129	125	17.2	-	-	-
	500	3.45	5396	116	16.3	-	-	-
	15	0.10	4640	106	15.3	-	-	-
Dewatered by Distillation	1500	10.34	14010	206	24.7	102	51	34
	1000	6.89	12249	189	23.2	100	51	34
	500	3.45	10660	173	21.7	98	49	33
	15	0.10	9004	157	20.2	94	48	32
Dewatered by Centrifugation	1500	10.34	8670	154	20.8	25	13	13
	1000	6.89	7542	141	19.2	23	13	12
	500	3.45	6631	130	17.6	23	12	8
	15	0.10	5606	118	16.0	21	11	5
Dewatered by Adding Demulsifier	1500	10.34	8043	148	19.4	16	9	5
	1000	6.89	7057	137	18.2	15	10	6
	500	3.45	6193	125	17.1	15	8	5
	15	0.10	5276	115	16.0	14	8	4

Note: All the viscosities in the above table were measured by capillary viscometer.

*ARD, average relative difference = (Dewatered – Original)/Original×100.

Table 18: Density Comparison of Dewatered Oils – Low Viscous Oil

Name	P, psia	P, MPa	Density, g/mL			ARD* From STO, %		
			38°C	93°C	149°C	38°C	93°C	149°C
STO	14.7	0.10	0.920	0.883	0.845	-	-	-
	500	3.45	0.922	0.885	0.848	-	-	-
	1000	6.89	0.924	0.888	0.852	-	-	-
	1500	10.34	0.926	0.890	0.855	-	-	-
Dewatered by Distillation	14.7	0.10	0.939	0.904	0.867	2.03	2.36	2.61
	500	3.45	0.941	0.906	0.8700	2.02	2.30	2.59
	1000	6.89	0.943	0.909	0.8734	2.02	2.29	2.57
	1500	10.34	0.945	0.911	0.8765	2.02	2.29	2.60
Dewatered by Centrifugation	14.7	0.10	0.925	0.888	0.850	0.49	0.54	0.60
	500	3.45	0.9269	0.8904	0.853	0.50	0.55	0.58
	1000	6.89	0.9290	0.8931	0.856	0.49	0.55	0.57
	1500	10.34	0.9310	0.8953	0.86	0.51	0.55	0.50
Dewatered by Adding Demulsifier	14.7	0.10	0.927	0.890	0.852	0.71	0.75	0.82
	500	3.45	0.929	0.892	0.855	0.72	0.76	0.82
	1000	6.89	0.931	0.895	0.858	0.73	0.74	0.82
	1500	10.34	0.933	0.897	0.862	0.74	0.74	0.81

Note: *ARD, average relative difference = (Dewatered – Original)/Original×100.

Table 19: Density Comparison of Dewatered Oils – Medium Viscous Oil

Name	P, psia	P, MPa	Density, g/mL			ARD* From STO, %		
			38°C	93°C	149°C	38°C	93°C	149°C
STO	15	0.10	0.963	0.928	0.893	-	-	-
	500	3.45	0.965	0.930	0.895	-	-	-
	1000	6.89	0.967	0.933	0.898	-	-	-
	1500	10.34	0.968	0.935	0.901	-	-	-
Dewatered by Distillation	15	0.10	0.966	0.930	0.894	0.29	0.23	0.16
	500	3.45	0.968	0.933	0.897	0.29	0.24	0.16
	1000	6.89	0.969	0.935	0.900	0.29	0.24	0.17
	1500	10.34	0.971	0.937	0.902	0.30	0.25	0.16
Dewatered by Centrifugation	15	0.10	0.964	0.929	0.891	0.12	0.05	-0.15
	500	3.45	0.966	0.931	0.894	0.11	0.06	-0.13
	1000	6.89	0.968	0.933	0.897	0.11	0.06	-0.12
	1500	10.34	0.969	0.935	0.900	0.10	0.06	-0.10
Dewatered by Adding Demulsifier	15	0.10	0.964	0.929	0.893	0.14	0.06	0.04
	500	3.45	0.966	0.931	0.896	0.14	0.06	0.03
	1000	6.89	0.968	0.933	0.899	0.13	0.06	0.04
	1500	10.34	0.970	0.935	0.901	0.14	0.06	0.03

Note: *ARD, average relative difference = (Dewatered – Original)/Original×100.

Table 20: Density Comparison of Dewatered Oils – High Viscous Oil

Name	P, psia	P, MPa	Density, g/mL			ARD* From STO, %		
			38°C	93°C	149°C	38°C	93°C	149°C
STO	15	0.10	0.978	0.943	0.908	-	-	-
	500	3.45	0.980	0.946	0.910	-	-	-
	1000	6.89	0.981	0.948	0.913	-	-	-
	1500	10.34	0.983	0.950	0.916	-	-	-
Dewatered by Distillation	15	0.10	0.982	0.948	0.913	0.41	0.46	0.61
	500	3.45	0.984	0.950	0.916	0.41	0.46	0.61
	1000	6.89	0.985	0.952	0.919	0.41	0.46	0.61
	1500	10.34	0.987	0.954	0.921	0.40	0.46	0.59
Dewatered by Centrifugation	15	0.10	0.979	0.944	0.909	0.07	0.07	0.14
	500	3.45	0.980	0.946	0.911	0.07	0.08	0.12
	1000	6.89	0.982	0.949	0.914	0.08	0.09	0.13
	1500	10.34	0.984	0.951	0.917	0.08	0.10	0.08
Dewatered by Adding Demulsifier	15	0.10	0.978	0.944	0.908	0.05	0.07	0.06
	500	3.45	0.9802	0.946	0.911	0.06	0.07	0.06
	1000	6.89	0.9820	0.948	0.914	0.06	0.07	0.08
	1500	10.34	0.9839	0.950	0.916	0.07	0.06	0.06

Note: *ARD, average relative difference = (Dewatered – Original)/Original×100.

Table 21: Summary of Capillary Viscometer (CV) Validation Results

Coil Name	Standard Name	T °C	Standard Viscosity, mPa•s	Measured Viscosity, mPa•s	STDEV	Difference %
5 070	N4000	25	9754	9598	51	-1.6
5 070	N4000	40	2986	2980	34	-0.2
5 070	N4000	50	1487	1453	6	-2.3
5 070	N4000	60	796	780	2	-2.0
5 070	N4000	80	272	266	5	-2.1
5 070	S8000	40	6688	6509	32	-2.7
5 070	S8000	80	498	485	5	-2.6
20 030	N4000	60	796	799	6	0.4
20 030	N4000	80	272	274	2	0.8
20 030	N4000	100	114	115	1	1.2
20 020	N35	20	72.4	73.4	0.3	1.4
20 020	N35	50	18.0	18.0	0.1	0.2
20 020	N35	100	4.42	4.44	0.02	0.5

Table 22: Summary of Electromagnetic Viscometer (EMV) Validation Results

Piston Name	Standard Name	T °C	Viscosity, mPa·s Standard Given	Viscosity, mPa·s Measured Raw Data	Viscosity, mPa·s Measured Corrected*	Relative Diff %	Piston Name	Standard Name	T °C	Viscosity, mPa·s Standard Given	Viscosity, mPa·s Measured Raw Data	Viscosity, mPa·s Measured Corrected*	Relative Diff %
500-10000	S8000	50	3160	3280	3280	3.8	1 - 20	N100	80	16.14	15.9	16.2	0.2
500-10000	S8000	50	3160	3090	3090	-2.2	1 - 20	N7.5	50	4.497	4.45	4.48	-0.3
500-10000	S8000	38	7977	8015	8015	0.5	1 - 20	N7.5	20	11.39	11.5	11.5	0.6
500-10000	S8000	50	3160	3150	3150	-0.3	1 - 20	N7.5	80	2.345	2.35	2.39	1.8
500-10000	S8000	50	3160	3045	3045	-3.6	1 - 20	N7.5	50	4.497	4.56	4.59	2.2
500-10000	N5100	40	4471	4445	4445	-0.6	1 - 20	N7.5	80	2.345	2.40	2.43	3.8
500-10000	N5100	60	1203.6	1175	1175	-2.4	1 - 20	N100	80	16.14	16.3	16.6	2.7
100 - 2000	N750	50	370.2	361	362	-2.1	1 - 20	N10	50	6.291	6.10	6.14	-2.4
100-2000	N750	25	1571	1614	1614	2.7	1 - 20	N10	20	19.45	19.6	19.5	0.2
100-2000	N750	80	103.1	107	108	5.1	1 - 20	N10	80	2.982	2.85	2.89	-3.0
100-2000	N750	50	370.2	363	364	-1.8	1 - 20	N10	50	6.291	6.15	6.19	-1.6
10-200	N100	25	203.8	202	202	-0.9	1 - 20	N10	80	2.982	2.89	2.93	-1.7
10-200	N100	80	16.14	15.9	16.0	-0.9	1 - 20	N10	20	19.45	19.6	19.5	0.5
10-200	N100	80	16.14	16.4	16.4	1.9	1 - 20	HT390	100	24.36	23.0	23.5	-3.6
10-200	N100	25	203.8	207	208	2.0	1 - 20	HT390	150	7.11	6.53	6.77	-4.7
10-200	N100	25	203.8	204	206	0.8	1 - 20	N10	20	19.45	19.6	19.6	0.8
10-200	N100	50	51.42	48.8	49.1	-4.6	1 - 20	N10	80	2.99	2.90	3.04	1.7
10-200	N100	50	51.42	49.1	49.4	-4.0	1 - 20	N10	80	2.99	2.90	2.97	-0.7
10-200	N75	50	40.33	38.5	38.7	-4.2	0.5-10	N7.5	85	2.15	2.18	2.23	3.5
10-200	N75	50	40.33	38.4	38.6	-4.3	0.5-10	N7.5	80	2.34	2.25	2.34	0.0
10-200	N75	20	169.9	170	170	0.0							
10-200	N75	80	14.61	14.8	15.1	3.6							
10-200	N75	50	40.33	39.3	39.5	-2.0							
10-200	N100	50	51.42	50.4	50.8	-1.2							
10-200	N100	25	203.8	205	205	0.7							
10-200	N100	80	16.14	15.8	15.9	-1.6							
10-200	N100	50	51.43	50.9	51.1	-0.7							
10-200	N100	25	203.8	204	204	0.2							
10-200	N100	80	16.14	16.0	16.2	0.6							
10-200	N75	50	40.33	38.5	38.5	-4.5							
10-200	N75	20	169.9	170	170	-0.1							
10-200	N75	80	14.61	14.8	14.9	2.0							
10-200	N75	50	40.33	39.2	39.3	-2.7							

Note: *the measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 23: Summary of Rheometer (Rheo) Validation Results

Standard Name	T °C	Standard Viscosity, mPa•s	Measured Viscosity, mPa•s	STDEV	Difference %	Note
N5100	20	22110	21947	232	-0.7	Pre-test
	40	4471	4434	41	-0.8	
	50	2246				
	60	1204	1223	13	1.5	
	80	409	411	2	0.3	
	100	169	172	0	1.7	
N1000	20	2845	2796	45	-1.7	
	40	784	761	6	-2.9	
	60	283	278	1	-1.9	
	80	124	121	1	-2.8	
	100	64				
N100	20	286	286	1	0.0	
	40	84.43	85	0	1.1	
	50	51.4				
	60					
	80	16.1				
	100	9.1				
N5100	20	22110	21804	186	-1.4	Post-test
	40	4471				
	50	2246	2212	17	-1.5	
	60	1204	1223	9	1.6	
	80	409				
	100	169	171	2	1.0	
N1000	20	2845	2796	25	-1.7	
	40	784				
	60	283	281	2	-0.9	
	80	124				
	100	64	64	1	0.2	
N100	20	286	283	2	-1.0	
	40	84				
	50	51	51.7	0.7	0.6	
	60		35.0	0.5		
	80	16				
	100	9	10.6	0.2	15.7	

Table 24: Summary of Stock Tank Oil Viscosities Measured by Capillary Viscometer (CV)

T °C	T °F	LVO		MVO		HVO	
		Visc, mPa•s	STDEV	Visc, mPa•s	STDEV	Visc, mPa•s	STDEV
38	**100**	130	4	924	5	4640	18
93	**200**	13.9	0.2	32.0	0.1	106	1
149	**300**	4.17	0.03	6.05	0.04	15.3	0.1

Table 25: Summary of Stock Tank Oil Viscosities Measured by Electromagnetic Viscometer (EMV)

T °C	T °F	LVO	MVO	HVO
		Visc, mPa•s	Visc, mPa•s	Visc, mPa•s
38	**100**	119	938	4698
93	**200**	14.7	30.1	102
149	**300**	4.18	5.94	15.5

Table 26: Summary of Stock Tank Oil Viscosities Measured by Rheometer (Rheo)

LVO			MVO			HVO		
T °C	**Viscosity mPa·s**	**STDEV**	**T °C**	**Viscosity mPa·s**	**STDEV**	**T °C**	**Viscosity mPa·s**	**STDEV**
20.0	498	5	**20.0**	7241	67	**20.0**	40583	691
60.0	56.6	1.3	**59.9**	182	2	**60.0**	784	11
100.0	17.7	0.9	**100.0**	25.9	0.6	**100.0**	83.1	1.9
20.0	890	16	**20.0**	7186	41			

Table 27: Viscosity of Low Viscous Oil (LVO) Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) at Various Temperature and Pressure Conditions

T °C	T °F	P, psia	P, MPa	EMV Raw mPa·s	EMV Corrected mPa·s*	CV mPa·s	STDEV	Diff% EMV_{Raw}: CV	Diff% EMV_{Corr}: CV	Notes
38	100	15	0.1	119	119	131	4	-10	-10	EMV_{Piston} 10-200
		1500	10.3	155	156	159	1	-3	-2	
		1000	6.9	140	141	149	4	-6	-6	
		500	3.4	132	132	141	2	-7	-6	
93	200	15	0.1	14.4	14.7	13.9	0.2	3	5	EMV_{Piston} 1-20
		1500	10.3	17.0	17.6	16.0	0.2	6	10	
		1000	6.9	15.9	16.4	15.2	0.0	4	8	
		500	3.4	15.3	15.7	14.6	0.0	4	7	
149	300	15	0.1	3.99	4.13	4.17	0.03	-4	-1	EMV_{Piston} 1-20
		1500	10.3	4.60	4.85	4.64	0.02	-1	5	
		1000	6.9	4.39	4.61	4.47	0.02	-2	3	
		500	3.4	4.19	4.37	4.33	0.03	-3	1	

Note: *The measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 28: Viscosity of Medium Viscous Oil (MVO) Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) at Various Temperature and Pressure Conditions

T °C	T °F	P, psia	P, MPa	EMV Raw mPa·s	EMV Corrected mPa·s*	CV mPa·s	STDEV	Diff% EMV_{Raw}: CV	Diff% EMV_{Corr}: CV	Notes
38	100	15	0.1	938	938	924	5	1	1	EMV_{Piston} 100-2000
		1500	10.3	1504	1504	1404	5	7	7	
		1000	6.9	1305	1305	1233	4	6	6	
		500	3.4	1125	1125	1084	4	4	4	
93	200	15	0.1	29.2	29	32.0	0.1	-9	-8	EMV_{Piston} 10-200
		1500	10.3	38.0	38.5	40.2	0.1	-6	-4	
		1000	6.9	34.9	35.3	37.3	0.1	-7	-6	
		500	3.4	32.1	32.4	34.7	0.1	-8	-7	
149	300	15	0.1	5.67	6	6.05	0.04	-7	-3	EMV_{Piston} 1-20
		1500	10.3	6.77	7.1	7.03	0.01	-4	2	
		1000	6.9	6.39	6.7	6.68	0.04	-4	0	
		500	3.4	6.03	6.3	6.38	0.03	-6	-1	

Note: *The measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 29: Viscosity of High Viscous Oil (HVO) Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) at Various Temperature and Pressure Conditions

T °C	T °F	P, psia	P, MPa	EMV Raw mPa·s	EMV Corrected mPa·s*	CV mPa·s	STDEV	Diff% EMV_{Raw}: CV	Diff% EMV_{Corr}: CV	Notes
38	100	15	0.1	4777	4777	4640	18	5	5	EMV_{Piston} 500-1000
		1500	10.3	7315	7315	6930	18	5	5	
		1000	6.9	6425	6425	6129	7	5	5	
		500	3.4	5555	5555	5396	10	3	3	
93	200	15	0.1	101	101	106	1	-5	-5	EMV_{Piston} 10-200
		1500	10.3	136	137	136	1	0	1	
		1000	6.9	124	125	125	1	-1	0	
		500	3.4	112	113	116	0.4	-4	-3	
149	300	15	0.1	14.9	15	15.3	0.1	-2	1	EMV_{Piston} 1-20
		1500	10.3	17.8	18.8	18.4	0.0	-3	2	
		1000	6.9	16.8	17.6	17.2	0.1	-3	2	
		500	3.4	15.9	16.6	16.3	0.1	-3	1	

Note: *The measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 30: Viscosity Difference of Medium Viscous Oil (MVO) Measured by Electromagnetic Viscometer (EMV) by Two Different Pistons

T °C	T °F	P, psia	P, MPa	EMV-1 100-2000	EMV-2 500-10000	CV	Diff%-1 EMV1:CV	Diff%-2 EMV2-CV	Diff%-3 EMV1:EMV2
38	100	15	0.1	938	784	924	1	-16	18
38	100	1500	10.3	1504	1261	1404	7	-11	18
38	100	1000	6.9	1305	1092	1233	6	-12	18
38	100	500	3.4	1125	942	1084	4	-14	18

Table 31: Summary of Gas-Oil-Ratio (GOR) Test Results of Recombined Oil/Methane Fluids

Name		GOR SCF/STB	Relative Difference %	Flashed Oil Density* g/mL	STO API	Flashing Method		GOR Apparatus	
						Standard Flash	Direct Flash	Regular	Low
Live LVO	Target	250.1		0.936	19.6				
	Average	268.7	7.5	0.939	19.0				
	STDEV	2.8		0.001	0.1				
	GOR 1	265.5	6.2	0.939	19.0	√		√	
	GOR 2	270.6	8.2	0.939	19.0	√		√	
	GOR 3	270.1	8.0	0.940	18.9	√		√	
Live MVO	Target	170.1		0.977	13.1				
	Average	164.6	-3.2	0.979	12.9				
	STDEV	1.8		0.000	0.1				
	GOR 1	166.1	-2.3	0.979	12.9		√		√
	GOR 2	162.7	-4.3	0.979	12.9		√		√
	GOR 3	165.0	-3.0	0.978	13.0		√	√	
Live HVO	Target	99.7		0.992	11.1				
	Average	97.9	-1.8	0.988	11.7				
	STDEV	0.4		0.004	0.6				
	GOR 1	98.0	-1.7	0.988	11.8		√		√
	GOR 2	97.4	-2.3	0.985	12.2		√		√
	GOR 3	98.2	-1.5	0.993	11.0		√		√

Table 32 Compositions of Recombined Low Viscous Oil/Methane Fluid – Test 1

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	80.495	94.739	0.000	0.000	3.106	37.541
C2	30.07	0.233	0.147	0.000	0.000	0.009	0.058
C3	44.10	1.654	0.708	0.003	0.023	0.067	0.295
i-C4	58.12	0.783	0.254	0.006	0.033	0.036	0.121
n-C4	58.12	3.285	1.067	0.044	0.233	0.169	0.563
i-C5	72.15	2.118	0.554	0.087	0.373	0.166	0.445
n-C5	72.15	3.198	0.837	0.186	0.794	0.302	0.811
C6	84.00	3.864	0.869	0.708	2.601	0.830	1.915
Mcyclo-C5	84.16	0.449	0.101	0.146	0.537	0.158	0.364
Benzene	78.11	0.152	0.037	0.062	0.247	0.066	0.164
Cyclo-C6	84.16	0.255	0.057	0.108	0.397	0.114	0.263
C7	100.21	1.760	0.332	1.167	3.595	1.190	2.302
Mcyclo-C6	98.19	0.284	0.055	0.265	0.833	0.266	0.524
Toluene	92.14	0.199	0.041	0.242	0.810	0.240	0.505
C8	112.22	0.718	0.121	1.699	4.674	1.661	2.870
C2-Benzene	106.17	0.034	0.006	0.135	0.392	0.131	0.239
m&p-Xylene	106.17	0.033	0.006	0.315	0.916	0.304	0.555
o-Xylene	106.17	0.018	0.003	0.132	0.383	0.127	0.232
C9	126.36	0.311	0.046	1.913	4.674	1.851	2.840
C10	134.00	0.107	0.015	2.598	5.986	2.502	3.620
C11	147.00	0.033	0.004	2.407	5.055	2.315	3.053
C12	161.00	0.012	0.001	2.327	4.462	2.237	2.694
C13	175.00	0.003	0.000	2.417	4.264	2.324	2.574
C14	190.00	0.002	0.000	2.311	3.756	2.222	2.267
C15	206.00	0.002	0.000	2.421	3.629	2.328	2.191
C16	222.00	0.000	0.000	2.271	3.158	2.183	1.907
C17	237.00	0.000	0.000	2.164	2.819	2.080	1.702
C18	251.00	0.000	0.000	2.132	2.622	2.050	1.583
C19	263.00	0.000	0.000	2.227	2.614	2.141	1.578
C20	275.00	0.000	0.000	2.038	2.288	1.960	1.382
C21	291.00	0.000	0.000	1.970	2.091	1.894	1.262
C22	305.00	0.000	0.000	1.916	1.940	1.843	1.171
C23	318.00	0.000	0.000	1.816	1.763	1.746	1.065
C24	331.00	0.000	0.000	1.740	1.623	1.673	0.980
C25	345.00	0.000	0.000	1.689	1.511	1.624	0.913
C26	359.00	0.000	0.000	1.643	1.413	1.580	0.853
C27	374.00	0.000	0.000	1.650	1.362	1.587	0.823
C28	388.00	0.000	0.000	1.606	1.278	1.544	0.772
C29	402.00	0.000	0.000	1.661	1.275	1.597	0.770
C30+	678.00	0.000	0.000	51.780	23.579	49.782	14.236
MW			18.9		308.7		193.9
Mole %			39.6		60.4		

Table 33 Properties of Recombined Low Viscous Oil/Methane Fluid – Test 1

Single Stage Flash Data	
	Original STO
GOR (SCF/STB)	265.5
STO Density (g/mL)	0.939
STO API Gravity	19.0
Mass Balance Error (mass%)	0.15

Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.83	95.94	58.25
C10+	0.02	78.49	47.39
C12+	0.00	67.45	40.72
C20+	0.00	40.12	24.22
C30+	0.00	23.58	14.24
Mass %			
C7+	4.37	98.97	95.32
C10+	0.16	92.78	89.21
C12+	0.02	87.78	84.39
C20+	0.00	69.51	66.83
C30+	0.00	51.78	49.78
Molar Mass			
C7+	99.98	318.47	317.24
C10+	140.02	364.98	364.94
C12+	170.16	401.81	401.81
C20+		534.86	534.86
C30+		678.00	678.00
Density (g/mL)			
C7+	0.770	0.936	0.936
C10+	0.784	0.949	0.949
C12+	0.808	0.960	0.960
C20+		1.001	1.001
C30+		1.050	1.050
Fluid Density at STP Condition (g/mL)		0.939	
Gas Gravity (Air=1)	0.652		
Dry Gross Heat Content (KJ/m^3)	43385.0		
Wet Gross Heat Content (KJ/m^3)	42628.2		

Table 34 Compositions of Recombined Low Viscous Oil/Methane Fluid – Test 2

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	80.443	94.757	0.000	0.000	3.165	38.335
C2	30.07	0.232	0.146	0.000	0.000	0.009	0.059
C3	44.10	1.611	0.690	0.004	0.029	0.067	0.297
i-C4	58.12	0.753	0.245	0.007	0.036	0.036	0.120
n-C4	58.12	3.181	1.034	0.043	0.231	0.166	0.556
i-C5	72.15	2.080	0.545	0.080	0.347	0.159	0.427
n-C5	72.15	3.170	0.830	0.165	0.715	0.283	0.762
C6	84.00	3.910	0.880	0.632	2.358	0.761	1.760
Mcyclo-C5	84.16	0.458	0.103	0.136	0.506	0.149	0.343
Benzene	78.11	0.156	0.038	0.054	0.219	0.058	0.146
Cyclo-C6	84.16	0.257	0.058	0.097	0.360	0.103	0.238
C7	100.21	1.844	0.349	1.277	4.014	1.299	2.532
Mcyclo-C6	98.19	0.292	0.056	0.239	0.762	0.241	0.476
Toluene	92.14	0.214	0.044	0.213	0.726	0.213	0.450
C8	112.22	0.793	0.134	1.544	4.315	1.515	2.623
C2-Benzene	106.17	0.039	0.007	0.120	0.354	0.117	0.214
m&p-Xylene	106.17	0.036	0.006	0.281	0.829	0.271	0.496
o-Xylene	106.17	0.020	0.004	0.120	0.353	0.116	0.212
C9	126.36	0.350	0.052	1.728	4.290	1.674	2.575
C10	134.00	0.118	0.017	2.413	5.647	2.323	3.369
C11	147.00	0.036	0.005	2.272	4.846	2.184	2.887
C12	161.00	0.006	0.001	2.228	4.340	2.141	2.585
C13	175.00	0.001	0.000	2.342	4.195	2.250	2.498
C14	190.00	0.000	0.000	2.262	3.733	2.173	2.223
C15	206.00	0.000	0.000	2.390	3.638	2.296	2.166
C16	222.00	0.000	0.000	2.272	3.209	2.183	1.911
C17	237.00	0.000	0.000	2.180	2.885	2.095	1.718
C18	251.00	0.000	0.000	2.164	2.703	2.079	1.610
C19	263.00	0.000	0.000	2.281	2.719	2.191	1.619
C20	275.00	0.000	0.000	2.114	2.410	2.031	1.435
C21	291.00	0.000	0.000	2.039	2.197	1.959	1.308
C22	305.00	0.000	0.000	2.020	2.077	1.941	1.237
C23	318.00	0.000	0.000	1.886	1.859	1.811	1.107
C24	331.00	0.000	0.000	1.825	1.728	1.753	1.029
C25	345.00	0.000	0.000	1.786	1.624	1.716	0.967
C26	359.00	0.000	0.000	1.756	1.533	1.686	0.913
C27	374.00	0.000	0.000	1.751	1.468	1.682	0.874
C28	388.00	0.000	0.000	1.768	1.428	1.698	0.851
C29	402.00	0.000	0.000	1.790	1.396	1.719	0.831
C30+	678.00	0.000	0.000	51.725	23.921	49.690	14.244
MW			18.9		313.6		194.3
Mole %			40.5		59.5		

Table 35 Properties of Recombined Low Viscous Oil/Methane Fluid – Test 2

Single Stage Flash Data	
GOR (SCF/STB)	270.6
STO Density (g/mL)	0.939
STO API Gravity	19.0
Mass Balance Error (mass%)	0.17

Properties	Flashed	Flashed	Monophasic
Mole %			
C7+	0.87	96.28	57.68
C10+	0.02	79.56	47.38
C12+	0.00	69.06	41.12
C20+	0.00	41.64	24.80
C30+	0.00	23.92	14.24
Mass %			
C7+	4.62	99.07	95.36
C10+	0.16	93.26	89.60
C12+	0.01	88.58	85.09
C20+	0.00	70.46	67.69
C30+	0.00	51.72	49.69
Molar Mass			
C7+	100.05	322.63	321.27
C10+	137.86	367.57	367.53
C12+	162.78	402.14	402.14
C20+		530.53	530.53
C30+		678.00	678.00
Density (g/mL)			
C7+	0.770	0.937	0.937
C10+	0.782	0.949	0.949
C12+	0.802	0.960	0.960
C20+		0.999	0.999
C30+		1.050	1.050
Fluid Density at STP Condition (g/mL)		0.9392	
Gas Gravity (Air=1)	0.6525		
Dry Gross Heat Content	43419.7		
Wet Gross Heat Content	42662.3		

Table 36 Compositions of Recombined Low Viscous Oil/Methane Fluid – Test 3

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	79.472	94.481	0.000	0.000	3.145	38.094
C2	30.07	0.232	0.147	0.000	0.000	0.009	0.059
C3	44.10	1.649	0.713	0.003	0.022	0.068	0.301
i-C4	58.12	0.780	0.256	0.006	0.030	0.036	0.121
n-C4	58.12	3.283	1.077	0.038	0.205	0.166	0.556
i-C5	72.15	2.139	0.565	0.076	0.329	0.158	0.424
n-C5	72.15	3.260	0.862	0.160	0.693	0.283	0.761
C6	84.00	4.100	0.931	0.632	2.354	0.769	1.780
Mcyclo-C5	84.16	0.486	0.110	0.138	0.514	0.152	0.351
Benzene	78.11	0.166	0.041	0.057	0.227	0.061	0.152
Cyclo-C6	84.16	0.286	0.065	0.099	0.369	0.107	0.246
C7	100.19	2.042	0.389	1.170	3.652	1.205	2.336
Mcyclo-C6	98.19	0.333	0.065	0.246	0.784	0.250	0.494
Toluene	92.14	0.241	0.050	0.224	0.760	0.225	0.474
C8	112.22	0.900	0.153	1.628	4.536	1.599	2.769
C2-	106.17	0.042	0.007	0.127	0.373	0.123	0.225
m&p-	106.17	0.040	0.007	0.304	0.897	0.294	0.538
o-Xylene	106.17	0.023	0.004	0.125	0.368	0.121	0.221
C9	126.46	0.378	0.057	1.796	4.442	1.740	2.674
C10	134.00	0.109	0.016	2.497	5.826	2.402	3.483
C11	147.00	0.031	0.004	2.329	4.954	2.238	2.958
C12	161.00	0.009	0.001	2.269	4.407	2.180	2.631
C13	175.00	0.002	0.000	2.377	4.248	2.283	2.535
C14	190.00	0.000	0.000	2.285	3.761	2.195	2.245
C15	206.00	0.000	0.000	2.412	3.661	2.316	2.185
C16	222.00	0.000	0.000	2.280	3.212	2.190	1.917
C17	237.00	0.000	0.000	2.191	2.890	2.104	1.725
C18	251.00	0.000	0.000	2.164	2.696	2.079	1.609
C19	263.00	0.000	0.000	2.274	2.704	2.184	1.614
C20	275.00	0.000	0.000	2.148	2.443	2.063	1.458
C21	291.00	0.000	0.000	1.963	2.109	1.885	1.259
C22	305.00	0.000	0.000	1.944	1.993	1.867	1.190
C23	318.00	0.000	0.000	1.863	1.832	1.789	1.093
C24	331.00	0.000	0.000	1.785	1.686	1.714	1.006
C25	345.00	0.000	0.000	1.707	1.547	1.640	0.924
C26	359.00	0.000	0.000	1.678	1.462	1.612	0.872
C27	374.00	0.000	0.000	1.678	1.403	1.612	0.837
C28	388.00	0.000	0.000	1.648	1.328	1.583	0.793
C29	402.00	0.000	0.000	1.663	1.294	1.597	0.772
C30+	678.00	0.000	0.000	52.016	23.991	49.957	14.318
MW			19.1		312.7		194.3
Mole %			40.3		59.7		

Table 37 Properties of Recombined Low Viscous Oil/Methane Fluid – Test 3

Single Stage Flash Data	
	Original STO
GOR (SCF/STB)	270.1
STO Density (g/mL)	0.940
STO API Gravity	18.9
Mass Balance Error (mass%)	0.3035

Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.97	96.37	57.90
C10+	0.02	79.45	47.42
C12+	0.00	68.67	40.98
C20+	0.00	41.09	24.52
C30+	0.00	23.99	14.32
Mass %			
C7+	5.09	99.09	95.37
C10+	0.15	93.17	89.49
C12+	0.01	88.35	84.85
C20+	0.00	70.09	67.32
C30+	0.00	52.02	49.96
Molar Mass			
C7+	100.20	321.52	320.03
C10+	138.28	366.72	366.68
C12+	163.37	402.32	402.31
C20+		533.45	533.45
C30+		678.00	678.00
Density (g/mL)			
C7+	0.770	0.937	0.937
C10+	0.782	0.949	0.949
C12+	0.802	0.960	0.960
C20+		1.001	1.001
C30+		1.050	1.050
Fluid Density at STP Condition (g/mL)		0.9402	
Gas Gravity (Air=1)	0.6586		
Dry Gross Heat Content (KJ/m^3)	43764.9		
Wet Gross Heat Content (KJ/m^3)	43001.4		

Table 38 Compositions of Recombined Medium Viscous Oil/Methane Fluid – Test 1

	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	98.813	99.838	0.000	0.000	2.002	31.196
C2	30.07	0.002	0.001	0.000	0.000	0.000	0.000
C3	44.10	0.011	0.004	0.000	0.000	0.000	0.001
i-C4	58.12	0.012	0.003	0.000	0.000	0.000	0.001
n-C4	58.12	0.022	0.006	0.000	0.001	0.001	0.003
i-C5	72.15	0.035	0.008	0.001	0.003	0.001	0.004
n-C5	72.15	0.033	0.007	0.001	0.007	0.002	0.007
C6	84.00	0.103	0.020	0.004	0.018	0.006	0.019
Mcyclo-C5	84.16	0.033	0.006	0.002	0.008	0.003	0.008
Benzene	78.11	0.002	0.000	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.013	0.002	0.001	0.003	0.001	0.003
C7	98.21	0.097	0.016	0.021	0.077	0.023	0.058
Mcyclo-C6	98.19	0.013	0.002	0.002	0.008	0.002	0.006
Toluene	92.14	0.002	0.000	0.000	0.000	0.000	0.000
C8	112.22	0.128	0.019	0.028	0.089	0.030	0.067
C2-	106.17	0.006	0.001	0.003	0.009	0.003	0.006
m&p-	106.17	0.006	0.001	0.007	0.023	0.007	0.016
o-Xylene	106.17	0.009	0.001	0.002	0.008	0.003	0.006
C9	123.33	0.120	0.016	0.090	0.259	0.090	0.183
C10	134.00	0.074	0.009	0.256	0.681	0.252	0.471
C11	147.00	0.041	0.004	0.690	1.672	0.677	1.151
C12	161.00	0.022	0.002	1.165	2.577	1.142	1.773
C13	175.00	0.004	0.000	1.992	4.054	1.952	2.787
C14	190.00	0.016	0.001	2.437	4.569	2.388	3.142
C15	206.00	0.384	0.030	2.968	5.132	2.916	3.538
C16	222.00	0.000	0.000	2.902	4.656	2.843	3.201
C17	237.00	0.000	0.000	3.289	4.944	3.223	3.399
C18	251.00	0.000	0.000	3.554	5.043	3.482	3.467
C19	263.00	0.000	0.000	3.390	4.592	3.322	3.157
C20	275.00	0.000	0.000	3.808	4.932	3.731	3.391
C21	291.00	0.000	0.000	3.475	4.254	3.405	2.925
C22	305.00	0.000	0.000	3.370	3.936	3.302	2.706
C23	318.00	0.000	0.000	3.273	3.667	3.207	2.521
C24	331.00	0.000	0.000	3.087	3.322	3.025	2.284
C25	345.00	0.000	0.000	2.917	3.011	2.857	2.070
C26	359.00	0.000	0.000	2.885	2.862	2.826	1.968
C27	374.00	0.000	0.000	2.864	2.727	2.806	1.875
C28	388.00	0.000	0.000	2.732	2.508	2.676	1.724
C29	402.00	0.000	0.000	2.846	2.521	2.788	1.734
C30+	588.00	0.000	0.000	45.939	27.828	45.008	19.133
MW			16.2		356.2		250.0
Mole %			31.2		68.8		

Table 39 Properties of Recombined Medium Viscous Oil/Methane Fluid – Test 1

Single Stage Flash Data			
	Original STO		
GOR (SCF/STB)	166.1		
STO Density (g/mL)	0.979		
STO API Gravity	12.9		
Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.11	99.97	68.77
C10+	0.05	99.49	68.42
C12+	0.03	97.13	66.79
C20+	0.00	61.57	42.33
C30+	0.00	27.83	19.13
Mass %			
C7+	0.97	99.99	97.99
C10+	0.54	99.84	97.83
C12+	0.43	98.89	96.90
C20+	0.00	77.19	75.63
C30+	0.00	45.94	45.01
Molar Mass			
C7+	139.22	356.27	356.16
C10+	184.07	357.45	357.41
C12+	202.16	362.64	362.61
C20+		446.60	446.60
C30+		588.00	588.00
Density (g/mL)			
C7+	0.797	0.981	0.981
C10+	0.819	0.982	0.982
C12+	0.830	0.984	0.984
C20+		1.035	1.035
C30+		1.175	1.175
Fluid Density at STP Condition (g/mL)		0.979	
Gas Gravity (Air=1)	0.5597		
Dry Gross Heat Content (KJ/m^3)	38043.0		
Wet Gross Heat Content (KJ/m^3)	37379.4		

Table 40 Compositions of Recombined Medium Viscous Oil/Methane Fluid – Test 2

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	98.245	99.778	0.000	0.000	1.960	30.576
C2	30.07	0.001	0.001	0.000	0.000	0.000	0.000
C3	44.10	0.011	0.004	0.000	0.000	0.000	0.001
i-C4	58.12	0.011	0.003	0.000	0.000	0.000	0.001
n-C4	58.12	0.019	0.005	0.000	0.001	0.001	0.002
i-C5	72.15	0.029	0.007	0.000	0.002	0.001	0.004
n-C5	72.15	0.031	0.007	0.001	0.005	0.002	0.005
C6	84.00	0.095	0.018	0.008	0.033	0.010	0.029
Mcyclo-C5	84.16	0.034	0.007	0.002	0.007	0.002	0.007
Benzene	78.11	0.003	0.001	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.015	0.003	0.001	0.003	0.001	0.003
C7	98.78	0.113	0.019	0.016	0.056	0.018	0.045
Mcyclo-C6	98.19	0.015	0.003	0.003	0.009	0.003	0.007
Toluene	92.14	0.005	0.001	0.000	0.000	0.000	0.000
C8	112.22	0.189	0.027	0.030	0.095	0.033	0.075
C2-	106.17	0.011	0.002	0.003	0.010	0.003	0.007
m&p-	106.17	0.010	0.002	0.007	0.024	0.007	0.017
o-Xylene	106.17	0.013	0.002	0.003	0.009	0.003	0.007
C9	123.33	0.180	0.024	0.097	0.278	0.099	0.200
C10	134.00	0.100	0.012	0.275	0.726	0.272	0.507
C11	147.00	0.096	0.011	0.723	1.739	0.710	1.209
C12	161.00	0.128	0.013	1.212	2.663	1.191	1.851
C13	175.00	0.041	0.004	2.066	4.174	2.026	2.896
C14	190.00	0.120	0.010	2.510	4.671	2.462	3.243
C15	206.00	0.487	0.039	3.050	5.235	2.999	3.643
C16	222.00	0.000	0.000	2.948	4.695	2.889	3.257
C17	237.00	0.000	0.000	3.339	4.981	3.272	3.455
C18	251.00	0.000	0.000	3.608	5.082	3.536	3.525
C19	263.00	0.000	0.000	3.454	4.644	3.385	3.221
C20	275.00	0.000	0.000	3.822	4.915	3.746	3.409
C21	291.00	0.000	0.000	3.526	4.285	3.456	2.972
C22	305.00	0.000	0.000	3.396	3.937	3.328	2.731
C23	318.00	0.000	0.000	3.320	3.691	3.253	2.560
C24	331.00	0.000	0.000	3.122	3.335	3.059	2.313
C25	345.00	0.000	0.000	2.961	3.035	2.902	2.105
C26	359.00	0.000	0.000	2.779	2.737	2.724	1.898
C27	374.00	0.000	0.000	2.968	2.806	2.909	1.946
C28	388.00	0.000	0.000	2.615	2.383	2.563	1.653
C29	402.00	0.000	0.000	2.824	2.484	2.768	1.723
C30+	588.00	0.000	0.000	45.312	27.248	44.408	18.898
MW			16.3		353.6		250.2
Mole %			30.6		69.4		

Table 41 Properties of Recombined Medium Viscous Oil/Methane Fluid – Test 2

Single Stage Flash Data			
	Original STO		
GOR (SCF/STB)	162.7		
STO Density (g/mL)	0.979		
STO API Gravity	12.9		
Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.18	99.96	69.38
C10+	0.09	99.47	69.01
C12+	0.07	97.00	67.30
C20+	0.00	60.86	42.21
C30+	0.00	27.25	18.90
Mass %			
C7+	1.56	99.99	98.03
C10+	0.97	99.83	97.86
C12+	0.78	98.83	96.87
C20+	0.00	76.65	75.12
C30+	0.00	45.31	44.41
Molar Mass			
C7+	143.74	353.70	353.54
C10+	179.23	354.88	354.81
C12+	192.83	360.26	360.21
C20+		445.33	445.33
C30+		588.00	588.00
Density (g/mL)			
C7+	0.799	0.979	0.979
C10+	0.815	0.980	0.980
C12+	0.824	0.982	0.982
C20+		1.034	1.034
C30+		1.175	1.175
Fluid Density at STP Condition (g/mL)		0.979	
Gas Gravity (Air=1)	0.5626		
Dry Gross Heat Content (KJ/m^3)	38211.3		
Wet Gross Heat Content (KJ/m^3)	37544.8		

Table 42 Compositions of Recombined Medium Viscous Oil/Methane Fluid – Test 3

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	98.380	99.766	0.000	0.000	1.989	30.925
C2	30.07	0.005	0.003	0.000	0.000	0.000	0.001
C3	44.10	0.016	0.006	0.000	0.000	0.000	0.002
i-C4	58.12	0.013	0.004	0.000	0.000	0.000	0.001
n-C4	58.12	0.028	0.008	0.000	0.001	0.001	0.003
i-C5	72.15	0.040	0.009	0.001	0.003	0.001	0.005
n-C5	72.15	0.043	0.010	0.001	0.006	0.002	0.007
C6	84.00	0.119	0.023	0.004	0.017	0.006	0.019
Mcyclo-C5	84.16	0.041	0.008	0.002	0.008	0.003	0.008
Benzene	78.11	0.005	0.001	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.020	0.004	0.001	0.004	0.001	0.004
C7	98.62	0.137	0.023	0.020	0.073	0.023	0.058
Mcyclo-C6	98.19	0.029	0.005	0.003	0.009	0.003	0.008
Toluene	92.14	0.003	0.000	0.000	0.000	0.000	0.000
C8	112.22	0.206	0.030	0.038	0.119	0.041	0.092
C2-	106.17	0.014	0.002	0.004	0.013	0.004	0.010
m&p-	106.17	0.021	0.003	0.009	0.031	0.009	0.022
o-Xylene	106.17	0.017	0.003	0.007	0.022	0.007	0.016
C9	123.63	0.195	0.026	0.132	0.379	0.134	0.269
C10	134.00	0.187	0.023	0.318	0.840	0.315	0.586
C11	147.00	0.153	0.017	0.713	1.718	0.702	1.191
C12	161.00	0.073	0.007	1.243	2.735	1.220	1.890
C13	175.00	0.013	0.001	2.048	4.145	2.007	2.861
C14	190.00	0.008	0.001	2.384	4.444	2.336	3.067
C15	206.00	0.234	0.018	2.949	5.071	2.894	3.505
C16	222.00	0.000	0.000	3.073	4.903	3.011	3.383
C17	237.00	0.000	0.000	3.157	4.718	3.093	3.255
C18	251.00	0.000	0.000	3.508	4.950	3.437	3.416
C19	263.00	0.000	0.000	3.574	4.813	3.502	3.321
C20	275.00	0.000	0.000	3.705	4.773	3.631	3.293
C21	291.00	0.000	0.000	3.416	4.158	3.347	2.869
C22	305.00	0.000	0.000	3.385	3.931	3.317	2.713
C23	318.00	0.000	0.000	3.301	3.677	3.235	2.537
C24	331.00	0.000	0.000	3.059	3.274	2.997	2.259
C25	345.00	0.000	0.000	2.965	3.044	2.905	2.100
C26	359.00	0.000	0.000	2.818	2.780	2.761	1.918
C27	374.00	0.000	0.000	2.867	2.716	2.809	1.874
C28	388.00	0.000	0.000	3.004	2.743	2.944	1.893
C29	402.00	0.000	0.000	2.849	2.510	2.792	1.732
C30+	588.00	0.000	0.000	45.443	27.375	44.525	18.889
MW			16.3		354.2		249.5
Mole %			31.0		69.0		

Table 43 Properties of Recombined Medium Viscous Oil/Methane Fluid – Test 3

Single Stage Flash Data			
	Original STO		
GOR (SCF/STB)	165.0		
STO Density (g/mL)	0.978		
STO API Gravity	13.0		
Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.17	99.97	69.04
C10+	0.07	99.32	68.55
C12+	0.03	96.76	66.77
C20+	0.00	60.98	42.08
C30+	0.00	27.37	18.89
Mass %			
C7+	1.35	99.99	98.00
C10+	0.67	99.78	97.78
C12+	0.33	98.75	96.76
C20+	0.00	76.81	75.26
C30+	0.00	45.44	44.52
Molar Mass			
C7+	128.51	354.28	354.10
C10+	161.29	355.86	355.80
C12+	192.28	361.49	361.47
C20+		446.18	446.18
C30+		588.00	588.00
Density (g/mL)			
C7+	0.788	0.980	0.980
C10+	0.802	0.980	0.980
C12+	0.824	0.983	0.983
C20+		1.034	1.034
C30+		1.175	1.175
Fluid Density at STP Condition (g/mL)		0.978	
Gas Gravity (Air=1)	0.5618		
Dry Gross Heat Content (KJ/m^3)	38164.3		
Wet Gross Heat Content (KJ/m^3)	37498.6		

Table 44 Compositions of Recombined High Viscous Oil/Methane Fluid – Test 1

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	99.105	99.828	0.000	0.000	1.180	23.751
C2	30.07	0.044	0.024	0.000	0.000	0.001	0.006
C3	44.10	0.028	0.010	0.000	0.000	0.000	0.002
i-C4	58.12	0.041	0.012	0.000	0.000	0.000	0.003
n-C4	58.12	0.032	0.009	0.001	0.007	0.001	0.007
i-C5	72.15	0.035	0.008	0.000	0.002	0.001	0.004
n-C5	72.15	0.060	0.013	0.000	0.002	0.001	0.005
C6	84.00	0.101	0.019	0.003	0.016	0.004	0.017
Mcyclo-C5	84.16	0.020	0.004	0.001	0.005	0.001	0.005
Benzene	78.11	0.003	0.001	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.023	0.004	0.001	0.007	0.002	0.006
C7	98.19	0.091	0.015	0.020	0.085	0.021	0.068
Mcyclo-C6	98.19	0.038	0.006	0.003	0.015	0.004	0.013
Toluene	92.14	0.008	0.001	0.000	0.000	0.000	0.000
C8	112.22	0.077	0.011	0.018	0.066	0.018	0.053
C2-	106.17	0.006	0.001	0.002	0.010	0.003	0.008
m&p-	106.17	0.008	0.001	0.004	0.016	0.004	0.012
o-Xylene	106.17	0.014	0.002	0.003	0.012	0.003	0.009
C9	123.81	0.070	0.009	0.059	0.200	0.059	0.155
C10	134.00	0.072	0.009	0.193	0.604	0.192	0.462
C11	147.00	0.044	0.005	0.437	1.243	0.432	0.948
C12	161.00	0.056	0.006	0.735	1.912	0.727	1.458
C13	175.00	0.001	0.000	1.152	2.755	1.138	2.099
C14	190.00	0.003	0.000	1.546	3.406	1.528	2.596
C15	206.00	0.017	0.001	1.814	3.686	1.793	2.810
C16	222.00	0.000	0.000	2.018	3.804	1.994	2.899
C17	237.00	0.000	0.000	2.113	3.731	2.088	2.843
C18	251.00	0.000	0.000	2.437	4.063	2.408	3.097
C19	263.00	0.000	0.000	2.452	3.902	2.423	2.974
C20	275.00	0.000	0.000	2.385	3.629	2.356	2.766
C21	291.00	0.000	0.000	2.387	3.433	2.359	2.616
C22	305.00	0.000	0.000	2.345	3.218	2.318	2.453
C23	318.00	0.000	0.000	2.414	3.177	2.385	2.421
C24	331.00	0.000	0.000	2.206	2.790	2.180	2.126
C25	345.00	0.000	0.000	2.172	2.635	2.146	2.008
C26	359.00	0.000	0.000	2.051	2.391	2.027	1.822
C27	374.00	0.000	0.000	2.117	2.369	2.092	1.805
C28	388.00	0.000	0.000	2.128	2.296	2.103	1.750
C29	402.00	0.000	0.000	2.171	2.260	2.145	1.723
C30+	620.14	0.000	0.000	62.609	42.253	61.863	32.201
MW			16.2		418.5		322.8
Mole %			23.8		76.2		

Table 45 Properties of Recombined High Viscous Oil/Methane Fluid – Test 1

Single Stage Flash Data			
	Original STO		
GOR (SCF/STB)	98.0		
STO Density (g/mL)	0.988		
STO API Gravity	11.6		
Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.08	99.97	76.21
C10+	0.02	99.56	75.88
C12+	0.01	97.71	74.47
C20+	0.00	70.45	53.69
C30+	0.00	42.25	32.20
Mass %			
C7+	0.55	99.99	98.81
C10+	0.19	99.88	98.70
C12+	0.08	99.25	98.07
C20+	0.00	84.99	83.97
C30+	0.00	62.61	61.86
Molar Mass			
C7+	116.00	418.62	418.54
C10+	149.98	419.89	419.87
C12+	170.68	425.13	425.12
C20+		504.86	504.86
C30+		620.14	620.14
Density (g/mL)			
C7+	0.781	0.992	0.992
C10+	0.792	0.993	0.993
C12+	0.808	0.994	0.994
C20+		1.026	1.026
C30+		1.091	1.091
Fluid Density at STP Condition (g/mL)		0.988	
Gas Gravity (Air=1)	0.558		
Dry Gross Heat Content (KJ/m^3)	37943.1		
Wet Gross Heat Content (KJ/m^3)	37281.2		

Table 46 Compositions of Recombined High Viscous Oil/Methane Fluid – Test 2

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	99.229	99.841	0.000	0.000	1.177	23.575
C2	30.07	0.045	0.024	0.000	0.000	0.001	0.006
C3	44.10	0.030	0.011	0.000	0.000	0.000	0.003
i-C4	58.12	0.041	0.011	0.000	0.003	0.001	0.005
n-C4	58.12	0.034	0.009	0.000	0.002	0.001	0.004
i-C5	72.15	0.036	0.008	0.001	0.003	0.001	0.004
n-C5	72.15	0.061	0.014	0.002	0.012	0.003	0.012
C6	84.00	0.096	0.018	0.004	0.018	0.005	0.018
Mcyclo-C5	84.16	0.019	0.004	0.001	0.005	0.001	0.005
Benzene	78.11	0.003	0.001	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.021	0.004	0.002	0.009	0.002	0.007
C7	98.19	0.089	0.015	0.029	0.121	0.029	0.096
Mcyclo-C6	98.19	0.036	0.006	0.005	0.020	0.005	0.017
Toluene	92.14	0.004	0.001	0.000	0.000	0.000	0.000
C8	112.22	0.078	0.011	0.051	0.188	0.051	0.146
C2-	106.17	0.006	0.001	0.004	0.015	0.004	0.011
m&p-	106.17	0.008	0.001	0.007	0.026	0.007	0.020
o-Xylene	106.17	0.013	0.002	0.006	0.023	0.006	0.018
C9	123.47	0.067	0.009	0.114	0.383	0.113	0.295
C10	134.00	0.062	0.007	0.248	0.768	0.245	0.589
C11	147.00	0.016	0.002	0.487	1.377	0.481	1.052
C12	161.00	0.004	0.000	0.763	1.969	0.754	1.505
C13	175.00	0.001	0.000	1.197	2.844	1.183	2.172
C14	190.00	0.001	0.000	1.479	3.236	1.461	2.472
C15	206.00	0.003	0.000	1.889	3.811	1.866	2.912
C16	222.00	0.000	0.000	2.002	3.750	1.979	2.864
C17	237.00	0.000	0.000	2.205	3.868	2.179	2.955
C18	251.00	0.000	0.000	2.365	3.917	2.337	2.992
C19	263.00	0.000	0.000	2.385	3.771	2.357	2.880
C20	275.00	0.000	0.000	2.569	3.883	2.538	2.966
C21	291.00	0.000	0.000	2.571	3.674	2.541	2.806
C22	305.00	0.000	0.000	2.142	2.919	2.116	2.230
C23	318.00	0.000	0.000	2.356	3.081	2.329	2.353
C24	331.00	0.000	0.000	2.181	2.740	2.156	2.093
C25	345.00	0.000	0.000	2.173	2.619	2.147	2.000
C26	359.00	0.000	0.000	2.082	2.412	2.058	1.842
C27	374.00	0.000	0.000	2.043	2.271	2.019	1.735
C28	388.00	0.000	0.000	2.081	2.230	2.056	1.703
C29	402.00	0.000	0.000	2.080	2.151	2.055	1.643
C30+	620.14	0.000	0.000	62.479	41.885	61.738	31.995
MW			16.1		415.7		321.4
Mole %			23.6		76.4		

Table 47 Properties of Recombined High Viscous Oil/Methane Fluid – Test 2

Single Stage Flash Data			
	Original STO		
GOR (SCF/STB)	97.4		
STO Density (g/mL)	0.985		
STO API Gravity	12.0		
Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.06	99.96	76.37
C10+	0.01	99.17	75.76
C12+	0.00	97.03	74.12
C20+	0.00	69.86	53.37
C30+	0.00	41.88	31.99
Mass %			
C7+	0.43	99.99	98.81
C10+	0.09	99.78	98.59
C12+	0.01	99.04	97.87
C20+	0.00	84.76	83.75
C30+	0.00	62.48	61.74
Molar Mass			
C7+	109.24	415.86	415.80
C10+	139.63	418.26	418.25
C12+	178.18	424.36	424.36
C20+		504.37	504.37
C30+		620.14	620.14
Density (g/mL)			
C7+	0.776	0.992	0.992
C10+	0.783	0.992	0.992
C12+	0.814	0.994	0.994
C20+		1.026	1.026
C30+		1.091	1.091
Fluid Density at STP Condition (g/mL)		0.985	
Gas Gravity (Air=1)	0.5574		
Dry Gross Heat Content (KJ/m^3)	37907.2		
Wet Gross Heat Content (KJ/m^3)	37246.0		

Table 48 Compositions of Recombined High Viscous Oil/Methane Fluid – Test 3

Component	MW	Flashed Gas		Flashed Liquid		Monophasic	
	(g/mol)	wt %	mole %	wt %	mole %	wt %	mole %
CO2	44.01	0.000	0.000	0.000	0.000	0.000	0.000
H2S	34.08	0.000	0.000	0.000	0.000	0.000	0.000
N2	28.01	0.000	0.000	0.000	0.000	0.000	0.000
C1	16.04	99.345	99.864	0.000	0.000	1.178	23.901
C2	30.07	0.050	0.027	0.000	0.000	0.001	0.006
C3	44.10	0.000	0.000	0.000	0.000	0.000	0.000
i-C4	58.12	0.032	0.009	0.000	0.003	0.001	0.004
n-C4	58.12	0.033	0.009	0.000	0.003	0.001	0.004
i-C5	72.15	0.035	0.008	0.001	0.006	0.001	0.006
n-C5	72.15	0.057	0.013	0.001	0.006	0.002	0.008
C6	84.00	0.101	0.019	0.005	0.023	0.006	0.022
Mcyclo-C5	84.16	0.014	0.003	0.001	0.006	0.001	0.005
Benzene	78.11	0.002	0.001	0.000	0.000	0.000	0.000
Cyclo-C6	84.16	0.015	0.003	0.001	0.007	0.002	0.006
C7	98.19	0.068	0.011	0.020	0.086	0.020	0.068
Mcyclo-C6	98.19	0.027	0.005	0.004	0.016	0.004	0.013
Toluene	92.14	0.006	0.001	0.000	0.000	0.000	0.000
C8	112.22	0.056	0.008	0.022	0.083	0.022	0.065
C2-	106.17	0.005	0.001	0.003	0.011	0.003	0.008
m&p-	106.17	0.007	0.001	0.004	0.017	0.004	0.013
o-Xylene	106.17	0.011	0.002	0.003	0.012	0.003	0.010
C9	123.82	0.057	0.007	0.063	0.215	0.063	0.165
C10	134.00	0.061	0.007	0.201	0.633	0.199	0.483
C11	147.00	0.018	0.002	0.436	1.256	0.432	0.956
C12	161.00	0.001	0.000	0.727	1.911	0.719	1.454
C13	175.00	0.000	0.000	1.131	2.733	1.117	2.079
C14	190.00	0.000	0.000	1.465	3.261	1.447	2.480
C15	206.00	0.000	0.000	1.810	3.716	1.788	2.826
C16	222.00	0.000	0.000	1.884	3.590	1.862	2.730
C17	237.00	0.000	0.000	2.103	3.754	2.079	2.856
C18	251.00	0.000	0.000	2.258	3.805	2.231	2.894
C19	263.00	0.000	0.000	2.446	3.934	2.417	2.992
C20	275.00	0.000	0.000	2.266	3.485	2.239	2.651
C21	291.00	0.000	0.000	2.284	3.320	2.257	2.526
C22	305.00	0.000	0.000	2.233	3.097	2.206	2.355
C23	318.00	0.000	0.000	2.202	2.929	2.176	2.228
C24	331.00	0.000	0.000	2.236	2.858	2.210	2.174
C25	345.00	0.000	0.000	2.074	2.543	2.049	1.934
C26	359.00	0.000	0.000	1.946	2.293	1.923	1.744
C27	374.00	0.000	0.000	2.016	2.281	1.993	1.735
C28	388.00	0.000	0.000	2.113	2.304	2.088	1.752
C29	402.00	0.000	0.000	2.060	2.168	2.036	1.649
C30+	620.14	0.000	0.000	63.980	43.639	63.222	33.195
MW			16.1		423.0		325.6
Mole %			23.9		76.1		

Table 49 Properties of Recombined High Viscous Oil/Methane Fluid – Test 3

Single Stage Flash Data			
	Original STO		
GOR (SCF/STB)	98.2		
STO Density (g/mL)	0.993		
STO API Gravity	10.9		
Properties	**Flashed Gas**	**Flashed Liquid**	**Monophasic**
Mole %			
C7+	0.05	99.96	76.05
C10+	0.01	99.51	75.69
C12+	0.00	97.62	74.25
C20+	0.00	70.91	53.94
C30+	0.00	43.64	33.19
Mass %			
C7+	0.35	99.99	98.81
C10+	0.08	99.87	98.69
C12+	0.00	99.23	98.06
C20+	0.00	85.41	84.40
C30+	0.00	63.98	63.22
Molar Mass			
C7+	109.96	423.12	423.07
C10+	136.98	424.53	424.53
C12+	161.00	429.99	429.99
C20+		509.45	509.45
C30+		620.14	620.14
Density (g/mL)			
C7+	0.777	0.996	0.996
C10+	0.781	0.996	0.996
C12+	0.800	0.998	0.998
C20+		1.029	1.029
C30+		1.091	1.091
Fluid Density at STP Condition (g/mL)		0.993	
Gas Gravity (Air=1)	0.5569		
Dry Gross Heat Content (KJ/m^3)	37877.0		
Wet Gross Heat Content (KJ/m^3)	37216.2		

Table 50: Summary of Saturation Pressure Measurement of Three Live Oil Samples

Temperature		P_{sat} (MPa)			P_{sat} (Psia)		
°F	**°C**	**LVO**	**MVO**	**HVO**	**LVO**	**MVO**	**HVO**
100	**38**	13.46	11.81	6.92	1952	1713	1004
200	**93**	15.68	12.93	8.34	2275	1875	1210
300	**149**	16.51	13.45	8.56	2395	1950	1242

Table 51: Results of Saturation Pressure Measurement of Live Low Viscous Oil (Live LVO) at 310.9K/100°F

No 13	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	34.58	5015	0.984	100.00	98.44	0.892	6.34	
Step 2	27.68	4015	0.989	100.00	98.91	0.888	7.01	
Step 3	20.79	3015	0.994	100.00	99.39	0.883	7.75	
Step 4	17.34	2515	0.997	100.00	99.67	0.881	8.15	
Step 5	15.61	2265	0.998	100.00	99.83	0.879	8.36	
Step 6	13.89	2015	1.000	100.00	99.96	0.878	8.57	
* Bubble-point	13.46	1952	1.000	100.00	100.00	0.878	8.62	
Step 8	12.17	1765	1.025					4.259
Step 9	11.82	1715	1.033					4.227
Step 10	8.03	1165	1.174					3.888
Step 11	6.31	915	1.304					3.732
Step 12	3.55	515	1.801					3.486
Step 13	2.86	415	2.086					3.413

Table 52: Results of Saturation Pressure Measurement of Live Low Viscous Oil (Live LVO) at 366.5K/200°F

No 17	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	34.58	5015	0.982	100.00	98.23	0.856	7.73	
Step 2	31.13	4515	0.985	100.00	98.49	0.853	8.31	
Step 3	27.68	4015	0.988	100.00	98.79	0.851	8.93	
Step 4	24.23	3515	0.991	100.00	99.11	0.848	9.60	
Step 5	20.79	3015	0.995	100.00	99.45	0.845	10.31	
Step 6	17.34	2515	0.998	100.00	99.81	0.842	11.07	
* Bubble-point	15.68	2275	1.000	100.00	100.00	0.840	11.45	
Step 8	15.61	2265	1.001					4.456
Step 9	14.93	2165	1.012					4.406
Step 10	14.44	2095	1.020					4.360
Step 11	13.89	2015	1.030					4.310
Step 12	13.55	1965	1.037					4.283
Step 13	13.20	1915	1.044					4.248
Step 14	12.17	1765	1.070					4.153
Step 15	10.44	1515	1.126					3.997
Step 16	7.00	1015	1.337					3.689
Step 17	5.27	765	1.558					3.539

Table 53: Results of Saturation Pressure Measurement of Live Low Viscous Oil (Live LVO) at 422.0K/300°F

No 14	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	34.58	5015	0.977	100.00	97.68	0.821	10.98	
Step 2	31.13	4515	0.980	100.00	98.05	0.818	11.67	
Step 3	27.68	4015	0.985	100.00	98.45	0.814	12.42	
Step 4	24.23	3515	0.989	100.00	98.91	0.811	13.25	
Step 5	20.79	3015	0.994	100.00	99.38	0.807	14.17	
Step 6	17.34	2515	0.999	100.00	99.86	0.803	15.19	
* Bubble-point	16.51	2395	1.000	100.00	100.00	0.802	15.45	
Step 8	16.48	2390	1.001					3.815
Step 9	15.74	2283	1.013					3.771
Step 10	13.89	2015	1.051					3.662
Step 11	10.44	1515	1.168					3.467
Step 12	8.72	1265	1.265					3.366
Step 13	7.00	1015	1.415					3.274
Step 14	4.58	665	1.831					3.133

Table 54: Results of Saturation Pressure Measurement of Live Medium Viscous Oil (Live MVO) at 310.9K/100°F

No 14	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	33.30	4830	0.987	100.00	98.65	0.949	5.22	
Step 2	24.23	3515	0.992	100.00	99.16	0.945	6.09	
Step 3	20.79	3015	0.994	100.00	99.38	0.943	6.46	
Step 4	17.34	2515	0.996	100.00	99.60	0.940	6.85	
Step 5	13.89	2015	0.998	100.00	99.84	0.938	7.25	
Step 6	12.17	1765	1.000	100.00	99.98	0.937	7.47	
* Bubble-point	11.81	1713	1.000	100.00	100.00	0.937	7.51	
Step 8	11.48	1665	1.005					6.152
Step 9	11.13	1615	1.010					6.079
Step 10	10.79	1565	1.016					6.017
Step 11	7.85	1139	1.093					5.433
Step 12	5.04	731	1.276					4.877
Step 13	3.60	523	1.495					4.595
Step 14	2.48	360	1.858					4.383

Table 55: Results of Saturation Pressure Measurement of Live Medium Viscous Oil (Live MVO) at 366.5K/200°F

No 20	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	33.31	4831	0.986	100.00	98.60	0.915	5.50	
Step 2	31.13	4515	0.987	100.00	98.72	0.914	5.77	
Step 3	27.68	4015	0.989	100.00	98.94	0.912	6.21	
Step 4	24.23	3515	0.991	100.00	99.15	0.910	6.69	
Step 5	20.79	3015	0.994	100.00	99.39	0.908	7.20	
Step 6	17.34	2515	0.996	100.00	99.63	0.906	7.75	
Step 7	15.61	2265	0.998	100.00	99.77	0.905	8.04	
Step 8	13.89	2015	0.999	100.00	99.92	0.903	8.34	
Step 9	13.55	1965	1.000	100.00	99.95	0.903	8.41	
Step 10	13.20	1915	1.000	100.00	99.98	0.903	8.47	
* Bubble-point	12.93	1875	1.000	100.00	100.00	0.903	8.52	
Step 12	12.86	1865	1.001					5.700
Step 13	12.52	1816	1.006					5.663
Step 14	12.17	1765	1.011					5.611
Step 15	11.82	1715	1.017					5.567
Step 16	11.13	1615	1.029					5.469
Step 17	9.75	1414	1.062					5.269
Step 18	6.15	893	1.232					4.747
Step 19	5.27	764	1.316					4.608
Step 20	3.53	513	1.609					4.361

Table 56: Results of Saturation Pressure Measurement of Live Medium Viscous Oil (Live MVO) at 422.0K/300°F

No 17	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	34.58	5015	0.978	100.00	97.84	0.882	7.54	
Step 2	31.13	4515	0.981	100.00	98.12	0.879	8.29	
Step 3	27.68	4015	0.984	100.00	98.43	0.876	9.12	
Step 4	24.23	3515	0.987	100.00	98.74	0.874	10.02	
Step 5	20.79	3015	0.991	100.00	99.09	0.870	11.01	
Step 6	17.34	2515	0.995	100.00	99.48	0.867	12.09	
Step 7	15.61	2265	0.997	100.00	99.69	0.865	12.67	
Step 8	14.04	2037	0.999	100.00	99.91	0.863	13.22	
Step 9	13.89	2015	0.999	100.00	99.92	0.863	13.27	
Step 10	13.55	1965	1.000	100.00	99.99	0.863	13.39	
* Bubble-point	13.45	1950	1.000	100.00	100.00	0.863	13.43	
Step 12	13.20	1915	1.004					4.248
Step 13	12.17	1765	1.025					4.208
Step 14	10.44	1515	1.069					4.140
Step 15	7.00	1015	1.230					4.007
Step 16	5.27	765	1.394					3.939
Step 17	3.55	515	1.721					3.868

Table 57: Results of Saturation Pressure Measurement of Live High Viscous Oil (Live HVO) at 310.9K/100°F

No 22	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	34.58	5015	0.983	100.00	98.32	0.975	5.20	
Step 2	31.13	4515	0.985	100.00	98.51	0.973	5.41	
Step 3	27.68	4015	0.987	100.00	98.70	0.971	5.62	
Step 4	24.23	3515	0.989	100.00	98.90	0.969	5.84	
Step 5	20.79	3015	0.991	100.00	99.09	0.967	6.07	
Step 6	17.34	2515	0.993	100.00	99.31	0.965	6.31	
Step 7	13.89	2015	0.995	100.00	99.52	0.963	6.55	
Step 8	12.51	1815	0.996	100.00	99.61	0.962	6.65	
Step 9	9.06	1315	0.998	100.00	99.85	0.960	6.91	
Step 10	8.38	1215	0.999	100.00	99.90	0.960	6.97	
Step 11	7.69	1115	1.000	100.00	99.95	0.959	7.02	
Step 12	7.00	1015	1.000	100.00	99.99	0.959	7.07	
* Bubble-point	6.92	1004	1.000	100.00	100.00	0.959	7.08	
Step 14	6.48	940	1.015	100.59	102.14			4.459
Step 15	6.31	915	1.022	100.50	102.71			4.445
Step 16	6.13	890	1.029	100.50	103.42			4.428
Step 17	5.96	865	1.037	100.53	104.21			4.414
Step 18	4.36	632	1.138	91.38	104.01			4.269
Step 19	2.71	394	1.376	74.78	102.9			4.124
Step 20	1.84	267	1.683	61.77	103.98			4.046
Step 21	1.37	199	2.013	51.66	103.98			4.002

Table 58: Results of Saturation Pressure Measurement of Live High Viscous Oil (Live HVO) at 366.5K/200°F

No 18	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	33.20	4815	0.982	100.00	98.19	0.941	5.92	
Step 2	27.68	4015	0.985	100.00	98.54	0.938	6.48	
Step 3	20.79	3015	0.990	100.00	99.00	0.934	7.27	
Step 4	17.34	2515	0.993	100.00	99.26	0.931	7.69	
Step 5	13.88	2014	0.995	100.00	99.53	0.929	8.14	
Step 6	10.44	1515	0.998	100.00	99.81	0.926	8.61	
Step 7	8.72	1265	1.000	100.00	99.97	0.925	8.86	
Step 8	8.38	1215	1.000	100.00	100.00	0.924	8.91	
* Bubble-point	8.34	1210	1.000	100.00	100.00	0.924	8.91	
Step 10	8.02	1164	1.008					4.977
Step 11	7.69	1115	1.017					4.943
Step 12	6.26	908	1.070					4.794
Step 13	4.91	713	1.150					4.660
Step 14	3.53	513	1.301					4.521
Step 15	2.50	363	1.529					4.421
Step 16	2.16	313	1.654					4.387
Step 17	1.81	263	1.830					4.347
Step 18	1.36	198	2.192					4.296

Table 59: Results of Saturation Pressure Measurement of Live High Viscous Oil (Live HVO) at 422.0K/300°F

No 20	Pressure Mpa	Pressure psia	Relative Vol V_{tot}/V_{sat}	% V_{liq}/V_{tot}	% V_{liq}/V_{sat}	Bulk Density g/mL	Compressibility 10^{-7}/kPa	Y Function
Step 1	34.58	5015	0.977	100.00	97.70	0.914	7.35	
Step 2	27.68	4015	0.982	100.00	98.23	0.909	8.13	
Step 3	24.23	3515	0.985	100.00	98.51	0.906	8.55	
Step 4	20.79	3015	0.988	100.00	98.80	0.903	8.98	
Step 5	17.34	2515	0.991	100.00	99.12	0.901	9.44	
Step 6	13.89	2015	0.994	100.00	99.45	0.898	9.92	
Step 7	12.17	1765	0.996	100.00	99.63	0.896	10.17	
Step 8	10.44	1515	0.998	100.00	99.81	0.8943	10.43	
Step 9	9.75	1415	0.999	100.00	99.88	0.8937	10.53	
Step 10	9.44	1370	0.999	100.00	99.90	0.8935	10.58	
Step 11	9.06	1315	0.999	100.00	99.95	0.8931	10.63	
Step 12	8.72	1265	1.000	100.00	99.98	0.8928	10.69	
* Bubble-point	8.56	1242	1.000	100.00	100.00	0.8926	10.71	
Step 14	8.38	1215	1.005					4.408
Step 15	7.69	1115	1.026					4.366
Step 16	7.00	1015	1.052					4.325
Step 17	6.31	915	1.083					4.286
Step 18	4.93	714.7	1.175					4.205
Step 19	3.55	514.7	1.342					4.127
Step 20	2.51	365	1.592					4.065

Table 60: Density of Live Low Viscous Oil (Live LVO) Measured by High-Pressure Anton-Paar Densitometer at Various Temperature and Pressure Conditions

T °C	T °F	P psia	P MPa	Density g/mL
38	100	1952	13.5	0.878
		2000	13.8	0.879
		2500	17.2	0.881
		3000	20.7	0.883
		3500	24.1	0.885
		4000	27.6	0.887
93	200	2275	15.7	0.840
		2300	15.9	0.840
		2500	17.2	0.842
		3000	20.7	0.845
		3500	24.1	0.848
		4000	27.6	0.850
149	300	2395	16.5	0.802
		2500	17.2	0.802
		3000	20.7	0.806
		3500	24.1	0.810
		4000	27.6	0.814
		4514	31.1	0.817

Table 61: Density of Live Medium Viscous Oil (Live MVO) Measured by High-Pressure Anton-Paar Densitometer at Various Temperature and Pressure Conditions

T °C	T °F	P psia	P MPa	Density g/mL
38	100	1713	11.8	0.941
		2000	13.8	0.942
		2500	17.2	0.944
		3000	20.7	0.946
		3500	24.1	0.948
		4000	27.6	0.950
93	200	1875	12.9	0.902
		2000	13.8	0.903
		2500	17.2	0.905
		3000	20.7	0.907
		3500	24.1	0.909
		4000	27.6	0.912
149	300	1950	13.4	0.861
		2000	13.8	0.862
		2500	17.2	0.864
		3000	20.7	0.867
		3500	24.1	0.870
		4000	27.6	0.873

Table 62: Density of Live High Viscous Oil (Live HVO) Measured by High-Pressure Anton-Paar Densitometer at Various Temperature and Pressure Conditions

T °C	T °F	P psia	P MPa	Density g/mL
38	100	1004	6.9	0.961
		1100	7.6	0.961
		1500	10.3	0.962
		2000	13.8	0.964
		2500	17.2	0.966
		3000	20.7	0.968
93	200	1210	8.3	0.926
		1500	10.3	0.927
		2000	13.8	0.929
		2500	17.2	0.932
		3000	20.7	0.934
		3500	24.1	0.936
149	300	1242	8.6	0.891
		1600	11.0	0.893
		2000	13.8	0.895
		2500	17.2	0.898
		3000	20.7	0.900
		3500	24.1	0.903

Table 63: Viscosity of Live Low Viscous Oil (Live LVO) Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) at Various Temperature and Pressure Conditions

T °C	T °F	P, psia	P, MPa	EMV Raw mPa·s	EMV Corrected mPa·s*	CV mPa·s	STDEV	Diff% EMV_{Raw}: CV	Diff% EMV_{Corr}: CV	Notes
38	100	1952	13	40.2	40.5	35.7	0.0	12	13	EMV_{Piston} 10-200
		4000	28	50.3	51.1	43.3	0.1	15	16	
		3500	24	47.8	48.4	41.0	0.1	15	16	
		3000	21	45.3	45.8	39.5	0.1	14	15	
		2500	17	42.9	43.3	37.8	0.2	12	13	
		2000	14	40.5	40.8	35.8	0.1	12	13	
93	200	2275	16	5.87	6.15	6.14	0.00	-4	0	EMV_{Piston} 1-20
		4000	28	6.80	7.26	6.98	0.02	-3	4	
		3500	24	6.52	6.92	6.74	0.02	-3	3	
		3000	21	6.30	6.65	6.47	0.01	-3	3	
		2500	17	6.02	6.32	6.22	0.02	-3	2	
		2300	16	5.85	6.13	6.19	0.02	-6	-1	
149	300	2395	17	2.12	2.26	2.29	0.00	-8	-1	EMV_{Piston} 1-20
		4500	31	2.52	2.75	2.66	0.00	-5	3	
		4000	28	2.43	2.64	2.55	0.00	-5	3	
		3500	24	2.33	2.51	2.48	0.00	-6	2	
		3000	21	2.23	2.39	2.40	0.00	-7	0	
		2500	17	2.15	2.29	2.31	0.00	-7	-1	

Note: *the measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 64: Viscosity of Live Medium Viscous Oil (Live MVO) Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) at Various Temperature and Pressure Conditions

T °C	T °F	P, psia	P, MPa	EMV Raw mPa·s	EMV Corrected mPa·s*	CV mPa·s	STDEV	Diff% EMV_{Raw}: CV	Diff% EMV_{Corr}: CV	Notes
38	100	1713	12	145	146	150	0	-3	-3	EMV_{Piston} 100-2000
		4000	28	236	239	274	0	-15	-14	
		3500	24	213	215	247	0	-15	-14	
		3000	21	193	195	220	0	-13	-12	
		2500	17	175	176	192	0	-9	-8	
		2000	14	158	159	166	0	-5	-4	
93	200	1875	13	11.5	12.0	12.4	0.0	-7	-3	EMV_{Piston} 1-20
		4000	28	15.1	16.1	15.4	0.0	-2	5	
		3500	24	14.3	15.2	14.7	0.0	-3	3	
		3000	21	13.4	14.1	14.0	0.0	-4	1	
		2500	17	12.6	13.2	13.3	0.0	-5	0	
		2000	14	11.7	12.2	12.5	0.0	-7	-3	
149	300	1950	13	3.04	3.22	2.70	0.00	12	18	EMV_{Piston} 1-20
		4000	28	3.75	4.07	3.11	0.00	19	27	
		3500	24	3.56	3.84	3.01	0.00	17	24	
		3000	21	3.38	3.63	2.91	0.00	15	22	
		2500	17	3.23	3.45	2.82	0.00	14	20	
		2000	14	3.07	3.26	2.71	0.00	13	18	

Note: *the measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 65: Viscosity of Live High Viscous Oil (Live HVO) Measured by Electromagnetic Viscometer (EMV) and Capillary Viscometer (CV) at Various Temperature and Pressure Conditions

T °C	T °F	P, psia	P, MPa	EMV Raw mPa·s	EMV Corrected mPa·s*	CV mPa·s	STDEV	Diff% EMV_{Raw}: CV	Diff% EMV_{Corr}: CV	Notes
38	100	1004	7	1109	1109	1215	0	-9	-9	EMV_{Piston} 100-2000
		3000	21	1725	1725	1817	1	-5	-5	
		2500	17	1560	1560	1646	7	-5	-5	
		2000	14	1402	1402	1505	6	-7	-7	
		1500	10	1255	1255	1354	3	-8	-8	
		1100	8	1149	1149	1254	4	-9	-9	
93	200	1210	8	50.6	51.2	54.3	0.0	-7	-6	EMV_{Piston} 10-200
		3500	24	71.6	72.9	73.4	0.5	-2	-1	
		3000	21	66.7	67.8	68.7	0.5	-3	-1	
		2500	17	62.1	63.0	64.8	0.2	-4	-3	
		2000	14	57.7	58.5	60.7	0.3	-5	-4	
		1500	10	53.5	54.1	56.9	0.2	-6	-5	
149	300	1242	9	9.6	10.1	10.7	0.0	-11	-6	EMV_{Piston} 1-20
		3500	24	12.7	13.6	13.5	0.0	-6	1	
		3000	21	11.8	12.7	12.7	0.0	-8	-1	
		2500	17	11.2	12.0	12.2	0.0	-9	-2	
		2000	14	10.5	11.1	11.6	0.0	-10	-4	
		1600	11	10.2	10.8	11.2	0.0	-9	-4	

Note: *the measured raw data, less than 200 mPa·s, were corrected using the kp, kt correction equation provided by the electromagnetic viscometer producer.

Table 66: Purity of Xylenes and Heptane Used in Oil/Solvent Mixture Preparation

Component	MW	Xylene		Heptane	
	(g/mol)	wt %	mole %	wt %	mole %
C6	84.00	0.000	0.000	0.003	0.003
Mcyclo-C5	84.16	0.000	0.000	0.001	0.001
Benzene	78.11	0.000	0.000	0.002	0.002
Cyclo-C6	84.16	0.000	0.000	0.004	0.005
C7	100.21	0.000	0.000	99.796	99.791
Mcyclo-C6	98.19	0.000	0.000	0.190	0.193
Toluene	92.14	0.015	0.017	0.000	0.000
C8	107.00	0.004	0.004	0.004	0.004
C2-Benzene	106.17	0.056	0.056	0.000	0.000
m&p-Xylene	106.17	99.786	99.801	0.000	0.000
o-Xylene	106.17	0.004	0.004	0.000	0.000
C9	121.00	0.125	0.110	0.000	0.000
C10	134.00	0.010	0.008	0.000	0.000
MW			106.2		100.2

Table 67: Summary of Heptane (nC7) Concentrations in Asphaltene Titration Tests with LVO and MVO

LVO + nC7 at 50°C and 3.45 Mpa/500 psia				MVO + nC7 at 50°C and 3.45 Mpa/500 psia			
	Concentration of nC7				Concentration of nC7		
	mol%	wt%	vol%		mol%	wt%	vol%
Addition 1	30.6	12.3	16.3	**Addition 1**	50.7	22.6	29.6
Addition 2	40.9	18.1	23.3	**Addition 2**	60.8	30.5	38.8
Addition 3	50.9	24.8	31.3	**Addition 3**	70.7	40.6	49.7
Addition 4	55.9	28.7	35.8	**Addition 4**	75.6	46.8	55.9
Addition 5	60.9	33.1	40.6	**Addition 5**	80.5	53.9	62.9
Addition 6	65.8	38.0	45.9	**Addition 6**	85.4	62.4	70.6
Addition 7	70.8	43.5	51.5				

Table 68: Summary of Solvent Concentrations in Prepared Oil/Solvent Mixtures

	Xylenes				Heptane			
HVO	**wt%**	8.61	17.34	66.40	**wt%**	6.82	14.42	30.96
	mol%	27.14	45.35	88.66	**mol%**	23.46	41.38	65.27
	vol%	9.84	19.56	69.61	**vol%**	9.70	19.83	39.71
MVO	**wt%**	8.51	17.32	66.15	**wt%**	6.75	14.00	30.69
	mol%	23.68	41.13	86.70	**mol%**	20.37	36.52	61.00
	vol%	9.60	19.30	69.04	**vol%**	9.48	19.06	39.03
LVO	**wt%**	9.06	18.51	67.52	**wt%**	7.20	14.30	31.37
	mol%	22.81	40.25	86.05	**mol%**	19.60	34.40	58.96
	vol%	9.79	19.84	69.38	**vol%**	9.68	18.73	38.70

Note: Volume percentage was calculated at 50°C and 3.45 Mpa (500 Psia)

Table 69: Summary of Viscosities of Low Viscous Oil (LVO)/Solvent Mixtures

Temperature (°C)	Pressure (psia)	Solvent Weight Fraction (wt/wt)									
		Xylenes					Heptane				
		0.00	**0.09**	**0.19**	**0.68**	**1.00**	**0.00**	**0.07**	**0.14**	**0.31**	**1.00**
38	1500	159	52.7	19.7	1.38	0.53	159	61.8	25.0	5.74	0.35
	1000	149	49.9	18.8	1.41	0.52	149	58.2	23.8	5.55	0.37
	500	141	46.5	17.9	1.34	0.51	141	54.8	22.7	5.37	0.38
	14.7	131	43.6	16.9	1.34	0.50	131	51.3	21.5	5.19	0.40
93	1500	16.0	8.80	4.76	0.73	0.33	16.0	9.29	5.15	1.88	0.21
	1000	15.2	8.38	4.60	0.71	0.32	15.2	8.86	4.95	1.82	0.22
	500	14.6	8.10	4.42	0.69	0.32	14.6	8.48	4.73	1.75	0.23
	14.7	13.9	7.74	4.26	0.68	0.31	13.9	8.08	4.53	1.69	0.24
149	1500	4.64	3.15	2.03	0.47	0.23	4.64	3.19	2.05	0.93	0.14
	1000	4.47	3.04	1.94	0.46	0.23	4.47	3.05	1.97	0.89	0.15
	500	4.33	2.88	1.87	0.45	0.22	4.33	2.94	1.88	0.87	0.16
	14.7	4.17	2.76	1.79	0.44	0.22	4.17	2.82	1.80	0.84	0.17

Table 70: Summary of Viscosities of Medium Viscous Oil (MVO)/Solvent Mixtures

Temperature (°C)	Pressure (psia)	Solvent Weight Fraction (wt/wt)									
		Xylenes					Heptane				
		0.00	**0.09**	**0.17**	**0.66**	**1.00**	**0.00**	**0.07**	**0.14**	**0.31**	**1.00**
38	1500	1404	165	38.8	1.57	0.53	1404	133	38.0	6.02	0.35
	1000	1233	150	36.4	1.52	0.52	1233	122	35.4	5.76	0.37
	500	1084	136	34.0	1.46	0.51	1084	112	32.8	5.50	0.38
	14.7	925	122	31.7	1.41	0.50	925	102	30.3	5.25	0.40
93	1500	40.2	13.7	5.95	0.71	0.33	40.2	11.9	5.93	1.86	0.21
	1000	37.3	12.8	5.67	0.70	0.32	37.3	11.3	5.58	1.78	0.22
	500	34.7	12.1	5.40	0.69	0.32	34.7	10.5	5.29	1.71	0.23
	14.7	32.0	11.2	5.14	0.67	0.31	32.0	9.9	4.97	1.63	0.24
149	1500	7.03	3.83	2.19	0.46	0.23	7.03	3.37	2.07	0.87	0.14
	1000	6.68	3.63	2.09	0.45	0.23	6.68	3.24	1.98	0.84	0.15
	500	6.38	3.45	2.01	0.43	0.22	6.38	3.08	1.90	0.80	0.16
	14.7	6.06	3.26	1.92	0.42	0.22	6.06	2.95	1.81	0.78	0.17

Table 71: Summary of Viscosities of High Viscous Oil (HVO)/Solvent Mixtures

Temperature (°C)	Pressure (psia)	Solvent Weight Fraction (wt/wt)									
		Xylenes					Heptane				
		0.00	**0.09**	**0.17**	**0.66**	**1.00**	**0.00**	**0.07**	**0.14**	**0.31**	**1.00**
38	1500	6930	637	105	1.84	0.53	6930	670	114	13.6	0.37
	1000	6129	579	98.0	1.79	0.52	6129	613	106	13.0	0.36
	500	5396	527	91.7	1.74	0.51	5396	558	98.6	12.4	0.35
	14.7	4640	472	85.1	1.70	0.50	4640	503	91.2	11.8	0.34
93	1500	136	37.8	14.2	0.91	0.33	136	40.2	13.9	3.54	0.24
	1000	125	35.2	13.5	0.89	0.32	125	37.9	13.1	3.40	0.23
	500	116	33.1	12.8	0.87	0.32	116	35.4	12.5	3.26	0.22
	14.7	106	30.7	12.1	0.86	0.31	106	33.1	11.8	3.13	0.22
149	1500	18	8.38	4.49	0.60	0.23	18.4	9.07	4.28	1.59	0.17
	1000	17	8.00	4.30	0.59	0.23	17.2	8.59	4.10	1.51	0.16
	500	16	7.57	4.10	0.58	0.22	16.3	8.12	3.90	1.45	0.15
	14.7	15.2	7.18	3.91	0.57	0.22	15.2	7.66	3.72	1.37	0.15

Table 72: Summary of Densities of Low Viscous Oil (LVO)/Solvent Mixtures

Temperature (°C)	Pressure (psia)	Solvent Weight Fraction (wt/wt)									
		Xylenes					Heptane				
		0.00	0.09	0.19	0.68	1.00	0.00	0.07	0.14	0.31	1.00
38	1500.000	0.926	0.919	0.912	0.876	0.854	0.926	0.901	0.876	0.825	0.679
	1000.000	0.924	0.917	0.910	0.874	0.852	0.924	0.904	0.879	0.828	0.676
	500.000	0.922	0.915	0.907	0.871	0.849	0.922	0.899	0.874	0.823	0.672
	14.700	0.920	0.913	0.905	0.869	0.847	0.920	0.899	0.874	0.823	0.669
93	1500.000	0.890	0.882	0.874	0.834	0.808	0.890	0.866	0.841	0.788	0.634
	1000.000	0.888	0.880	0.871	0.830	0.805	0.888	0.864	0.838	0.785	0.630
	500.000	0.885	0.877	0.868	0.827	0.801	0.885	0.861	0.835	0.781	0.624
	14.700	0.883	0.875	0.865	0.824	0.798	0.883	0.858	0.832	0.777	0.620
149	1500.000	0.855	0.846	0.837	0.790	0.759	0.855	0.830	0.804	0.748	0.587
	1000.000	0.852	0.843	0.833	0.786	0.755	0.852	0.827	0.800	0.743	0.580
	500.000	0.848	0.839	0.829	0.781	0.750	0.848	0.823	0.796	0.738	0.571
	14.700	0.845	0.835	0.825	0.777	0.745	0.845	0.820	0.792	0.733	0.564

Table 73: Summary of Densities of Medium Viscous Oil (MVO)/Solvent Mixtures

Temperature (°C)	Pressure (psia)	Solvent Weight Fraction (wt/wt)									
		Xylenes					Heptane				
		0.00	**0.09**	**0.17**	**0.66**	**1.00**	**0.00**	**0.07**	**0.14**	**0.31**	**1.00**
38	1500	0.968	0.958	0.946	0.890	0.854	0.968	0.937	0.912	0.856	0.679
	1000	0.967	0.956	0.944	0.888	0.852	0.967	0.935	0.910	0.853	0.676
	500	0.965	0.954	0.942	0.885	0.849	0.965	0.933	0.907	0.851	0.672
	14.7	0.963	0.952	0.940	0.883	0.847	0.963	0.931	0.905	0.848	0.669
93	1500	0.935	0.924	0.910	0.848	0.808	0.935	0.902	0.876	0.817	0.634
	1000	0.933	0.921	0.908	0.845	0.805	0.933	0.900	0.873	0.814	0.630
	500	0.930	0.918	0.905	0.842	0.801	0.930	0.897	0.871	0.811	0.624
	14.7	0.928	0.915	0.903	0.839	0.798	0.928	0.894	0.868	0.808	0.620
149	1500	0.901	0.888	0.874	0.805	0.759	0.901	0.867	0.840	0.779	0.587
	1000	0.898	0.885	0.871	0.801	0.755	0.898	0.864	0.836	0.775	0.580
	500	0.895	0.882	0.868	0.797	0.750	0.895	0.861	0.833	0.771	0.571
	14.7	0.893	0.879	0.865	0.793	0.745	0.893	0.858	0.829	0.767	0.564

Table 74: Summary of Densities of High Viscous Oil (HVO)/Solvent Mixtures

Temperature (°C)	Pressure (psia)	Solvent Weight Fraction (wt/wt)									
		Xylenes					Heptane				
		0.00	**0.09**	**0.17**	**0.66**	**1.00**	**0.00**	**0.07**	**0.14**	**0.31**	**1.00**
38	1500	0.983	0.971	0.959	0.894	0.854	0.983	0.956	0.923	0.867	0.679
	1000	0.981	0.969	0.957	0.892	0.852	0.981	0.954	0.921	0.865	0.675
	500	0.980	0.967	0.955	0.889	0.849	0.980	0.952	0.919	0.862	0.672
	14.7	0.978	0.965	0.953	0.887	0.847	0.978	0.950	0.917	0.860	0.669
93	1500	0.950	0.936	0.924	0.852	0.808	0.950	0.922	0.887	0.829	0.633
	1000	0.948	0.934	0.921	0.849	0.805	0.948	0.919	0.885	0.826	0.629
	500	0.946	0.931	0.919	0.846	0.801	0.946	0.917	0.882	0.823	0.624
	14.7	0.943	0.929	0.917	0.842	0.798	0.943	0.914	0.880	0.820	0.619
149	1500	0.916	0.901	0.887	0.809	0.759	0.916	0.887	0.852	0.792	0.585
	1000	0.913	0.898	0.884	0.805	0.755	0.913	0.885	0.849	0.788	0.578
	500	0.910	0.895	0.881	0.801	0.750	0.910	0.881	0.845	0.783	0.569
	14.7	0.908	0.892	0.878	0.797	0.745	0.908	0.879	0.842	0.779	0.562

Table 75: Comparison of Measured Viscosities of m-xylene and p-xylene Mixtures (1:1 by Weight) with Other Literature Data

T	P	Viscosity, cP				Relative Difference, %		
K	Mpa	Measured	Lit1-DIPPR		Lit2-JCED2009	Lit1-DIPPR		Lit2-JCED2009
		m/p-xylenes	m-xylene	p-xylene	m-xylene	m-xylene	p-xylene	m-xylene
310.9	**10.34**	0.529	na	na	0.540	na	na	-2.0
310.9	**6.89**	0.521	na	na	0.526	na	na	-0.9
310.9	**3.45**	0.513	na	na	0.516	na	na	-0.6
310.9	**0.10**	0.505	0.503	0.522	0.501	0.4	-3.4	0.7
366.5	**10.34**	0.327	na	na	0.341	na	na	-4.2
366.5	**6.89**	0.322	na	na	0.332	na	na	-2.9
366.5	**3.45**	0.317	na	na	0.324	na	na	-2.0
366.5	**0.10**	0.313	0.302	0.306	0.314	3.7	2.0	-0.4
422.0	**10.34**	0.232	na	na	0.230	na	na	0.6
422.0	**6.89**	0.228	na	na	0.223	na	na	2.4
422.0	**3.45**	0.224	na	na	0.217	na	na	2.9
422.0	**0.10**	0.220	0.208	0.205	0.210	6.0	7.5	4.8

Lit1: Daubert T.E, Sibul H.M., Stebbins C.C., Danner R.P., Rowley R.L., Adams M.E., Wilding W.V., Marshall T.L., 2000, *Physical and Thermodynamic Properties of Pure Chemicals: DIPPR*, Revised edition, Taylor & Francis

Lit2: Caudwell, D.R., Trusler, J.P.M., Vesovic, V., Wakeham, W.A., 2009 Viscosity and Density of Five Hydrocarbon Liquids at Pressures up to 200 MPa and Temperatures up to 473 K, *Journal of Chemical and Engineering Data*, 54 (2), 359-366.

Table 76: Comparison of Measured Viscosities of Heptane with Other Literature Data

T	P	Viscosity, cP			Relative Difference, %	
K	Mpa	Measured	Lit3-NIST	Lit4-IJT2013	Lit3-NIST	Lit4-IJT2013
310.9	**10.34**	0.369	0.383	0.387	-3.7	-4.5
310.9	**6.89**	0.360	0.368	0.376	-2.1	-4.1
310.9	**3.45**	0.351	0.352	0.365	-0.3	-3.8
310.9	**0.10**	0.342	0.337	0.355	1.5	-3.5
366.5	**10.34**	0.238	0.234	0.248	1.3	-4.1
366.5	**6.89**	0.231	0.224	0.240	3.1	-3.9
366.5	**3.45**	0.224	0.214	0.233	4.7	-4.1
366.5	**0.10**	0.217	0.204	0.227	6.6	-4.1
422.0	**10.34**	0.165	0.158	0.178	4.8	-7.3
422.0	**6.89**	0.160	0.150	0.173	7.1	-7.5
422.0	**3.45**	0.153	0.141	0.168	9.0	-8.7
422.0	**0.10**	0.148	0.133	0.163	11.5	-9.4

Lit3: The NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP version 7). http://webbook.nist.gov/chemistry/

Lit4: Sagdeev, D.I., Fomina, M.G., Mukhamedzyanov, G.K., Abdulagatov, I.M., 2013, Experimental Study of the Density and Viscosity of n-Heptane at Temperatures from 298 K to 470 K and Pressure up to 245 MPa, *International Journal of Thermophysics*, 34 (1),1-33

Table 77: Comparison of Measured Densities of m-xylene and p-xylene Mixtures (1:1 by Weight) with Other Literature Data

T	P	Density, g/mL						Relative Difference, %				
K	Mpa	Measured	Lit1-DIPPER		Lit5-I&EC		Lit6-JCED 2013	Lit1-DIPPER		Lit5-I&EC		Lit6-JCED 2013
		m/p-xylenes	m-xylene	p-xylene	m-xylene	p-xylene	xylenes	m-xylene	p-xylene	m-xylene	p-xylene	xylenes
310.9	**10.34**	0.854	na	na	0.857	0.847	0.856	na	na	-0.3	0.8	-0.2
310.9	**6.89**	0.852	na	na	0.854	0.845	0.854	na	na	-0.2	0.8	-0.2
310.9	**3.45**	0.849	na	na	0.850	0.844	0.851	na	na	-0.1	0.7	-0.2
310.9	**0.10**	0.847	0.849	0.846	0.847	0.842	0.848	-0.3	0.1	-0.1	0.6	-0.2
366.5	**10.34**	0.808	na	na	0.809	0.803	0.810	na	na	-0.1	0.6	-0.2
366.5	**6.89**	0.805	na	na	0.805	0.800	0.806	na	na	0.0	0.6	-0.2
366.5	**3.45**	0.801	na	na	0.801	0.796	0.802	na	na	0.1	0.6	-0.2
366.5	**0.10**	0.798	0.800	0.797	0.796	0.793	0.799	-0.3	0.1	0.2	0.6	-0.2
422.0	**10.34**	0.759	na	na	0.761	0.760	0.763	na	na	-0.3	0.0	-0.5
422.0	**6.89**	0.755	na	na	0.756	0.754	0.759	na	na	-0.2	0.1	-0.5
422.0	**3.45**	0.750	na	na	0.751	0.749	0.754	na	na	-0.1	0.1	-0.6
422.0	**0.10**	0.745	0.746	0.742	0.745	0.743	0.750	-0.2	0.4	-0.1	0.2	-0.6

Lit1: Daubert T.E, Sibul H.M., Stebbins C.C., Danner R.P., Rowley R.L., Adams M.E., Wilding W.V., Marshall T.L., 2000, *Physical and Thermodynamic Properties of Pure Chemicals: DIPPR*, Revised edition, Taylor & Francis

Lit5: Wu, Y., Bamgbade, B.A., Baled, H., Enick, R.M., Burgess, W.A., Tapriyal, D., McHugh, M.A., 2013, Liquid Densities of Xylene Isomers and 2-methylnaphthalene at Temperatures to 523 K and Pressures to 265 MPa: Experimental Determination and Equation of State Modeling, *Industrial and Engineering Chemistry Research*, 52 (33), 11732-11740.

Lit6: Guan, J.G., Kariznovi, M., Nourozieh, H., Abedi, J., 2013, Density and Viscosity for Mixtures of Athabasca Bitumen and Aromatic Solvents, *Journal of Chemical and Engineering Data*, 58 (3), 611-624.

Table 78: Comparison of Measured Densities of Heptane with Other Literature Data

T	P	Density, g/mL			Relative Difference, %	
°C	Mpa	Measured	Lit3-NIST	Lit4-IJT2013	Lit3-NIST	Lit4-IJT2013
38	**10.34**	0.679	0.679	0.680	0.0	-0.2
38	**6.89**	0.675	0.676	0.676	0.0	-0.2
38	**3.45**	0.672	0.672	0.673	0.0	-0.1
38	**0.10**	0.669	0.669	0.669	0.0	-0.1
93	**10.34**	0.633	0.635	0.634	-0.2	-0.2
93	**6.89**	0.629	0.630	0.630	-0.2	-0.1
93	**3.45**	0.624	0.625	0.625	-0.2	-0.1
93	**0.10**	0.619	0.620	0.619	-0.1	0.0
149	**10.34**	0.585	0.587	0.587	-0.3	-0.3
149	**6.89**	0.578	0.580	0.580	-0.3	-0.4
149	**3.45**	0.569	0.571	0.573	-0.3	-0.6
149	**0.10**	0.562	0.563	0.566	-0.3	-0.6

Lit3: The NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP version 7). http://webbook.nist.gov/chemistry/

Lit4: Sagdeev, D.I., Fomina, M.G., Mukhamedzyanov, G.K., Abdulagatov, I.M., 2013, Experimental Study of the Density and Viscosity of n-Heptane at Temperatures from 298 K to 470 K and Pressure up to 245 MPa, *International Journal of Thermophysics*, 34 (1),1-33.

12. APPENDIX

Table A 1 Simulated Distillation Results of Three Stock Tank Oil Samples

HVO			MVO			LVO		
Recovered mass%	BP		Recovered mass%	BP		Recovered mass%	BP	
	°C	K		°C	K		°C	K
0.5	180.2	453.35	0.5	173.8	446.95	0.5	64.2	337.35
1	199.6	472.75	1	191	464.15	1	77.4	350.55
2	220.4	493.55	2	207.8	480.95	2	97	370.15
3	234.8	507.95	3	218.4	491.55	3	110.2	383.35
4	247.6	520.75	4	227.2	500.35	4	124.8	397.95
5	258	531.15	5	235.2	508.35	5	133.6	406.75
6	267.4	540.55	6	243	516.15	6	142.4	415.55
7	276.2	549.35	7	250.4	523.55	7	151.4	424.55
8	284.6	557.75	8	256.6	529.75	8	162.6	435.75
9	292.2	565.35	9	262.6	535.75	9	172.8	445.95
10	299.2	572.35	10	268.4	541.55	10	179.6	452.75
11	305.8	578.95	11	274	547.15	11	189.8	462.95
12	312.2	585.35	12	279.8	552.95	12	198.4	471.55
13	318.4	591.55	13	285	558.15	13	208.6	481.75
14	324.8	597.95	14	290	563.15	14	216.2	489.35
15	331.2	604.35	15	294.8	567.95	15	225.6	498.75
16	337.2	610.35	16	299.2	572.35	16	234.4	507.55
17	343.6	616.75	17	303.8	576.95	17	243	516.15
18	349.4	622.55	18	307.8	580.95	18	250.8	523.95
19	355.2	628.35	19	312	585.15	19	258.6	531.75
20	361	634.15	20	316.2	589.35	20	266.2	539.35
21	367	640.15	21	320.2	593.35	21	273.2	546.35
22	372.6	645.75	22	324.4	597.55	22	281.8	554.95
23	378.4	651.55	23	328.4	601.55	23	289.2	562.35
24	384.2	657.35	24	332.4	605.55	24	297	570.15
25	390	663.15	25	336.6	609.75	25	303.8	576.95
26	395.8	668.95	26	340.8	613.95	26	311.6	584.75
27	401.6	674.75	27	344.8	617.95	27	317.6	590.75
28	407.2	680.35	28	348.8	621.95	28	325.8	598.95
29	412.6	685.75	29	352.8	625.95	29	332.8	605.95
30	418	691.15	30	356.6	629.75	30	341	614.15
31	423	696.15	31	360.6	633.75	31	348	621.15
32	428.2	701.35	32	364.6	637.75	32	355.6	628.75
33	433.2	706.35	33	368.4	641.55	33	362.8	635.95
34	438.2	711.35	34	372.4	645.55	34	370	643.15
35	443.2	716.35	35	376.4	649.55	35	377.8	650.95
36	448.4	721.55	36	380.4	653.55	36	385	658.15
37	453.8	726.95	37	384.4	657.55	37	392.2	665.35
38	459.2	732.35	38	388.4	661.55	38	400	673.15
39	464.6	737.75	39	392.4	665.55	39	407.2	680.35
40	470.2	743.35	40	396.6	669.75	40	414.2	687.35
41	475.6	748.75	41	400.4	673.55	41	421.2	694.35
42	480.8	753.95	42	404.4	677.55	42	428.2	701.35
43	486.2	759.35	43	408.2	681.35	43	435.2	708.35
44	491.4	764.55	44	412.2	685.35	44	442.2	715.35
45	496.6	769.75	45	415.8	688.95	45	449.2	722.35
46	501.4	774.55	46	419.4	692.55	46	456.6	729.75

47	506	779.15	47	423	696.15	47	464	737.15
48	510.8	783.95	48	426.4	699.55	48	471.2	744.35
49	515.2	788.35	49	429.6	702.75	49	478.2	751.35
50	519.8	792.95	50	433.2	706.35	50	485	758.15
51	524.4	797.55	51	436.6	709.75	51	492	765.15
52	528.8	801.95	52	440.2	713.35	52	498.6	771.75
53	533.4	806.55	53	444	717.15	53	505	778.15
54	538.2	811.35	54	447.8	720.95	54	511.2	784.35
55	543.2	816.35	55	451.8	724.95	55	517.2	790.35
56	548.4	821.55	56	456	729.15	56	523.2	796.35
57	553.6	826.75	57	460.6	733.75	57	528.8	801.95
58	558.8	831.95	58	465.2	738.35	58	534.8	807.95
59	563.8	836.95	59	469.8	742.95	59	540.8	813.95
60	569.2	842.35	60	474.4	747.55	60	547.2	820.35
61	574.6	847.75	61	479.2	752.35	61	553.8	826.95
62	580	853.15	62	483.8	756.95	62	560.4	833.55
63	585.4	858.55	63	488.8	761.95	63	566.6	839.75
64	590.8	863.95	64	493.4	766.55	64	573.2	846.35
65	596.4	869.55	65	498.2	771.35	65	579.8	852.95
66	602	875.15	66	502.8	775.95	66	586.2	859.35
67	607.6	880.75	67	507.8	780.95	67	593	866.15
68	613.2	886.35	68	512.6	785.75	68	599.6	872.75
69	618.8	891.95	69	517.6	790.75	69	606.4	879.55
70	624.4	897.55	70	522.6	795.75	70	613.2	886.35
71	630.2	903.35	71	527.6	800.75	71	620.2	893.35
72	636	909.15	72	532.8	805.95	72	627.2	900.35
73	642	915.15	73	538.4	811.55	73	634.4	907.55
74	648	921.15	74	544.2	817.35	74	641.6	914.75
75	654.2	927.35	75	550.2	823.35	75	649	922.15
76	660.4	933.55	76	556.4	829.55	76	656.8	929.95
77	666.8	939.95	77	562.6	835.75	77	664.8	937.95
78	673.2	946.35	78	569	842.15	78	673	946.15
79	680	953.15	79	575.4	848.55	79	681.6	954.75
80	687	960.15	80	582	855.15	80	690.8	963.95
81	693.6	966.75	81	588.6	861.75	81	698.6	971.75
82	699.8	972.95	82	595.6	868.75	82	707.6	980.75
83	706.6	979.75	83	603	876.15	83	717.2	990.35
84	713.8	986.95	84	610.4	883.55	84	727.8	1000.95
85	721.2	994.35	85	618	891.15	85	740.2	1013.35
86	729	1002.15	86	626	899.15	85.6	749.8	1022.95
87	737.8	1010.95	87	634.4	907.55	85.6	749.8	1022.95
88	748.2	1021.35	88	643	916.15			
88.1	750	1023.15	89	652	925.15			
88.1	750	1023.15	90	661.4	934.55			
			91	671.4	944.55			
			92	682.2	955.35			
			93	693.4	966.55			
			94	704	977.15			
			95	716.2	989.35			
			96	730	1003.15			
			97	747.2	1020.35			
			97.1	750	1023.15			
			97.1	750	1023.15			

Table A 2 Experimental Data of Viscosity Measurement by Capillary Viscometer - Low Viscous Oil Dewatered by Centrifugation

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	20	34.50	244.78		-0.3	0.931		0.03	0.00
	10.3	1500	30	52.00	245.96	**245**	0.2	0.931		0.04	0.00
	10.3	1500	10	17.30	245.49		0.0	0.931		0.01	0.00
	6.9	1000	30	47.80	226.09		0.5	0.929		0.04	0.00
38	6.9	1000	20	31.70	224.91	**225**	-0.1	0.929	20 040	0.03	0.00
	6.9	1000	10	15.80	224.20		-0.4	0.929		0.01	0.00
	3.4	500	30	44.45	210.25		0.5	0.927		0.05	0.00
	3.4	500	20	29.50	209.30	**209**	0.1	0.927		0.03	0.00
	3.4	500	10	14.65	207.88		-0.6	0.927		0.02	0.00
	10.3	1500	24	55.10	20.73		0.1	0.895		0.72	0.00
	10.3	1500	18	41.40	20.77	**20.7**	0.2	0.895		0.54	0.00
	10.3	1500	12	27.45	20.66		-0.3	0.895		0.36	0.00
				30.30	20.51						
	6.9	1000	24	52.60	19.79		0.4	0.893		0.75	0.00
93	6.9	1000	18	39.30	19.72	**19.7**	0.0	0.893	20 020	0.57	0.00
	6.9	1000	12	26.10	19.64		-0.4	0.893		0.38	0.00
	3.4	500	24	49.80	18.74		0.5	0.890		0.79	0.00
	3.4	500	18	37.20	18.66	**18.6**	0.1	0.890		0.60	0.00
	3.4	500	12	24.65	18.55		-0.5	0.890		0.40	0.00
	10.3	1500	100	62.80	5.464		0.4	0.859		10.95	0.04
	10.3	1500	70	43.80	5.444	**5.44**	0.0	0.859		7.69	0.03
	10.3	1500	40	24.90	5.416		-0.5	0.859		4.42	0.01
	6.9	1000	100	60.00	5.220		0.5	0.856		11.42	0.04
149	6.9	1000	70	41.75	5.189	**5.19**	0.0	0.856	20 020	8.04	0.03
	6.9	1000	40	23.75	5.166		-0.5	0.856		4.62	0.02
	3.4	500	100	56.80	4.942		0.2	0.853		12.02	0.04
	3.4	500	70	39.70	4.934	**4.93**	0.1	0.853		8.42	0.03
	3.4	500	40	22.60	4.916		-0.3	0.853		4.83	0.02

Table A 3 Experimental Data of Viscosity Measurement by Capillary Viscometer - Medium Viscous Oil Dewatered by Centrifugation

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	6	69.50	1643.68		0.3	0.969		0.00	0.00
	10.3	1500	5	57.80	1640.36	**1639**	0.1	0.969		0.00	0.00
	10.3	1500	3	34.50	1631.85		-0.4	0.969		0.00	0.00
	6.9	1000	6	59.90	1416.64		0.7	0.968		0.00	0.00
38	6.9	1000	5	49.60	1407.65	**1407**	0.1	0.968	20 040	0.00	0.00
	6.9	1000	3	29.50	1395.35		-0.8	0.968		0.00	0.00
	3.4	500	6	52.10	1232.17		0.4	0.966		0.00	0.00
	3.4	500	5	43.30	1228.85	**1227**	0.1	0.966		0.00	0.00
	3.4	500	3	25.80	1220.34		-0.6	0.966		0.00	0.00
	10.3	1500	200	61.80	41.84		0.8	0.935		1.56	0.01
	10.3	1500	150	45.90	41.43	**41.5**	-0.2	0.935		1.18	0.01
	10.3	1500	100	30.50	41.30		-0.5	0.935		0.79	0.01
	6.9	1000	200	28.20	38.18		-0.7	0.933		1.70	0.01
93	6.9	1000	150	42.50	38.36	**38.4**	-0.2	0.933	20 040	1.27	0.01
	6.9	1000	100	57.30	38.79		0.9	0.933		0.84	0.01
	3.4	500	200	52.20	35.34		0.2	0.931		1.83	0.01
	3.4	500	150	39.10	35.29	**35.3**	0.0	0.931		1.38	0.01
	3.4	500	100	26.00	35.20		-0.2	0.931		0.92	0.01
	10.3	1500	70	55.40	6.89		-0.2	0.900		6.37	0.02
	10.3	1500	50	39.60	6.89	**6.90**	-0.2	0.900		4.55	0.02
	10.3	1500	30	23.90	6.93		0.4	0.900		2.71	0.01
	6.9	1000	70	52.30	6.50		-0.3	0.897		6.73	0.02
149	6.9	1000	50	37.40	6.51	**6.52**	-0.2	0.897	20 020	4.80	0.02
	6.9	1000	30	22.60	6.55		0.5	0.897		2.86	0.01
	3.4	500	70	49.30	6.13		-0.3	0.894		7.11	0.02
	3.4	500	50	35.40	6.16	**6.14**	0.2	0.894		5.05	0.02
	3.4	500	30	21.20	6.15		0.0	0.894		3.04	0.01

Table A 4 Experimental Data of Viscosity Measurement by Capillary Viscometer - High Viscous Oil Dewatered by Centrifugation

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	50	67.80	8715		0.5	0.984		0.00	0.00
	10.3	1500	35	47.20	8667	**8670**	0.0	0.984		0.00	0.00
	10.3	1500	20	26.85	8628		-0.5	0.984		0.00	0.00
	6.9	1000	50	59.25	7616		1.0	0.982		0.00	0.00
38	6.9	1000	35	41.05	7538	**7542**	-0.1	0.982	5 085	0.00	0.00
	6.9	1000	20	23.25	7471		-0.9	0.982		0.00	0.00
	3.4	500	50	51.95	6678		0.7	0.980		0.00	0.00
	3.4	500	35	36.10	6629	**6631**	0.0	0.980		0.00	0.00
	3.4	500	20	20.50	6588		-0.7	0.980		0.00	0.00
	10.3	1500	60	68.75	155.15		0.6	0.951		0.13	0.00
	10.3	1500	40	45.55	154.19	**154**	0.0	0.951		0.09	0.00
	10.3	1500	20	22.65	153.34		-0.6	0.951		0.04	0.00
	6.9	1000	60	63.00	142.17		0.7	0.949		0.14	0.00
93	6.9	1000	40	41.70	141.15	**141**	0.0	0.949	20 040	0.09	0.00
	6.9	1000	20	20.70	140.14		-0.7	0.949		0.05	0.00
	3.4	500	60	57.85	130.55		0.5	0.946		0.15	0.00
	3.4	500	40	38.40	129.98	**130**	0.0	0.946		0.10	0.00
	3.4	500	20	19.10	129.31		-0.5	0.946		0.05	0.00
	10.3	1500	200	32.40	20.85		0.0	0.917		3.06	0.02
	10.3	1500	150	24.30	20.85	**20.8**	0.0	0.917		2.30	0.02
	10.3	1500	100	16.20	20.85		0.0	0.917		1.53	0.01
	6.9	1000	200	29.90	19.24		0.0	0.914		3.31	0.02
149	6.9	1000	150	22.40	19.22	**19.2**	-0.1	0.914	20 040	2.48	0.02
	6.9	1000	100	14.95	19.24		0.0	0.914		1.65	0.01
	3.4	500	200	27.30	17.57		0.0	0.911		3.61	0.02
	3.4	500	150	20.50	17.59	**17.6**	0.1	0.911		2.71	0.02
	3.4	500	100	13.65	17.57		0.0	0.911		1.81	0.01

Table A 5 Experimental Data of Viscosity Measurement by Capillary Viscometer - Low Viscous Oil Dewatered by Distillation

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	16	54.00	478.91		0.4	0.945		0.02	0.00
	10.3	1500	12	40.20	475.37	**477**	-0.4	0.945		0.02	0.00
	10.3	1500	8	26.90	477.14		0.0	0.945		0.01	0.00
				54.60	511.06						
	6.9	1000	16	50.30	446.10		0.3	0.943		0.02	0.00
38	6.9	1000	12	37.60	444.62	**445**	0.0	0.943	20 020	0.02	0.00
	6.9	1000	8	25.00	443.44		-0.3	0.943		0.01	0.00
				46.10	396.46						
	3.4	500	16	46.60	413.28		0.3	0.941		0.03	0.00
	3.4	500	12	34.80	411.51	**412**	-0.1	0.941		0.02	0.00
	3.4	500	8	23.20	411.51		-0.1	0.941		0.01	0.00
	10.3	1500	12	39.50	29.72		0.0	0.911		0.26	0.00
	10.3	1500	18	59.70	29.95	**29.7**	0.8	0.911		0.38	0.00
	10.3	1500	6	19.60	29.50		-0.8	0.911		0.13	0.00
	6.9	1000	18	56.50	28.34		0.6	0.909		0.40	0.00
93	6.9	1000	12	37.50	28.22	**28.2**	0.1	0.909	20 020	0.27	0.00
	6.9	1000	6	18.60	27.99		-0.7	0.909		0.14	0.00
	3.4	500	18	53.30	26.74		0.5	0.906		0.42	0.00
	3.4	500	12	35.30	26.56	**26.6**	-0.1	0.906		0.28	0.00
	3.4	500	6	17.60	26.49		-0.4	0.906		0.14	0.00
	10.3	1500	70	55.80	6.94		0.1	0.877		6.16	0.02
	10.3	1500	50	39.80	6.93	**6.93**	-0.1	0.877		4.41	0.01
	10.3	1500	30	23.90	6.93		0.0	0.877		2.64	0.01
	6.9	1000	70	53.50	6.65		-0.2	0.873		6.40	0.02
149	6.9	1000	50	38.30	6.66	**6.66**	0.0	0.873	20 020	4.56	0.02
	6.9	1000	30	23.00	6.67		0.1	0.873		2.73	0.01
	3.4	500	70	51.10	6.35		-0.1	0.870		6.68	0.02
	3.4	500	50	36.60	6.37	**6.36**	0.2	0.870		4.76	0.02
	3.4	500	30	21.90	6.35		-0.1	0.870		2.86	0.01

Table A 6 Experimental Data of Viscosity Measurement by Capillary Viscometer - Medium Viscous Oil Dewatered by Distillation

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
38	10.3	1500	5	66.30	1881.59	1870	0.6	0.971	20 040	0.00	0.00
	10.3	1500	4	52.80	1873.08		0.2	0.971		0.00	0.00
	10.3	1500	3	39.20	1854.16		-0.8	0.971		0.00	0.00
	6.9	1000	5	57.90	1643.20	1631	0.8	0.969		0.00	0.00
	6.9	1000	4	46.00	1631.85		0.1	0.969		0.00	0.00
	6.9	1000	3	34.20	1617.66		-0.8	0.969		0.00	0.00
	3.4	500	5	50.10	1421.84	1415	0.5	0.968		0.00	0.00
	3.4	500	4	39.90	1415.45		0.0	0.968		0.00	0.00
	3.4	500	3	29.75	1407.18		-0.5	0.968		0.00	0.00
93	10.3	1500	180	58.45	43.97	43.6	0.8	0.937	20 040	1.34	0.01
	10.3	1500	130	41.85	43.59		0.0	0.937		0.97	0.01
	10.3	1500	80	25.55	43.24		-0.8	0.937		0.60	0.00
	6.9	1000	180	53.80	40.47	40.2	0.7	0.935		1.45	0.01
	6.9	1000	130	38.65	40.26		0.2	0.935		1.05	0.01
	6.9	1000	80	23.55	39.86		-0.8	0.935		0.65	0.00
	3.4	500	180	49.85	37.50	37.3	0.7	0.933		1.56	0.01
	3.4	500	130	35.80	37.29		0.1	0.933		1.13	0.01
	3.4	500	80	21.85	36.98		-0.7	0.933		0.70	0.00
149	10.3	1500	70	57.60	7.16	7.11	0.7	0.903	20 020	6.14	0.02
	10.3	1500	50	40.80	7.10		-0.2	0.903		4.43	0.01
	10.3	1500	30	24.40	7.08		-0.5	0.903		2.66	0.01
	6.9	1000	70	53.90	6.70	6.70	0.0	0.900		6.55	0.02
	6.9	1000	50	38.50	6.70		0.0	0.900		4.68	0.02
	6.9	1000	30	23.10	6.70		0.0	0.900		2.81	0.01
	3.4	500	70	50.90	6.33	6.33	-0.1	0.897		6.91	0.02
	3.4	500	50	36.30	6.32		-0.2	0.897		4.94	0.02
	3.4	500	30	21.90	6.35		0.3	0.897		2.95	0.01

Table A 7 Experimental Data of Viscosity Measurement by Capillary Viscometer - High Viscous Oil Dewatered by Distillation

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	24	52.70	14113		0.7	0.987		0.00	0.00
	10.3	1500	16	34.90	14019	14010	0.1	0.987		0.00	0.00
	10.3	1500	8	17.30	13898		-0.8	0.987		0.00	0.00
	6.9	1000	24	45.95	12305		0.5	0.985		0.00	0.00
38	6.9	1000	16	30.45	12231	12249	-0.1	0.985	5 085	0.00	0.00
	6.9	1000	8	15.20	12211		-0.3	0.985		0.00	0.00
	3.4	500	24	40.00	10712		0.5	0.984		0.00	0.00
	3.4	500	16	26.55	10665	10660	0.0	0.984		0.00	0.00
	3.4	500	8	13.20	10605		-0.5	0.984		0.00	0.00
	10.3	1500	40	61.20	207.16		0.5	0.954		0.06	0.00
	10.3	1500	30	45.70	206.26	206	0.1	0.954		0.05	0.00
	10.3	1500	20	30.25	204.79		-0.6	0.954		0.03	0.00
	6.9	1000	40	56.10	189.90		0.4	0.952		0.07	0.00
93	6.9	1000	30	41.90	189.11	189	0.0	0.952	20 040	0.05	0.00
	6.9	1000	20	27.80	188.21		-0.5	0.952		0.04	0.00
	3.4	500	40	51.35	173.82		0.4	0.950		0.08	0.00
	3.4	500	30	38.35	173.09	173	0.0	0.950		0.06	0.00
	3.4	500	20	25.45	172.30		-0.4	0.950		0.04	0.00
	10.3	1500	250	48.20	24.81		0.7	0.921		3.23	0.02
	10.3	1500	200	38.30	24.65	24.7	0.0	0.921		2.60	0.02
	10.3	1500	150	28.55	24.50		-0.6	0.921		1.96	0.01
	6.9	1000	250	45.20	23.27		0.5	0.919		3.44	0.02
149	6.9	1000	200	36.10	23.23	23.2	0.3	0.919	20 040	2.75	0.02
	6.9	1000	150	26.80	22.99		-0.7	0.919		2.09	0.01
	3.4	500	250	42.30	21.78		0.4	0.917		3.66	0.02
	3.4	500	200	33.85	21.78	21.7	0.5	0.917		2.93	0.02
	3.4	500	150	25.05	21.49		-0.9	0.917		2.23	0.01

Table A 8 Experimental Data of Viscosity Measurement by Capillary Viscometer - Low Viscous Oil Dewatered by Adding Chemical Demulsifiers

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	3	97.90	305.12		0.1	0.933		0.01	0.00
	10.3	1500	2	65.20	304.81	**305**	-0.1	0.933		0.00	0.00
	6.9	1000	3	91.20	284.24		0.1	0.931		0.01	0.00
38	6.9	1000	2	60.70	283.77	**284**	-0.1	0.931	20 020	0.00	0.00
	3.4	500	3	85.10	265.23		0.7	0.929		0.01	0.00
	3.4	500	2	56.50	264.14	**263**	0.3	0.929		0.00	0.00
	3.4	500	0	27.90	260.87		-1.0	0.929		0.00	0.00
	10.3	1500	24	61.30	23.06		0.2	0.897		0.65	0.00
	10.3	1500	18	45.90	23.03	**23.0**	0.1	0.897		0.49	0.00
	10.3	1500	12	30.50	22.95		-0.3	0.897		0.33	0.00
	6.9	1000	24	58.30	21.94		0.4	0.895		0.68	0.00
93	6.9	1000	18	43.60	21.87	**21.9**	0.1	0.895	20 020	0.51	0.00
	6.9	1000	12	28.90	21.75		-0.5	0.895		0.34	0.00
	3.4	500	24	55.40	20.84		0.2	0.892		0.72	0.00
	3.4	500	18	41.40	20.77	**20.8**	-0.1	0.892		0.54	0.00
	3.4	500	12	27.60	20.77		-0.1	0.892		0.36	0.00
	10.3	1500	100	65.80	5.725		0.6	0.862		10.48	0.03
	10.3	1500	70	45.80	5.692	**5.69**	0.0	0.862		7.38	0.02
	10.3	1500	40	26.00	5.655		-0.6	0.862		4.24	0.01
	6.9	1000	100	62.90	5.472		0.7	0.859		10.92	0.04
149	6.9	1000	70	43.70	5.431	**5.43**	0.0	0.859	20 020	7.70	0.03
	6.9	1000	40	24.80	5.394		-0.7	0.859		4.43	0.01
	3.4	500	100	59.80	5.203		0.7	0.855		11.44	0.04
	3.4	500	70	41.60	5.170	**5.17**	0.0	0.855		8.06	0.03
	3.4	500	40	23.60	5.133		-0.7	0.855		4.64	0.02

Table A 9 Experimental Data of Viscosity Measurement by Capillary Viscometer - Medium Viscous Oil Dewatered by Adding Chemical Demulsifiers

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	6	70.30	1662.6		0.4	0.970		0.00	0.00
	10.3	1500	5	58.60	1663.1	**1656**	0.4	0.970		0.00	0.00
	10.3	1500	3	34.70	1641.3		-0.9	0.970		0.00	0.00
	6.9	1000	6	60.80	1437.9		0.8	0.968		0.00	0.00
38	6.9	1000	5	50.40	1430.4	**1426**	0.3	0.968	20 040	0.00	0.00
	6.9	1000	3	29.80	1409.5		-1.1	0.968		0.00	0.00
	3.4	500	6	53.10	1255.8		0.3	0.966		0.00	0.00
	3.4	500	5	44.30	1257.2	**1252**	0.5	0.966		0.00	0.00
	3.4	500	3	26.25	1241.6		-0.8	0.966		0.00	0.00
	10.3	1500	200	60.40	40.89		0.4	0.935		1.59	0.01
	10.3	1500	150	45.10	40.71	**40.7**	0.0	0.935		1.20	0.01
	10.3	1500	100	29.95	40.55		-0.4	0.935		0.80	0.01
	6.9	1000	200	55.50	37.57		0.3	0.933		1.73	0.01
93	6.9	1000	150	41.50	37.46	**37.5**	0.0	0.933	20 040	1.30	0.01
	6.9	1000	100	27.60	37.37		-0.3	0.933		0.87	0.01
	3.4	500	200	51.40	34.80		0.5	0.931		1.86	0.01
	3.4	500	150	38.30	34.57	**34.6**	-0.2	0.931		1.41	0.01
	3.4	500	100	25.50	34.53		-0.3	0.931		0.94	0.01
	10.3	1500	70	55.60	6.91		-0.2	0.901		6.36	0.02
	10.3	1500	50	39.80	6.93	**6.92**	0.0	0.901		4.53	0.02
	10.3	1500	30	23.90	6.93		0.1	0.901		2.72	0.01
	6.9	1000	70	52.20	6.49		-0.1	0.899		6.75	0.02
149	6.9	1000	50	37.30	6.49	**6.49**	0.0	0.899	20 020	4.82	0.02
	6.9	1000	30	22.40	6.50		0.1	0.899		2.89	0.01
	3.4	500	70	49.20	6.11		-0.3	0.896		7.14	0.02
	3.4	500	50	35.30	6.14	**6.14**	0.1	0.896		5.08	0.02
	3.4	500	30	21.20	6.15		0.2	0.896		3.04	0.01

Table A 10 Experimental Data of Viscosity Measurement by Capillary Viscometer - High Viscous Oil Dewatered by Adding Chemical Demulsifiers

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	50	62.90	8085		0.5	0.984		0.00	0.00
	10.3	1500	40	50.05	8042	**8043**	0.0	0.984		0.00	0.00
	10.3	1500	30	37.35	8002		-0.5	0.984		0.00	0.00
	6.9	1000	50	55.10	7083		0.4	0.982		0.00	0.00
38	6.9	1000	40	43.95	7062	**7057**	0.1	0.982	5 085	0.00	0.00
	6.9	1000	30	32.80	7027		-0.4	0.982		0.00	0.00
	3.4	500	50	48.30	6208		0.2	0.980		0.00	0.00
	3.4	500	40	38.60	6202	**6193**	0.1	0.980		0.00	0.00
	3.4	500	30	28.80	6170		-0.4	0.980		0.00	0.00
	10.3	1500	4	65.70	148.32		0.5	0.950		0.02	0.00
	10.3	1500	3	49.10	147.79	**148**	0.1	0.950		0.01	0.00
	10.3	1500	2	32.50	146.74		-0.6	0.950		0.01	0.00
	6.9	1000	4	61.30	138.38		1.0	0.949		0.02	0.00
93	6.9	1000	3	45.40	136.65	**137**	-0.2	0.949	20 020	0.01	0.00
	6.9	1000	2	30.10	135.90		-0.8	0.949		0.01	0.00
	3.4	500	4	55.90	126.19		0.8	0.946		0.02	0.00
	3.4	500	3	41.50	124.92	**125**	-0.3	0.946		0.02	0.00
	3.4	500	2	27.60	124.61		-0.5	0.946		0.01	0.00
	10.3	1500	28	63.00	19.58		1.0	0.916		0.91	0.00
	10.3	1500	20	44.50	19.36	**19.4**	-0.1	0.916		0.66	0.00
	10.3	1500	12	26.50	19.21		-0.9	0.916		0.40	0.00
	6.9	1000	28	58.70	18.24		0.2	0.914		0.98	0.00
149	6.9	1000	20	41.90	18.23	**18.2**	0.2	0.914	20 020	0.70	0.00
	6.9	1000	12	25.00	18.13		-0.4	0.914		0.42	0.00
	3.4	500	28	55.20	17.15		0.3	0.911		1.04	0.00
	3.4	500	20	39.30	17.10	**17.1**	0.0	0.911		0.74	0.00
	3.4	500	12	23.50	17.04		-0.3	0.911		0.45	0.00

Table A 11 Experimental Data of Viscosity Measurement by Capillary Viscometer – Original Low Viscous Oil (LVO)

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	9	37.05	159.89		0.5	0.926		0.01	0.00
	10.3	1500	6	24.55	158.92	**159**	-0.1	0.926		0.01	0.00
	10.3	1500	3	12.25	158.60		-0.3	0.926		0.00	0.00
	6.9	1000	9	35.55	153.42		3.2	0.924		0.01	0.00
38	6.9	1000	6	22.80	147.59	**149**	-0.7	0.924	5 070	0.01	0.00
	6.9	1000	3	11.20	145.00		-2.5	0.924		0.00	0.00
	3.4	500	9	32.80	141.55		0.6	0.922		0.01	0.00
	3.4	500	6	21.75	140.80	**141**	0.1	0.922		0.01	0.00
	3.4	500	3	10.80	139.82		-0.6	0.922		0.00	0.00
	10.3	1500	120	51.65	16.13		0.6	0.890		3.08	0.02
	10.3	1500	80	34.40	16.11	**16.0**	0.6	0.890		2.05	0.01
	10.3	1500	40	16.90	15.83		-1.2	0.890		1.04	0.01
	6.9	1000	120	48.75	15.22		0.1	0.888		3.25	0.02
93	6.9	1000	80	32.50	15.22	**15.2**	0.1	0.888	20 030	2.17	0.01
	6.9	1000	40	16.20	15.18		-0.2	0.888		1.09	0.01
	3.4	500	120	46.75	14.60		-0.2	0.885		3.38	0.02
	3.4	500	80	31.35	14.68	**14.6**	0.4	0.885		2.24	0.01
	3.4	500	40	15.60	14.61		-0.1	0.885		1.12	0.01
	10.3	1500	300	38.75	4.66		0.5	0.855		25.54	0.13
	10.3	1500	200	25.60	4.62	**4.64**	-0.4	0.855		17.18	0.09
	10.3	1500	100	12.85	4.64		0.0	0.855		8.56	0.04
	6.9	1000	300	37.35	4.49		0.5	0.852		26.40	0.13
149	6.9	1000	200	24.70	4.46	**4.47**	-0.3	0.852	20 030	17.74	0.09
	6.9	1000	100	12.35	4.46		-0.3	0.852		8.87	0.04
	3.4	500	300	36.05	4.34		0.2	0.848		27.24	0.14
	3.4	500	200	24.10	4.35	**4.33**	0.5	0.848		18.11	0.09
	3.4	500	100	11.90	4.29		-0.7	0.848		9.17	0.05

Table A 12 Experimental Data of Viscosity Measurement by Capillary Viscometer – Original Medium Viscous Oil (MVO)

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	50	50.20	1405.24		0.1	0.968		0.01	0.00
	10.3	1500	35	35.20	1407.64	**1404**	0.2	0.968		0.00	0.00
	10.3	1500	20	20.00	1399.64		-0.3	0.968		0.00	0.00
	6.9	1000	50	44.10	1234.48		0.1	0.967		0.01	0.00
38	6.9	1000	35	30.90	1235.68	**1233**	0.2	0.967	5 070	0.01	0.00
	6.9	1000	20	17.55	1228.18		-0.4	0.967		0.00	0.00
	3.4	500	50	38.85	1087.52		0.4	0.965		0.01	0.00
	3.4	500	35	27.15	1085.72	**1084**	0.2	0.965		0.01	0.00
	3.4	500	20	15.40	1077.72		-0.5	0.965		0.00	0.00
	10.3	1500	50	53.70	40.24		0.2	0.935		0.54	0.00
	10.3	1500	35	37.60	40.25	**40.2**	0.2	0.935		0.38	0.00
	10.3	1500	20	21.35	40.00		-0.4	0.935		0.22	0.00
	6.9	1000	50	49.80	37.32		-0.1	0.933		0.58	0.00
93	6.9	1000	35	34.95	37.42	**37.3**	0.2	0.933	20 030	0.40	0.00
	6.9	1000	20	19.90	37.28		-0.2	0.933		0.23	0.00
	3.4	500	50	46.10	34.55		-0.3	0.930		0.62	0.00
	3.4	500	35	32.40	34.69	**34.7**	0.1	0.930		0.44	0.00
	3.4	500	20	18.55	34.75		0.3	0.930		0.25	0.00
	10.3	1500	300	58.40	7.02		-0.1	0.901		17.86	0.09
	10.3	1500	200	39.00	7.04	**7.03**	0.1	0.901		11.89	0.06
	10.3	1500	100	19.50	7.04		0.1	0.901		5.94	0.03
	6.9	1000	300	55.95	6.73		0.8	0.898		18.59	0.09
149	6.9	1000	200	36.85	6.65	**6.68**	-0.5	0.898	20 030	12.54	0.06
	6.9	1000	100	18.45	6.66		-0.3	0.898		6.26	0.03
	3.4	500	300	53.20	6.40		0.3	0.895		19.49	0.10
	3.4	500	200	35.40	6.39	**6.38**	0.1	0.895		13.01	0.07
	3.4	500	100	17.60	6.35		-0.4	0.895		6.54	0.03

Table A 13 Experimental Data of Viscosity Measurement by Capillary Viscometer – Original High Viscous Oil (HVO)

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	10.3	1500	12	59.25	6912		-0.3	0.983		0.00	0.00
	10.3	1500	8	39.60	6930	**6930**	0.0	0.983		0.00	0.00
	10.3	1500	4	19.85	6947		0.3	0.983		0.00	0.00
	6.9	1000	12	52.60	6136		0.1	0.981		0.00	0.00
38	6.9	1000	8	35.00	6125	**6129**	-0.1	0.981	5 070	0.00	0.00
	6.9	1000	4	17.50	6125		-0.1	0.981		0.00	0.00
	3.4	500	12	46.20	5390		-0.1	0.980		0.00	0.00
	3.4	500	8	30.80	5390	**5396**	-0.1	0.980		0.00	0.00
	3.4	500	4	15.45	5407		0.2	0.980		0.00	0.00
	10.3	1500	300	30.20	136.91		0.6	0.950		0.41	0.00
	10.3	1500	225	22.60	136.60	**136**	0.4	0.950		0.31	0.00
	10.3	1500	150	14.85	134.64		-1.0	0.950		0.21	0.00
	6.9	1000	300	27.70	125.57		0.5	0.948		0.45	0.01
93	6.9	1000	225	20.60	124.52	**125**	-0.3	0.948	5 070	0.34	0.00
	6.9	1000	150	13.75	124.67		-0.2	0.948		0.23	0.00
	3.4	500	300	25.75	116.73		0.4	0.946		0.48	0.01
	3.4	500	225	19.20	116.05	**116**	-0.2	0.946		0.36	0.00
	3.4	500	150	12.80	116.05		-0.2	0.946		0.24	0.00
	10.3	1500	120	61.20	18.40		0.0	0.916		2.77	0.01
	10.3	1500	80	40.75	18.38	**18.4**	-0.1	0.916		1.85	0.01
	10.3	1500	40	20.40	18.40		0.0	0.916		0.92	0.00
	6.9	1000	120	57.50	17.29		0.4	0.913		2.94	0.01
149	6.9	1000	80	38.25	17.25	**17.2**	0.1	0.913	20 030	1.97	0.01
	6.9	1000	40	19.00	17.14		-0.5	0.913		0.99	0.00
	3.4	500	120	54.50	16.39		0.2	0.910		3.09	0.02
	3.4	500	80	36.30	16.37	**16.3**	0.2	0.910		2.06	0.01
	3.4	500	40	18.05	16.28		-0.4	0.910		1.04	0.01

Table A 14: Experimental Data of Viscosity Measurement by Rheometer at 20°C – Low Viscous Oil (LVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3			Post 100°C Test		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
19.9	6.65E-01	493	19.9	6.65E-01	495	20.0	6.65E-01	496	20.1	4.91E-01	895
20.0	9.86E-01	499	19.9	9.86E-01	500	19.9	9.86E-01	503	20.0	7.78E-01	903
19.9	1.46E+00	499	20.0	1.46E+00	500	20.0	1.46E+00	503	20.0	1.23E+00	901
19.8	2.17E+00	501	20.0	2.17E+00	501	20.0	2.17E+00	505	19.9	1.95E+00	903
19.9	3.21E+00	501	19.9	3.21E+00	502	19.9	3.21E+00	504	20.1	3.08E+00	901
20.0	4.76E+00	501	20.0	4.77E+00	501	20.1	4.76E+00	504	19.9	4.88E+00	901
20.0	7.06E+00	499	20.0	7.06E+00	501	20.0	7.07E+00	504	20.0	7.72E+00	900
20.0	1.05E+01	500	20.0	1.05E+01	502	20.0	1.05E+01	505	20.0	1.22E+01	898
20.0	1.55E+01	501	20.1	1.55E+01	501	20.0	1.55E+01	505	19.9	1.93E+01	898
20.0	2.30E+01	501	20.0	2.30E+01	501	20.0	2.30E+01	504	19.8	3.06E+01	896
19.9	3.41E+01	498	19.9	3.41E+01	501	19.9	3.41E+01	501	19.9	4.83E+01	889
20.0	5.05E+01	495	19.9	5.05E+01	498	19.9	5.05E+01	499	20.0	7.65E+01	879
20.0	7.50E+01	492	20.0	7.50E+01	493	20.0	7.49E+01	495	19.9	1.21E+02	872
19.9	1.11E+02	489	20.0	1.11E+02	490	20.0	1.11E+02	492	20.1	1.91E+02	863
20.0	1.65E+02	484	19.9	1.65E+02	486	19.9	1.65E+02	489	20.0	3.03E+02	853
Average T		**20.0**	**°C**						**20.0**	**°C**	
Average viscosity		**498.5**	**mPa·s**						**890.0**	**mPa·s**	
Viscosity STDEV		**5.2**							**15.8**		

Table A 15: Experimental Data of Viscosity Measurement by Rheometer at 60°C – Low Viscous Oil (LVO)

Shear Sweep 1			Shear Sweep 2		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
60.0	3.22E+00	53.8	59.9	3.22E+00	54.6
59.9	4.78E+00	54.1	59.9	4.78E+00	55.4
60.0	7.08E+00	55.2	60.0	7.09E+00	56.2
60.0	1.05E+01	55.8	60.0	1.05E+01	56.7
60.0	1.56E+01	56.2	60.0	1.56E+01	56.9
59.9	2.31E+01	56.5	60.0	2.31E+01	57.2
60.0	3.42E+01	56.7	60.0	3.42E+01	57.4
60.1	5.07E+01	57.1	60.0	5.07E+01	57.7
60.0	7.51E+01	57.7	59.9	7.52E+01	57.9
60.0	1.11E+02	58.0	59.9	1.12E+02	58.0
60.0	1.65E+02	58.1	60.0	1.65E+02	58.2
Average T		**60.0**	**°C**		
Average viscosity		**56.6**	**mPa·s**		
Viscosity STDEV		**1.3**			

Table A 16: Experimental Data of Viscosity Measurement by Rheometer at 100°C – Low Viscous Oil (LVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
99.9	5.91E+00	15.8	100	5.91E+00	16.1	100	5.91E+00	16.6
100	9.23E+00	16.5	100	9.23E+00	16.7	100	9.22E+00	17.2
100	1.44E+01	16.8	99.9	1.44E+01	17.1	100	1.44E+01	17.6
100	2.25E+01	17.1	99.9	2.25E+01	17.5	99.9	2.24E+01	18.0
100.1	3.50E+01	17.3	100	3.50E+01	17.7	99.9	3.50E+01	18.2
100	5.47E+01	17.5	100	5.47E+01	17.9	99.9	5.46E+01	18.4
100	8.52E+01	17.6	100	8.52E+01	18.0	99.9	8.52E+01	18.5
100	1.33E+02	17.8	99.9	1.33E+02	18.2	100	1.33E+02	18.7
100	2.07E+02	18.0	99.9	2.07E+02	18.5	100	2.07E+02	18.9
100.1	3.24E+02	18.4	99.8	3.23E+02	18.9	100	3.23E+02	19.4
Average T		**100.0**	**°C**					
Average viscosity		**17.7**	**mPa·s**					
Viscosity STDEV		**0.9**						

Table A 17: Experimental Data of Viscosity Measurement by Rheometer at 20°C – Medium Viscous Oil (MVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3			Post 100°C Test		
T	Shear Rate	Viscosity	T	Shear Rate	Viscosity	T	Shear Rate	Viscosity	T	Shear Rate	Viscosity
°C	S^{-1}	mPa·s	°C	S^{-1}	mPa·s	°C	S^{-1}	mPa·s	°C	S^{-1}	mPa·s
20.0	5.39E-02	7438	20.1	5.39E-02	7238	20.0	5.39E-02	7232	20.0	9.22E-02	7133
20.0	7.78E-02	7433	20.0	7.76E-02	7218	20.0	7.77E-02	7222	20.0	1.30E-01	7150
19.9	1.12E-01	7303	19.9	1.12E-01	7278	20.0	1.12E-01	7243	19.9	1.83E-01	7177
20.0	1.61E-01	7353	19.9	1.61E-01	7273	19.9	1.61E-01	7303	20.0	2.57E-01	7167
20.1	2.32E-01	7308	20.1	2.32E-01	7275	20.0	2.32E-01	7310	20.0	3.61E-01	7184
20.0	3.35E-01	7249	20.0	3.35E-01	7310	19.9	3.35E-01	7308	20.0	5.08E-01	7200
19.9	4.82E-01	7259	20.1	4.83E-01	7296	19.9	4.82E-01	7303	20.0	7.16E-01	7234
19.9	6.96E-01	7282	20.0	6.95E-01	7284	19.9	6.95E-01	7322	20.0	1.01E+00	7229
19.9	1.00E+00	7283	19.9	1.00E+00	7312	20.0	1.00E+00	7293	20.1	1.42E+00	7200
20.0	1.44E+00	7276	19.9	1.44E+00	7317	20.0	1.44E+00	7292	20.0	1.99E+00	7186
20.1	2.08E+00	7227	19.9	2.08E+00	7292	20.0	2.08E+00	7275	20.0	2.80E+00	7210
20.1	3.00E+00	7214	20.1	3.00E+00	7255	20.1	3.00E+00	7254	19.9	3.95E+00	7211
20.1	4.32E+00	7192	20.0	4.32E+00	7239	20.0	4.32E+00	7244	19.9	5.55E+00	7212
20.1	6.23E+00	7147	20.0	6.23E+00	7213	19.9	6.23E+00	7232	19.9	7.82E+00	7189
20.0	8.98E+00	7160	20.0	8.98E+00	7173	20.0	8.98E+00	7189	20.1	1.10E+01	7106
20.0	1.29E+01	7143	20.0	1.29E+01	7147	20.0	1.29E+01	7156	20.1	1.55E+01	7090
19.8	1.86E+01	7171	19.9	1.86E+01	7140	20.1	1.86E+01	7122	20.0	2.18E+01	7140
19.9	2.69E+01	7174	19.9	2.69E+01	7175	20.0	2.69E+01	7141	19.9	3.06E+01	7187
19.9	3.87E+01	7175	20.1	3.87E+01	7133	20.0	3.87E+01	7186	19.9	4.31E+01	7206
20.0	5.58E+01	7178	20.0	5.57E+01	7157	20.0	5.58E+01	7226	19.9	6.06E+01	7197
20.0	8.04E+01	7202	20.0	8.03E+01	7217	19.9	8.04E+01	7254	19.9	8.53E+01	7226
19.9	1.16E+02	7205	20.0	1.16E+02	7233	20.1	1.16E+02	7262	19.9	1.20E+02	7258
Average T		**20.0 °C**							**20.0 °C**		
Average viscosity		**7241.2 mPa·s**							**7186.0 mPa·s**		
Viscosity STDEV		**67.3**							**41.4**		

Table A 18: Experimental Data of Viscosity Measurement by Rheometer at 60°C – Medium Viscous Oil (MVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
59.9	1.45E+00	181	59.8	1.46E+00	176	59.9	1.46E+00	177
59.8	2.09E+00	181	60	2.17E+00	178	59.9	2.17E+00	179
59.8	3.00E+00	183	59.9	3.21E+00	180	59.9	3.21E+00	181
59.9	4.33E+00	183	59.7	4.77E+00	181	59.8	4.77E+00	182
59.9	6.24E+00	184	59.9	7.07E+00	181	59.8	7.07E+00	183
59.8	8.99E+00	184	59.8	1.05E+01	182	59.8	1.05E+01	183
59.9	1.29E+01	185	60	1.55E+01	182	59.8	1.55E+01	183
59.9	1.87E+01	185	59.9	2.30E+01	182	59.8	2.31E+01	183
59.9	2.69E+01	185	59.9	3.42E+01	182	59.9	3.41E+01	183
59.9	3.88E+01	185	60	5.06E+01	182	59.9	5.06E+01	183
59.9	5.58E+01	185	59.9	7.50E+01	182	60	7.50E+01	183
59.8	8.05E+01	185	59.9	1.11E+02	183	59.9	1.11E+02	183
Average T		**59.9**	**°C**					
Average viscosity		**182.1**	**mPa·s**					
Viscosity STDEV		**2.1**						

Table A 19: Experimental Data of Viscosity Measurement by Rheometer at 100°C – Medium Viscous Oil (MVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
99.9	4.79E+00	24.6	100.0	7.86E+00	24.8	100.0	7.85E+00	24.8
100.0	7.10E+00	25.3	100.0	1.11E+01	25.2	99.9	1.10E+01	25.1
100.0	1.05E+01	25.7	100.0	1.55E+01	25.5	100.0	1.55E+01	25.4
99.9	1.56E+01	26.1	100.0	2.19E+01	25.7	99.9	2.19E+01	25.7
99.9	2.31E+01	26.3	100.0	3.08E+01	25.9	100.0	3.08E+01	25.8
100.0	3.43E+01	26.4	100.0	4.33E+01	26.0	100.1	4.33E+01	26.0
100.0	5.08E+01	26.6	100.0	6.09E+01	26.1	100.0	6.09E+01	26.1
99.9	7.53E+01	26.7	100.0	8.57E+01	26.3	100.1	8.57E+01	26.2
100.1	1.12E+02	26.9	100.0	1.21E+02	26.4	100.0	1.21E+02	26.4
Average T		**100.0**	**°C**					
Average viscosity		**25.9**	**mPa·s**					
Viscosity STDEV		**0.6**						

Table A 20: Experimental Data of Viscosity Measurement by Rheometer at 20°C – High Viscous Oil (HVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
20.1	1.42E-02	41330	19.9	1.42E-02	41330	20.0	1.42E-02	40980
20.0	2.14E-02	41660	20.1	2.14E-02	41320	19.9	2.14E-02	41400
20.0	3.21E-02	40850	20.0	3.21E-02	41460	20.0	3.21E-02	41300
20.0	4.83E-02	41000	19.9	4.83E-02	41450	20.0	4.83E-02	41180
19.9	7.26E-02	41150	20.0	7.26E-02	41320	20.0	7.26E-02	41350
20.0	1.11E-01	41800	20.1	1.09E-01	41040	20.0	1.09E-01	41330
20.0	1.64E-01	41090	20.1	1.64E-01	40850	20.0	1.64E-01	41330
20.0	2.47E-01	40900	20.0	2.47E-01	40900	19.9	2.47E-01	41180
20.1	3.71E-01	40810	19.9	3.71E-01	40900	19.9	3.71E-01	41240
19.9	5.58E-01	40820	20.0	5.57E-01	40660	20.0	5.58E-01	41050
20.0	8.39E-01	40780	20.0	8.39E-01	40690	19.9	8.39E-01	41160
20.0	1.26E+00	40560	20.0	1.26E+00	40660	20.0	1.26E+00	40910
19.9	1.90E+00	40500	20.0	1.90E+00	40580	20.0	1.90E+00	40740
20.0	2.85E+00	40240	20.0	2.85E+00	40360	20.0	2.85E+00	40400
20.0	4.29E+00	39840	19.9	4.29E+00	40200	20.0	4.29E+00	40040
20.0	6.45E+00	39610	19.9	6.45E+00	40040	20.0	6.44E+00	39770
20.0	9.70E+00	39630	20.0	9.69E+00	39870	19.9	9.69E+00	39790
20.0	1.46E+01	39500	19.9	1.46E+01	39830	20.0	1.46E+01	39830
19.9	2.19E+01	39500	19.9	2.19E+01	39850	20.1	2.19E+01	39660
19.9	3.19E+01	39330	20.0	3.19E+01	39340	20.0	3.19E+01	39450
20.0	3.97E+01	39600	20.0	3.97E+01	39720	20.0	3.96E+01	39790
Average T		**20.0**	**°C**					
Average viscosity		**40583.3**	**mPa·s**					
Viscosity STDEV		**690.6**						

Table A 21: Experimental Data of Viscosity Measurement by Rheometer at 60°C – High Viscous Oil (HVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
59.9	5.58E-01	798	59.9	5.49E-01	786	59.9	6.79E-01	778
59.9	8.39E-01	800	60.0	8.26E-01	787	59.9	1.03E+00	779
60.1	1.26E+00	796	60.0	1.24E+00	784	60.0	1.57E+00	779
60.0	1.90E+00	801	59.9	1.86E+00	787	60.0	2.40E+00	780
60.0	2.87E+00	806	59.9	2.80E+00	788	60.0	3.65E+00	781
59.9	4.29E+00	801	60.0	4.20E+00	787	60.0	5.56E+00	780
60.0	6.45E+00	800	60.0	6.32E+00	787	60.0	8.48E+00	780
60.0	9.69E+00	799	60.0	9.48E+00	785	59.9	1.29E+01	781
60.0	1.46E+01	797	60.1	1.42E+01	782	59.9	1.97E+01	779
60.0	2.19E+01	795	60.0	2.14E+01	782	59.9	3.00E+01	776
59.9	3.30E+01	791	60.0	3.21E+01	780	59.9	4.56E+01	771
60.0	4.96E+01	785	59.9	4.82E+01	776	60.0	6.96E+01	766
60.0	7.45E+01	779	59.9	7.24E+01	771	60.0	1.06E+02	763
60.0	1.12E+02	776	59.9	1.09E+02	767	60.0	1.61E+02	762
Average T		**60.0**	**°C**					
Average viscosity		**784.0**	**mPa·s**					
Viscosity STDEV		**10.8**						

Table A 22: Experimental Data of Viscosity Measurement by Rheometer at 100°C – High Viscous Oil (HVO)

Shear Sweep 1			Shear Sweep 2			Shear Sweep 3		
T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s	T °C	Shear Rate S^{-1}	Viscosity mPa·s
100.0	1.59E+00	80.6	100.0	1.59E+00	78.2	99.9	1.59E+00	78.0
100.0	2.42E+00	81.4	99.9	2.42E+00	80.1	100.0	2.42E+00	80.0
99.9	3.69E+00	82.7	100.0	3.69E+00	81.5	100.0	3.69E+00	81.2
100.0	5.62E+00	83.5	100.0	5.62E+00	82.2	100.0	5.63E+00	82.0
99.9	8.57E+00	84.0	100.0	8.57E+00	83.0	100.0	8.57E+00	82.8
100.0	1.30E+01	84.3	99.9	1.30E+01	83.2	100.0	1.30E+01	83.0
100.0	1.99E+01	84.5	100.0	1.99E+01	83.4	100.0	1.99E+01	83.2
99.9	3.03E+01	84.7	99.9	3.03E+01	83.7	99.9	3.03E+01	83.5
99.9	4.61E+01	84.9	100.0	4.61E+01	83.7	100.0	4.61E+01	83.7
100.0	7.02E+01	85.2	100.0	7.03E+01	84.2	100.0	7.02E+01	84.0
100.0	1.07E+02	85.6	100.0	1.07E+02	84.7	100.0	1.07E+02	84.4
100.0	1.63E+02	86.1	99.9	1.63E+02	85.2	100.1	1.63E+02	84.8
Average T		**100.0**	**°C**					
Average viscosity		**83.1**	**mPa·s**					
Viscosity STDEV		**1.9**						

Table A 23 Experimental Data of Viscosity Measurement by Capillary Viscometer – Live Low Viscous Oil (Live LVO)

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	27.6	4000	15	75.00	43.50		0.4	0.887		0.21	0.00
	27.6	4000	10	49.80	43.33	**43.3**	0.0	0.887		0.14	0.00
	27.6	4000	5	24.80	43.15		-0.4	0.887		0.07	0.00
	24.1	3500	15	70.95	41.15		0.3	0.885		0.22	0.00
	24.1	3500	10	47.05	40.93	**41.0**	-0.2	0.885		0.15	0.00
	24.1	3500	5	23.55	40.98		-0.1	0.885		0.08	0.00
	20.7	3000	15	67.90	39.38		-0.3	0.883		0.23	0.00
38	20.7	3000	10	45.40	39.50	**39.5**	0.0	0.883	20 020	0.16	0.00
	20.7	3000	5	22.75	39.59		0.2	0.883		0.08	0.00
	17.2	2500	15	65.30	37.87		0.1	0.881		0.24	0.00
	17.2	2500	10	43.55	37.89	**37.8**	0.1	0.881		0.16	0.00
	17.2	2500	5	21.70	37.76		-0.2	0.881		0.08	0.00
	13.8	2000	15	61.70	35.79		0.1	0.879		0.26	0.00
	13.8	2000	10	41.20	35.84	**35.8**	0.2	0.879		0.17	0.00
	13.8	2000	5	20.50	35.67		-0.3	0.879		0.09	0.00
	27.6	4000	80	67.10	6.97		-0.1	0.850		6.79	0.02
	27.6	4000	60	50.25	6.96	**6.98**	-0.2	0.850		5.10	0.02
	27.6	4000	40	33.70	7.00		0.3	0.850		3.38	0.01
	24.1	3500	80	64.70	6.72		-0.3	0.848		7.02	0.02
	24.1	3500	60	48.70	6.74	**6.74**	0.0	0.848		5.25	0.02
	24.1	3500	40	32.55	6.76		0.3	0.848		3.49	0.01
	20.7	3000	80	62.20	6.46		-0.2	0.845		7.28	0.02
93	20.7	3000	60	46.75	6.47	**6.47**	0.0	0.845	20 020	5.45	0.02
	20.7	3000	40	31.20	6.48		0.1	0.845		3.63	0.01
	17.2	2500	80	59.70	6.20		-0.3	0.842		7.56	0.03
	17.2	2500	60	44.90	6.22	**6.22**	0.0	0.842		5.65	0.02
	17.2	2500	40	30.00	6.23		0.2	0.842		3.76	0.01
	15.9	2300	80	59.40	6.17		-0.3	0.840		7.59	0.03
	15.9	2300	60	44.75	6.20	**6.19**	0.1	0.840		5.66	0.02
	15.9	2300	40	29.85	6.20		0.2	0.840		3.77	0.01
	31.0	4500	200	67.10	2.65		-0.2	0.817		42.85	0.14
	31.0	4500	150	50.45	2.66	**2.66**	0.1	0.817		32.06	0.11
	31.0	4500	100	33.65	2.66		0.1	0.817		21.36	0.07
	27.6	4000	200	64.35	2.55		-0.2	0.814		44.51	0.15
	27.6	4000	150	48.45	2.55	**2.55**	0.2	0.814		33.25	0.11
	27.6	4000	100	32.25	2.55		0.0	0.814		22.20	0.07
	24.1	3500	200	62.60	2.48		0.0	0.810		45.56	0.15
149	24.1	3500	150	46.90	2.47	**2.48**	-0.1	0.810	20 020	34.20	0.11
	24.1	3500	100	31.35	2.48		0.1	0.810		22.74	0.08
	20.7	3000	200	60.55	2.39		-0.1	0.806		46.87	0.16
	20.7	3000	150	45.50	2.40	**2.40**	0.0	0.806		35.09	0.12
	20.7	3000	100	30.35	2.40		0.1	0.806		23.38	0.08
	17.2	2500	200	58.40	2.31		0.0	0.802		48.37	0.16
	17.2	2500	150	43.85	2.31	**2.31**	0.1	0.802		36.23	0.12
	17.2	2500	100	29.20	2.31		0.0	0.802		24.18	0.08

Table A 24 Experimental Data of Viscosity Measurement by Capillary Viscometer – Live Medium Viscous Oil (Live MVO)

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	20.7	3000	8	44.40	219.56		-0.2	0.968		0.02	0.00
	20.7	3000	6	33.40	220.22	**220**	0.0	0.968		0.01	0.00
	20.7	3000	4	22.30	220.55		0.2	0.968		0.01	0.00
	17.2	2500	8	39.10	193.35		0.9	0.966		0.02	0.00
38	17.2	2500	6	28.80	189.89	**192**	-0.9	0.966	20 030	0.01	0.00
	17.2	2500	4	19.40	191.87		0.1	0.966		0.01	0.00
	13.8	2000	8	33.40	165.16		-0.5	0.963		0.02	0.00
	13.8	2000	6	25.30	166.81	**166**	0.5	0.963		0.02	0.00
	13.8	2000	4	16.80	166.15		0.1	0.963		0.01	0.00
	20.7	3000	150	54.70	13.93		-0.2	0.925		4.62	0.02
	20.7	3000	100	36.30	13.87	**14.0**	-0.6	0.925		3.09	0.02
	20.7	3000	50	18.40	14.06		0.8	0.925		1.53	0.01
	17.2	2500	150	52.40	13.34		0.7	0.922		4.81	0.02
93	17.2	2500	100	34.35	13.12	**13.3**	-1.0	0.922	20 030	3.26	0.02
	17.2	2500	50	17.40	13.29		0.3	0.922		1.61	0.01
	13.8	2000	150	49.00	12.48		-0.4	0.920		5.13	0.03
	13.8	2000	100	32.90	12.57	**12.5**	0.3	0.920		3.40	0.02
	13.8	2000	50	16.40	12.53		0.0	0.920		1.70	0.01
	20.7	3000	250	19.90	2.93		0.8	0.871		51.73	0.17
	20.7	3000	150	11.75	2.88	**2.91**	-0.8	0.871		31.54	0.11
	20.7	3000	50	3.95	2.91		0.0	0.871		10.42	0.03
	17.2	2500	250	19.00	2.80		-0.7	0.869		54.03	0.18
149	17.2	2500	150	11.50	2.82	**2.82**	0.1	0.869	20 020	32.13	0.11
	17.2	2500	50	3.85	2.84		0.6	0.869		10.66	0.04
	13.8	2000	250	18.30	2.70		-0.4	0.867		55.96	0.19
	13.8	2000	150	11.00	2.70	**2.71**	-0.2	0.867		33.52	0.11
	13.8	2000	50	3.70	2.72		0.7	0.867		11.07	0.04

Table A 25 Experimental Data of Viscosity Measurement by Capillary Viscometer – Live High Viscous Oil (Live HVO)

T °C	P MPa	P psia	Q mL/Hr	Δ P psia	Viscosity mPa·s	Avg. Viscosity mPa·s	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	20.7	3000	60	76.80	1818		0.0	0.968		0.01	0.00
	20.7	3000	40	51.15	1816	**1817**	-0.1	0.968		0.00	0.00
	20.7	3000	20	25.60	1818		0.0	0.968		0.00	0.00
	17.2	2500	60	69.90	1654		0.5	0.966		0.01	0.00
	17.2	2500	40	46.30	1644	**1646**	-0.1	0.966		0.00	0.00
	17.2	2500	20	23.10	1640		-0.4	0.966		0.00	0.00
	13.8	2000	60	63.70	1508		0.2	0.964		0.01	0.00
38	13.8	2000	40	42.50	1509	**1505**	0.3	0.964	5 070	0.01	0.00
	13.8	2000	20	21.10	1498		-0.4	0.964		0.00	0.00
	10.3	1500	60	57.35	1357		0.2	0.962		0.01	0.00
	10.3	1500	40	38.10	1353	**1354**	-0.1	0.962		0.01	0.00
	10.3	1500	20	19.05	1353		-0.1	0.962		0.00	0.00
	7.6	1100	60	53.10	1257		0.2	0.961		0.01	0.00
	7.6	1100	40	35.35	1255	**1254**	0.1	0.961		0.01	0.00
	7.6	1100	20	17.60	1250		-0.3	0.961		0.00	0.00
	24.1	3500	8	71.20	73.96		0.7	0.936		0.07	0.00
	24.1	3500	6	53.00	73.41	**73.4**	0.0	0.936		0.05	0.00
	24.1	3500	4	35.10	72.92		-0.7	0.936		0.04	0.00
	20.7	3000	8	66.60	69.18		0.7	0.934		0.08	0.00
	20.7	3000	6	49.60	68.70	**68.7**	0.0	0.934		0.06	0.00
	20.7	3000	4	32.85	68.25		-0.7	0.934		0.04	0.00
	17.2	2500	8	62.60	65.03		0.3	0.932		0.08	0.00
93	17.2	2500	6	46.80	64.82	**64.8**	0.0	0.932	20 020	0.06	0.00
	17.2	2500	4	31.10	64.61		-0.3	0.932		0.04	0.00
	13.8	2000	8	58.80	61.08		0.6	0.929		0.08	0.00
	13.8	2000	6	43.60	60.39	**60.7**	-0.5	0.929		0.06	0.00
	13.8	2000	4	29.20	60.66		-0.1	0.929		0.04	0.00
	10.3	1500	8	54.95	57.08		0.3	0.927		0.09	0.00
	10.3	1500	6	41.15	56.99	**56.9**	0.2	0.927		0.07	0.00
	10.3	1500	4	27.25	56.61		-0.5	0.927		0.05	0.00
	24.1	3500	40	68.20	13.49		0.2	0.903		1.86	0.01
	24.1	3500	30	51.00	13.45	**13.5**	-0.1	0.903		1.40	0.00
	24.1	3500	20	34.00	13.45		-0.1	0.903		0.93	0.00
	20.7	3000	40	64.50	12.75		0.1	0.900		1.97	0.01
	20.7	3000	30	48.40	12.76	**12.7**	0.2	0.900		1.47	0.00
	20.7	3000	20	32.10	12.70		-0.3	0.900		0.99	0.00
	17.2	2500	40	61.80	12.22		0.1	0.898		2.05	0.01
149	17.2	2500	30	46.40	12.23	**12.2**	0.2	0.898	20 020	1.53	0.01
	17.2	2500	20	30.80	12.18		-0.3	0.898		1.03	0.00
	13.8	2000	40	58.60	11.59		0.0	0.895		2.15	0.01
	13.8	2000	30	44.00	11.60	**11.6**	0.1	0.895		1.61	0.01
	13.8	2000	20	29.25	11.57		-0.2	0.895		1.08	0.00
	11.0	1600	40	56.50	11.17		0.0	0.893		2.23	0.01
	11.0	1600	30	42.50	11.21	**11.2**	0.3	0.893		1.66	0.01
	11.0	1600	20	28.20	11.15		-0.2	0.893		1.12	0.00

Table A 26 Experimental Data of Viscosity Measured by Capillary Viscometer – Low Viscous Oil / Oxylenes Mixture with 0.091 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	10	56.20	53.17		0.9	0.919		0.12	0.00
	1500	6	33.35	52.58	**52.7**	-0.2	0.919		0.07	0.00
	1500	2	11.05	52.27		-0.8	0.919		0.02	0.00
										0.00
	1000	10	53.10	50.23		0.8	0.917		0.13	0.00
38	1000	6	31.50	49.67	**49.9**	-0.4	0.917	20 020	0.08	0.00
	1000	2	10.50	49.67		-0.4	0.917		0.03	0.00
										0.00
	500	10	49.60	46.92		0.9	0.915		0.14	0.00
	500	6	29.50	46.51	**46.5**	0.0	0.915		0.08	0.00
	500	2	9.75	46.12		-0.9	0.915		0.03	0.00
	1500	60	57.95	8.85		0.6	0.882		4.17	0.01
	1500	40	38.40	8.79	**8.80**	0.0	0.882		2.79	0.01
	1500	20	19.10	8.75		-0.5	0.882		1.40	0.00
										0.00
	1000	60	55.10	8.41		0.3	0.880		4.37	0.01
93	1000	40	36.70	8.40	**8.38**	0.2	0.880	20 020	2.92	0.01
	1000	20	18.20	8.34		-0.6	0.880		1.47	0.00
										0.00
	500	60	53.45	8.16		0.7	0.877		4.49	0.01
	500	40	35.30	8.08	**8.10**	-0.2	0.877		3.02	0.01
	500	20	17.60	8.06		-0.5	0.877		1.52	0.01
	1500	150	54.10	3.19		1.3	0.846		27.69	0.09
	1500	100	35.65	3.16	**3.15**	0.1	0.846		18.68	0.06
	1500	50	17.55	3.11		-1.4	0.846		9.48	0.03
										0.00
	1000	150	51.90	3.06		0.7	0.843		28.74	0.10
149	1000	100	34.30	3.04	**3.04**	-0.2	0.843	20 020	19.33	0.06
	1000	50	17.10	3.03		-0.5	0.843		9.69	0.03
										0.00
	500	150	49.20	2.90		0.8	0.839		30.18	0.10
	500	100	32.65	2.89	**2.88**	0.3	0.839		20.21	0.07
	500	50	16.10	2.85		-1.1	0.839		10.25	0.03

Table A 27 Experimental Data of Viscosity Measured by Capillary Viscometer – Low Viscous Oil / Oxylenes Mixture with 0.173 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	24	50.40	19.87		0.2	0.912		0.38	0.00
	1500	16	33.40	19.75	**19.7**	0.0	0.912		0.26	0.00
	1500	8	16.60	19.63		-0.2	0.912		0.13	0.00
										0.00
	1000	24	47.95	18.90		0.2	0.910		0.40	0.00
38	1000	16	31.80	18.80	**18.8**	0.0	0.910	20 020	0.27	0.00
	1000	8	15.80	18.68		-0.2	0.910		0.14	0.00
										0.00
	500	24	45.60	17.97		0.2	0.907		0.42	0.00
	500	16	30.25	17.89	**17.9**	0.0	0.907		0.28	0.00
	500	8	15.00	17.74		-0.3	0.907		0.14	0.00
										0.00
	1500	100	52.50	4.81		0.5	0.874		12.65	0.04
	1500	60	31.15	4.76	**4.76**	-0.1	0.874		7.68	0.03
	1500	20	10.30	4.72		-0.5	0.874		2.58	0.01
										0.00
	1000	100	50.60	4.63		0.5	0.871		13.09	0.04
93	1000	60	30.10	4.60	**4.60**	0.0	0.871	20 020	7.92	0.03
	1000	20	9.95	4.56		-0.5	0.871		2.66	0.01
										0.00
	500	100	48.60	4.45		0.4	0.868		13.58	0.05
	500	60	28.90	4.41	**4.42**	-0.1	0.868		8.22	0.03
	500	20	9.60	4.40		-0.3	0.868		2.75	0.01
										0.00
	1500	250	58.05	2.05		0.8	0.837		70.88	0.24
	1500	150	34.20	2.02	**2.03**	-0.4	0.837		43.31	0.14
	1500	50	11.40	2.02		-0.4	0.837		14.44	0.05
										0.00
	1000	250	55.30	1.96		0.4	0.833		74.06	0.25
149	1000	150	33.00	1.95	**1.94**	0.1	0.833	20 020	44.68	0.15
	1000	50	10.90	1.93		-0.5	0.833		15.03	0.05
										0.00
	500	250	53.30	1.89		0.5	0.829		76.47	0.25
	500	150	31.70	1.87	**1.87**	-0.1	0.829		46.29	0.15
	500	50	10.50	1.86		-0.5	0.829		15.53	0.05

Table A 28 Experimental Data of Viscosity Measured by Capillary Viscometer – Low Viscous Oil / Oxylenes Mixture with 0.662 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	100	14.45	1.37		0.0	0.876		44.63	0.15
	1500	175	25.45	1.38	**1.38**	0.0	0.876		77.60	0.26
	1500	250	36.55	1.38		0.0	0.876		110.28	0.37
										0.00
	1000	100	14.75	1.40		0.0	0.874		43.60	0.15
38	1000	175	26.00	1.41	**1.41**	0.0	0.874	20 020	75.75	0.25
	1000	250	37.45	1.42		0.0	0.874		107.33	0.36
										0.00
	500	100	14.05	1.33		0.0	0.871		45.65	0.15
	500	175	24.75	1.34	**1.34**	0.0	0.871		79.36	0.26
	500	250	35.55	1.35		0.0	0.871		112.76	0.38
										0.00
	1500	100	7.90	0.72		0.0	0.834		80.19	0.27
	1500	200	15.80	0.72	**0.73**	0.0	0.834		160.39	0.53
	1500	300	24.00	0.73		0.1	0.834		237.57	0.79
										0.00
	1000	100	7.65	0.70		-0.1	0.830		82.50	0.27
93	1000	200	15.45	0.71	**0.71**	0.0	0.830	20 020	163.40	0.54
	1000	300	23.45	0.72		0.1	0.830		242.22	0.81
										0.00
	500	100	7.50	0.69		-0.1	0.827		83.80	0.28
	500	200	15.10	0.69	**0.69**	0.0	0.827		166.49	0.55
	500	300	22.90	0.70		0.1	0.827		247.01	0.82
										0.00
	1500	200	10.30	0.46		-0.5	0.790		241.43	0.80
	1500	300	15.85	0.47	**0.47**	-0.1	0.790		353.01	1.18
	1500	400	22.30	0.49		0.7	0.790		446.06	1.49
										0.00
	1000	200	10.00	0.44		-0.7	0.786		247.36	0.82
149	1000	300	15.60	0.46	**0.46**	-0.1	0.786	20 020	356.77	1.19
	1000	400	21.90	0.48		0.7	0.786		451.81	1.51
										0.00
	500	200	9.85	0.44		-0.6	0.781		249.60	0.83
	500	300	15.15	0.45	**0.45**	-0.2	0.781		365.13	1.22
	500	400	21.35	0.47		0.7	0.781		460.61	1.54

Table A 29 Experimental Data of Viscosity Measured by Capillary Viscometer – Low Viscous Oil / Heptane Mixture with 0.072 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	9	59.50	62.54		1.3	0.901		0.05	0.00
	1500	6	39.20	61.81	**61.8**	-0.1	0.901		0.03	0.00
	1500	3	19.40	61.17		-1.3	0.901		0.02	0.00
										0.00
	1000	9	55.95	58.81		1.3	0.904		0.05	0.00
38	1000	6	36.90	58.18	**58.2**	0.0	0.904	20 020	0.03	0.00
	1000	3	18.25	57.55		-1.3	0.904		0.02	0.00
										0.00
	500	9	52.70	55.39		1.3	0.899		0.05	0.00
	500	6	34.70	54.71	**54.8**	-0.2	0.899		0.03	0.00
	500	3	17.20	54.24		-1.2	0.899		0.02	0.00
										0.00
	1500	60	61.30	9.36		0.8	0.866		3.87	0.01
	1500	40	40.60	9.30	**9.29**	0.1	0.866		2.60	0.01
	1500	20	20.10	9.21		-0.9	0.866		1.31	0.00
										0.00
	1000	60	58.50	8.93		0.8	0.864		4.04	0.01
93	1000	40	38.70	8.86	**8.86**	0.0	0.864	20 020	2.71	0.01
	1000	20	19.20	8.79		-0.8	0.864		1.37	0.00
										0.00
	500	60	55.90	8.53		0.7	0.861		4.21	0.01
	500	40	37.00	8.47	**8.48**	-0.1	0.861		2.83	0.01
	500	20	18.40	8.43		-0.6	0.861		1.42	0.00
										0.00
	1500	200	72.90	3.23		1.1	0.830		35.83	0.12
	1500	150	54.35	3.21	**3.19**	0.5	0.830		27.03	0.09
	1500	100	35.50	3.14		-1.6	0.830		18.40	0.06
										0.00
	1000	200	69.30	3.07		0.6	0.827		37.54	0.13
149	1000	150	51.65	3.05	**3.05**	0.0	0.827	20 020	28.33	0.09
	1000	100	34.20	3.03		-0.7	0.827		19.02	0.06
										0.00
	500	200	67.00	2.96		0.8	0.823		38.66	0.13
	500	150	49.90	2.94	**2.94**	0.0	0.823		29.20	0.10
	500	100	33.00	2.92		-0.8	0.823		19.62	0.07

Table A 30 Experimental Data of Viscosity Measured by Capillary Viscometer – Low Viscous Oil / Heptane Mixture with 0.143 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	20	53.20	25.16		0.3	0.876		0.24	0.00
	1500	15	39.60	24.97	**25.0**	-0.1	0.876		0.18	0.00
	1500	10	26.30	24.88		-0.2	0.876		0.12	0.00
										0.00
	1000	20	50.55	23.91		0.2	0.879		0.26	0.00
38	1000	15	37.70	23.78	**23.8**	0.0	0.879	20 020	0.19	0.00
	1000	10	25.05	23.70		-0.2	0.879		0.13	0.00
										0.00
	500	20	48.05	22.73		0.1	0.874		0.27	0.00
	500	15	35.90	22.64	**22.7**	0.0	0.874		0.20	0.00
	500	10	23.90	22.61		-0.1	0.874		0.13	0.00
										0.00
	1500	100	56.40	5.17		0.2	0.841		11.34	0.04
	1500	70	39.40	5.16	**5.15**	0.1	0.841		7.95	0.03
	1500	40	22.40	5.13		-0.2	0.841		4.57	0.02
										0.00
	1000	100	54.40	4.98		0.4	0.838		11.71	0.04
93	1000	70	37.80	4.95	**4.95**	-0.1	0.838	20 020	8.26	0.03
	1000	40	21.50	4.92		-0.3	0.838		4.74	0.02
										0.00
	500	100	52.00	4.76		0.4	0.835		12.20	0.04
	500	70	36.20	4.74	**4.73**	0.1	0.835		8.59	0.03
	500	40	20.50	4.69		-0.5	0.835		4.95	0.02
										0.00
	1500	200	46.50	2.06		0.3	0.804		54.38	0.18
	1500	125	28.95	2.05	**2.05**	0.1	0.804		34.12	0.11
	1500	50	11.50	2.04		-0.4	0.804		13.74	0.05
										0.00
	1000	200	44.70	1.98		0.3	0.800		56.30	0.19
149	1000	125	27.70	1.96	**1.97**	-0.2	0.800	20 020	35.49	0.12
	1000	50	11.10	1.96		-0.1	0.800		14.17	0.05
										0.00
	500	200	42.80	1.89		0.5	0.796		58.50	0.19
	500	125	26.60	1.88	**1.88**	0.2	0.796		36.77	0.12
	500	50	10.50	1.86		-0.7	0.796		14.90	0.05

Table A 31 Experimental Data of Viscosity Measured by Capillary Viscometer – Low Viscous Oil / Heptane Mixture with 0.314 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	100	60.90	5.76		0.0	0.825		9.97	0.03
	1500	70	42.50	5.74	**5.74**	0.0	0.825		7.00	0.02
	1500	40	24.15	5.71		-0.1	0.825		4.02	0.01
										0.00
	1000	100	59.10	5.59		0.1	0.828		10.31	0.03
38	1000	70	41.10	5.55	**5.55**	0.0	0.828	20 020	7.27	0.02
	1000	40	23.30	5.51		-0.1	0.828		4.18	0.01
										0.00
	500	100	57.15	5.41		0.1	0.823		10.59	0.04
	500	70	39.75	5.37	**5.37**	0.0	0.823		7.46	0.02
	500	40	22.55	5.33		-0.1	0.823		4.30	0.01
										0.00
	1500	250	51.80	1.90		0.2	0.788		72.27	0.24
	1500	150	30.85	1.88	**1.88**	0.0	0.788		43.69	0.15
	1500	50	10.15	1.86		-0.2	0.788		14.75	0.05
										0.00
	1000	250	50.20	1.84		0.3	0.785		74.25	0.25
93	1000	150	29.75	1.82	**1.82**	0.0	0.785	20 020	45.11	0.15
	1000	50	9.80	1.80		-0.3	0.785		15.21	0.05
										0.00
	500	250	48.30	1.77		0.2	0.781		76.80	0.26
	500	150	28.70	1.75	**1.75**	0.0	0.781		46.53	0.16
	500	50	9.50	1.74		-0.2	0.781		15.62	0.05
										0.00
	1500	300	31.70	0.94		0.3	0.748		167.18	0.56
	1500	200	21.00	0.93	**0.93**	0.1	0.748		112.16	0.37
	1500	100	10.30	0.91		-0.4	0.748		57.17	0.19
										0.00
	1000	300	30.50	0.90		0.2	0.743		172.57	0.58
149	1000	200	20.30	0.90	**0.89**	0.1	0.743	20 020	115.23	0.38
	1000	100	10.00	0.89		-0.3	0.743		58.48	0.19
										0.00
	500	300	29.55	0.87		0.2	0.738		176.92	0.59
	500	200	19.60	0.87	**0.87**	0.1	0.738		118.55	0.40
	500	100	9.70	0.86		-0.3	0.738		59.89	0.20

Table A 32 Experimental Data of Viscosity Measured by Capillary Viscometer – Medium Viscous Oil / Oxylenes Mixture with 0.085 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	60	69.70	166.23		0.9	0.958		0.24	0.00
	1500	40	46.05	164.74	**165**	0.0	0.958		0.16	0.00
	1500	20	22.80	163.13		-1.0	0.958		0.08	0.00
										0.00
	1000	60	63.40	151.21		1.0	0.956		0.26	0.00
38	1000	40	41.85	149.72	**150**	0.0	0.956	20 040	0.18	0.00
	1000	20	20.70	148.11		-1.0	0.956		0.09	0.00
										0.00
	500	60	57.55	137.26		1.0	0.954		0.29	0.00
	500	40	37.95	135.77	**136**	-0.1	0.954		0.20	0.00
	500	20	18.80	134.51		-1.0	0.954		0.10	0.00
	1500	45	67.80	13.80		0.6	0.923		2.09	0.01
	1500	30	44.95	13.72	**13.7**	0.0	0.923		1.40	0.00
	1500	15	22.35	13.65		-0.6	0.923		0.71	0.00
										0.00
	1000	45	63.60	12.95		0.8	0.921		2.23	0.01
93	1000	30	42.05	12.84	**12.8**	-0.1	0.921	20 020	1.50	0.00
	1000	15	20.90	12.76		-0.7	0.921		0.75	0.00
										0.00
	500	45	59.75	12.16		0.8	0.918		2.36	0.01
	500	30	39.55	12.08	**12.1**	0.1	0.918		1.59	0.01
	500	15	19.60	11.97		-0.8	0.918		0.80	0.00
	1500	150	65.35	3.86		0.7	0.888		24.06	0.08
	1500	100	43.20	3.82	**3.83**	-0.1	0.888		16.18	0.05
	1500	50	21.50	3.81		-0.6	0.888		8.13	0.03
										0.00
	1000	150	62.05	3.66		0.7	0.885		25.26	0.08
149	1000	100	41.05	3.63	**3.63**	-0.1	0.885	20 020	16.97	0.06
	1000	50	20.40	3.61		-0.7	0.885		8.54	0.03
										0.00
	500	150	58.65	3.46		0.4	0.882		26.62	0.09
	500	100	38.90	3.44	**3.45**	-0.1	0.882		17.84	0.06
	500	50	19.40	3.43		-0.3	0.882		8.94	0.03

Table A 33 Experimental Data of Viscosity Measured by Capillary Viscometer – Medium Viscous Oil / Oxylenes Mixture with 0.173 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	15	62.00	39.10		0.2	0.946		0.13	0.00
	1500	10	41.10	38.88	**38.8**	0.0	0.946		0.08	0.00
	1500	5	20.35	38.50		-0.2	0.946		0.04	0.00
										0.00
	1000	15	58.10	36.64		0.1	0.944		0.13	0.00
38	1000	10	38.60	36.52	**36.4**	0.1	0.944	20 020	0.09	0.00
	1000	5	19.10	36.14		-0.2	0.944		0.05	0.00
										0.00
	500	15	54.25	34.21		0.1	0.942		0.14	0.00
	500	10	35.85	33.91	**34.0**	-0.1	0.942		0.10	0.00
	500	5	17.95	33.96		-0.1	0.942		0.05	0.00
										0.00
	1500	76	49.50	5.97		0.1	0.910		8.07	0.03
	1500	50	32.40	5.94	**5.9**	-0.1	0.910		5.34	0.02
	1500	25	16.20	5.94		-0.1	0.910		2.67	0.01
										0.00
	1000	76	47.25	5.69		0.2	0.908		8.43	0.03
93	1000	50	30.90	5.66	**5.7**	0.0	0.908	20 020	5.58	0.02
	1000	25	15.40	5.64		-0.2	0.908		2.80	0.01
										0.00
	500	76	45.00	5.42		0.2	0.905		8.83	0.03
	500	50	29.50	5.40	**5.4**	0.0	0.905		5.83	0.02
	500	25	14.70	5.39		-0.2	0.905		2.92	0.01
										0.00
	1500	200	49.70	2.20		0.3	0.874		55.36	0.18
	1500	125	30.90	2.19	**2.19**	0.0	0.874		34.78	0.12
	1500	76	18.70	2.18		-0.3	0.874		21.24	0.07
										0.00
	1000	200	47.60	2.11		0.4	0.871		57.58	0.19
149	1000	125	29.50	2.09	**2.09**	-0.1	0.871	20 020	36.29	0.12
	1000	76	17.90	2.08		-0.2	0.871		22.11	0.07
										0.00
	500	200	45.70	2.02		0.3	0.868		59.75	0.20
	500	125	28.40	2.01	**2.01**	0.0	0.868		37.56	0.13
	500	76	17.20	2.00		-0.3	0.868		22.93	0.08

Table A 34 Experimental Data of Viscosity Measured by Capillary Viscometer – Medium Viscous Oil / Oxylenes Mixture with 0.662 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	300	50.50	1.59		0.0	0.890		116.73	0.39
	1500	200	33.10	1.57	**1.57**	0.0	0.890		79.15	0.26
	1500	100	16.50	1.56		0.0	0.890		39.70	0.13
										0.00
	1000	300	48.40	1.53		0.0	0.888		121.47	0.40
38	1000	200	32.15	1.52	**1.52**	0.0	0.888	20 020	81.27	0.27
	1000	100	16.00	1.51		0.0	0.888		40.83	0.14
										0.00
	500	300	46.70	1.47		0.0	0.885		125.54	0.42
	500	200	30.95	1.46	**1.46**	0.0	0.885		84.19	0.28
	500	100	15.30	1.45		0.0	0.885		42.58	0.14
										0.00
	1500	300	23.40	0.71		0.0	0.848		248.03	0.83
	1500	200	15.50	0.71	**0.71**	0.0	0.848		166.42	0.55
	1500	100	7.70	0.71		0.0	0.848		83.75	0.28
										0.00
	1000	300	23.00	0.70		0.0	0.845		251.37	0.84
93	1000	200	15.20	0.70	**0.70**	0.0	0.845	20 020	169.05	0.56
	1000	100	7.55	0.69		0.0	0.845		85.08	0.28
										0.00
	500	300	22.70	0.69		0.1	0.842		253.69	0.85
	500	200	15.00	0.69	**0.69**	0.0	0.842		170.63	0.57
	500	100	7.40	0.68		-0.1	0.842		86.47	0.29
										0.00
	1500	300	15.80	0.47		0.2	0.805		360.89	1.20
	1500	200	10.35	0.46	**0.46**	0.0	0.805		244.86	0.82
	1500	100	5.10	0.45		-0.2	0.805		124.23	0.41
										0.00
	1000	300	15.35	0.45		0.2	0.801		369.61	1.23
149	1000	200	10.15	0.45	**0.45**	0.1	0.801	20 020	248.43	0.83
	1000	100	4.95	0.44		-0.2	0.801		127.35	0.42
										0.00
	500	300	15.00	0.44		0.3	0.797		376.10	1.25
	500	200	9.70	0.43	**0.43**	-0.1	0.797		258.49	0.86
	500	100	4.85	0.43		-0.1	0.797		129.24	0.43

Table A 35 Experimental Data of Viscosity Measured by Capillary Viscometer – Medium Viscous Oil / Heptane Mixture with 0.068 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	6	85.00	134.02		0.7	0.937		0.01	0.00
	1500	4	56.55	133.74	**133**	0.5	0.937		0.01	0.00
	1500	2	27.65	130.78		-1.3	0.937		0.00	0.00
										0.00
	1000	6	78.15	123.22		0.7	0.935		0.02	0.00
38	1000	4	51.85	122.63	**122**	0.3	0.935	20 020	0.01	0.00
	1000	2	25.50	120.62		-1.0	0.935		0.01	0.00
										0.00
	500	6	72.05	113.60		0.9	0.933		0.02	0.00
	500	4	47.45	112.22	**112**	-0.1	0.933		0.01	0.00
	500	2	23.55	111.39		-0.7	0.933		0.01	0.00
										0.00
	1500	50	65.50	12.00		0.7	0.902		2.62	0.01
	1500	35	45.50	11.91	**11.9**	0.0	0.902		1.85	0.01
	1500	20	25.80	11.82		-0.7	0.902		1.06	0.00
										0.00
	1000	50	61.95	11.35		0.7	0.900		2.76	0.01
93	1000	35	43.00	11.25	**11.3**	0.0	0.900	20 020	1.95	0.01
	1000	20	24.40	11.18		-0.7	0.900		1.12	0.00
										0.00
	500	50	58.00	10.63		0.7	0.897		2.94	0.01
	500	35	40.30	10.55	**10.5**	0.0	0.897		2.07	0.01
	500	20	22.85	10.47		-0.7	0.897		1.19	0.00
										0.00
	1500	200	76.30	3.38		0.2	0.867		35.75	0.12
	1500	150	57.30	3.38	**3.37**	0.3	0.867		26.78	0.09
	1500	100	37.80	3.35		-0.6	0.867		18.04	0.06
										0.00
	1000	200	73.60	3.26		0.6	0.864		36.93	0.12
149	1000	150	54.90	3.24	**3.24**	0.1	0.864	20 020	27.85	0.09
	1000	100	36.30	3.21		-0.6	0.864		18.72	0.06
										0.00
	500	200	70.30	3.11		0.9	0.861		38.52	0.13
	500	150	52.20	3.08	**3.08**	0.0	0.861		29.18	0.10
	500	100	34.50	3.05		-0.8	0.861		19.63	0.07

Table A 36 Experimental Data of Viscosity Measured by Capillary Viscometer – Medium Viscous Oil / Heptane Mixture with 0.140 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	15	60.85	38.38		0.2	0.912		0.12	0.00
	1500	10	40.15	37.98	**38.0**	0.0	0.912		0.08	0.00
	1500	5	19.85	37.56		-0.3	0.912		0.04	0.00
										0.00
	1000	15	56.90	35.88		0.4	0.910		0.13	0.00
38	1000	10	37.20	35.19	**35.4**	-0.1	0.910	20 020	0.09	0.00
	1000	5	18.50	35.00		-0.2	0.910		0.05	0.00
										0.00
	500	15	52.85	33.33		0.4	0.907		0.14	0.00
	500	10	34.70	32.83	**32.8**	0.0	0.907		0.10	0.00
	500	5	17.10	32.35		-0.4	0.907		0.05	0.00
										0.00
	1500	100	65.25	5.98		0.3	0.876		10.20	0.03
	1500	60	38.85	5.93	**5.9**	0.0	0.876		6.17	0.02
	1500	20	12.85	5.89		-0.3	0.876		2.07	0.01
										0.00
	1000	100	61.50	5.63		0.4	0.873		10.79	0.04
93	1000	60	36.55	5.58	**5.6**	0.0	0.873	20 020	6.54	0.02
	1000	20	12.05	5.52		-0.5	0.873		2.20	0.01
										0.00
	500	100	58.25	5.34		0.4	0.871		11.36	0.04
	500	60	34.70	5.30	**5.3**	0.0	0.871		6.86	0.02
	500	20	11.45	5.24		-0.4	0.871		2.31	0.01
										0.00
	1500	250	59.20	2.10		0.6	0.840		69.75	0.23
	1500	150	35.10	2.07	**2.07**	-0.1	0.840		42.35	0.14
	1500	50	11.60	2.05		-0.5	0.840		14.24	0.05
										0.00
	1000	250	56.30	1.99		0.4	0.836		73.03	0.24
149	1000	150	33.50	1.98	**1.98**	0.0	0.836	20 020	44.19	0.15
	1000	50	11.10	1.96		-0.4	0.836		14.82	0.05
										0.00
	500	250	54.10	1.92		0.4	0.833		75.69	0.25
	500	150	32.10	1.89	**1.90**	-0.2	0.833		45.92	0.15
	500	50	10.70	1.89		-0.2	0.833		15.31	0.05

Table A 37 Experimental Data of Viscosity Measured by Capillary Viscometer – Medium Viscous Oil / Heptane Mixture with 0.307 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	100	64.40	6.09		0.0	0.856		9.78	0.03
	1500	60	38.30	6.04	**6.0**	0.0	0.856		5.92	0.02
	1500	20	12.55	5.94		-0.1	0.856		2.01	0.01
										0.00
	1000	100	61.60	5.83		0.0	0.853		10.19	0.03
38	1000	60	36.50	5.75	**5.8**	0.0	0.853	20 020	6.19	0.02
	1000	20	12.05	5.70		0.0	0.853		2.08	0.01
										0.00
	500	100	58.60	5.54		0.0	0.851		10.68	0.04
	500	60	34.90	5.50	**5.5**	0.0	0.851		6.46	0.02
	500	20	11.55	5.46		0.0	0.851		2.17	0.01
										0.00
	1500	300	61.85	1.89		0.2	0.817		90.41	0.30
	1500	200	40.45	1.85	**1.86**	-0.1	0.817		61.44	0.20
	1500	100	20.20	1.85		-0.1	0.817		30.76	0.10
										0.00
	1000	300	59.30	1.81		0.2	0.814		93.94	0.31
93	1000	200	38.80	1.78	**1.78**	0.0	0.814	20 020	63.81	0.21
	1000	100	19.20	1.76		-0.2	0.814		32.24	0.11
										0.00
	500	300	57.05	1.74		0.3	0.811		97.23	0.32
	500	200	36.65	1.68	**1.71**	-0.2	0.811		67.27	0.22
	500	100	18.60	1.70		0.0	0.811		33.14	0.11
										0.00
	1500	300	29.70	0.88		0.3	0.779		185.64	0.62
	1500	200	19.60	0.87	**0.87**	0.0	0.779		125.02	0.42
	1500	100	9.65	0.85		-0.3	0.779		63.48	0.21
										0.00
	1000	300	28.80	0.85		0.2	0.775		190.41	0.63
149	1000	200	19.00	0.84	**0.84**	0.0	0.775	20 020	128.28	0.43
	1000	100	9.40	0.83		-0.2	0.775		64.82	0.22
										0.00
	500	300	27.80	0.82		0.5	0.771		196.31	0.65
	500	200	18.00	0.80	**0.80**	-0.2	0.771		134.75	0.45
	500	100	9.00	0.80		-0.2	0.771		67.38	0.22

Table A 38 Experimental Data of Viscosity Measured by Capillary Viscometer – High Viscous Oil / Oxylenes Mixture with 0.086 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	15	67.30	642.04		0.7	0.971		0.02	0.00
	1500	10	44.55	637.51	**637**	0.0	0.971		0.01	0.00
	1500	5	22.10	632.50		-0.8	0.971		0.01	0.00
										0.00
	1000	15	61.25	584.33		0.9	0.969		0.02	0.00
38	1000	10	40.45	578.84	**579**	0.0	0.969	20 020	0.01	0.00
	1000	5	20.05	573.83		-0.9	0.969		0.01	0.00
										0.00
	500	15	55.60	530.42		0.7	0.967		0.02	0.00
	500	10	36.90	528.04	**527**	0.2	0.967		0.01	0.00
	500	5	18.25	522.32		-0.9	0.967		0.01	0.00
										0.00
	1500	15	61.90	37.80		-0.1	0.936		0.26	0.00
	1500	10	41.30	37.83	**37.8**	0.0	0.936		0.17	0.00
	1500	5	20.65	37.83		0.0	0.936		0.09	0.00
										0.00
	1000	15	58.05	35.45		0.7	0.934		0.28	0.00
93	1000	10	38.40	35.17	**35.2**	-0.1	0.934	20 020	0.18	0.00
	1000	5	19.10	34.99		-0.6	0.934		0.09	0.00
										0.00
	500	15	54.45	33.25		0.6	0.931		0.29	0.00
	500	10	36.10	33.07	**33.1**	0.0	0.931		0.20	0.00
	500	5	17.95	32.88		-0.6	0.931		0.10	0.00
										0.00
	1500	70	66.30	8.38		0.0	0.901		5.24	0.02
	1500	50	47.40	8.39	**8.38**	0.1	0.901		3.74	0.01
	1500	30	28.40	8.38		-0.1	0.901		2.25	0.01
										0.00
	1000	70	63.50	8.03		0.4	0.898		5.45	0.02
149	1000	50	45.20	8.00	**8.00**	0.0	0.898	20 020	3.91	0.01
	1000	30	27.00	7.97		-0.4	0.898		2.35	0.01
										0.00
	500	70	60.00	7.59		0.2	0.895		5.75	0.02
	500	50	42.90	7.59	**7.57**	0.3	0.895		4.10	0.01
	500	30	25.50	7.52		-0.6	0.895		2.48	0.01

Table A 39 Experimental Data of Viscosity Measured by Capillary Viscometer – High Viscous Oil / Oxylenes Mixture with 0.173 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	100	74.05	105.97		0.1	0.959		0.31	0.00
	1500	60	44.05	105.06	**105**	0.0	0.959		0.19	0.00
	1500	30	21.85	104.22		-0.1	0.959		0.10	0.00
										0.00
	1000	100	69.20	99.03		0.2	0.957		0.34	0.00
38	1000	60	41.10	98.02	**98.0**	0.0	0.957	20 040	0.20	0.00
	1000	30	20.30	96.83		-0.2	0.957		0.10	0.00
										0.00
	500	100	64.65	92.51		0.2	0.955		0.36	0.00
	500	60	38.35	91.46	**91.7**	0.0	0.955		0.22	0.00
	500	30	19.10	91.11		-0.1	0.955		0.11	0.00
										0.00
	1500	40	62.20	14.24		0.1	0.924		1.81	0.01
	1500	25	38.70	14.18	**14.2**	-0.1	0.924		1.13	0.00
	1500	10	15.55	14.24		0.1	0.924		0.45	0.00
										0.00
	1000	40	59.05	13.52		0.1	0.921		1.90	0.01
93	1000	25	36.65	13.43	**13.5**	-0.1	0.921	20 020	1.19	0.00
	1000	10	14.70	13.47		0.0	0.921		0.48	0.00
										0.00
	500	40	55.95	12.81		0.1	0.919		2.00	0.01
	500	25	34.85	12.77	**12.8**	-0.1	0.919		1.25	0.00
	500	10	13.95	12.78		0.0	0.919		0.50	0.00
										0.00
	1500	125	63.70	4.51		0.3	0.887		17.11	0.06
	1500	85	43.10	4.49	**4.49**	0.0	0.887		11.70	0.04
	1500	45	22.70	4.46		-0.3	0.887		6.22	0.02
										0.00
	1000	125	61.20	4.33		0.4	0.884		17.76	0.06
149	1000	85	41.30	4.30	**4.30**	0.0	0.884	20 020	12.17	0.04
	1000	45	21.70	4.27		-0.4	0.884		6.49	0.02
										0.00
	500	125	58.40	4.13		0.5	0.881		18.54	0.06
	500	85	39.40	4.10	**4.10**	0.1	0.881		12.71	0.04
	500	45	20.60	4.05		-0.6	0.881		6.81	0.02

Table A 40 Experimental Data of Viscosity Measured by Capillary Viscometer – High Viscous Oil / Oxylenes Mixture with 0.664 wt/wt of Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	350	68.65	1.86		0.0	0.894		117.39	0.39
	1500	225	43.65	1.84	**1.84**	0.0	0.894		76.30	0.25
	1500	100	19.30	1.83		0.0	0.894		34.09	0.11
										0.00
	1000	350	67.00	1.81		0.0	0.891		119.95	0.40
38	1000	225	42.50	1.79	**1.79**	0.0	0.891	20 020	78.15	0.26
	1000	100	18.80	1.78		0.0	0.891		34.90	0.12
										0.00
	500	350	65.10	1.76		0.0	0.889		123.11	0.41
	500	225	41.40	1.74	**1.74**	0.0	0.889		80.00	0.27
	500	100	18.25	1.73		0.0	0.889		35.85	0.12
										0.00
	1500	500	50.60	0.93		0.0	0.852		319.99	1.07
	1500	300	29.70	0.91	**0.91**	0.0	0.852		196.26	0.65
	1500	100	9.80	0.90		0.0	0.852		66.09	0.22
										0.00
	1000	500	49.70	0.91		0.0	0.849		324.59	1.08
93	1000	300	29.15	0.89	**0.89**	0.0	0.849	20 020	199.23	0.66
	1000	100	9.65	0.88		0.0	0.849		66.87	0.22
										0.00
	500	500	48.40	0.89		0.0	0.846		331.94	1.11
	500	300	28.40	0.87	**0.87**	0.0	0.846		203.65	0.68
	500	100	9.50	0.87		0.0	0.846		67.65	0.23
										0.00
	1500	800	59.30	0.66		0.6	0.809		687.18	2.29
	1500	500	33.30	0.59	**0.60**	-0.2	0.809		478.02	1.59
	1500	300	19.10	0.56		-0.5	0.809		300.02	1.00
										0.00
	1000	800	58.05	0.64		0.6	0.805		698.37	2.33
149	1000	500	32.85	0.58	**0.59**	-0.1	0.805	20 020	482.07	1.61
	1000	300	18.55	0.55		-0.5	0.805		307.33	1.02
										0.00
	500	800	56.90	0.63		0.7	0.801		708.49	2.36
	500	500	32.30	0.57	**0.58**	-0.1	0.801		487.53	1.63
	500	300	18.10	0.53		-0.6	0.801		313.21	1.04

Table A 41 Experimental Data of Viscosity Measured by Capillary Viscometer – High Viscous Oil / Heptane Mixture with 0.068 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	15	70.70	674.48		0.7	0.956		0.01	0.00
	1500	10	46.80	669.71	**670**	0.0	0.956		0.00	0.00
	1500	5	23.25	665.42		-0.7	0.956		0.00	0.00
										0.00
	1000	15	64.70	617.24		0.8	0.954		0.01	0.00
38	1000	10	42.80	612.47	**613**	0.0	0.954	20 040	0.01	0.00
	1000	5	21.25	608.18		-0.8	0.954		0.00	0.00
										0.00
	500	15	58.95	562.38		0.9	0.952		0.01	0.00
	500	10	38.95	557.37	**558**	-0.1	0.952		0.01	0.00
	500	5	19.35	553.80		-0.8	0.952		0.00	0.00
										0.00
	1500	15	66.05	40.33		0.4	0.922		0.24	0.00
	1500	10	43.90	40.21	**40.2**	0.1	0.922		0.16	0.00
	1500	5	21.85	40.03		-0.4	0.922		0.08	0.00
										0.00
	1000	15	62.45	38.14		0.7	0.919		0.25	0.00
93	1000	10	41.35	37.88	**37.9**	0.0	0.919	20 020	0.17	0.00
	1000	5	20.55	37.65		-0.7	0.919		0.08	0.00
										0.00
	500	15	58.55	35.75		1.0	0.917		0.27	0.00
	500	10	38.60	35.36	**35.4**	-0.2	0.917		0.18	0.00
	500	5	19.20	35.17		-0.8	0.917		0.09	0.00
										0.00
	1500	70	72.15	9.12		0.7	0.887		4.74	0.02
	1500	50	51.30	9.08	**9.07**	0.2	0.887		3.40	0.01
	1500	30	30.50	9.00		-0.8	0.887		2.06	0.01
										0.00
	1000	70	68.35	8.64		0.6	0.884		4.99	0.02
149	1000	50	48.55	8.59	**8.59**	0.0	0.884	20 020	3.58	0.01
	1000	30	28.95	8.54		-0.6	0.884		2.16	0.01
										0.00
	500	70	64.55	8.16		0.6	0.881		5.26	0.02
	500	50	45.90	8.12	**8.12**	0.1	0.881		3.78	0.01
	500	30	27.35	8.07		-0.7	0.881		2.28	0.01

Table A 42 Experimental Data of Viscosity Measured by Capillary Viscometer – High Viscous Oil / Heptane Mixture with 0.144 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	80	64.15	114.75		0.2	0.923		0.22	0.00
	1500	50	39.70	113.62	**114**	0.0	0.923		0.14	0.00
	1500	30	23.65	112.81		-0.1	0.923		0.09	0.00
										0.00
	1000	80	59.80	106.97		0.2	0.921		0.24	0.00
38	1000	50	36.95	105.75	**106**	-0.1	0.921	20 040	0.15	0.00
	1000	30	22.10	105.42		-0.1	0.921		0.09	0.00
										0.00
	500	80	55.50	99.28		0.1	0.919		0.26	0.00
	500	50	34.45	98.60	**98.6**	0.0	0.919		0.16	0.00
	500	30	20.55	98.02		-0.1	0.919		0.10	0.00
										0.00
	1500	50	76.25	13.97		0.3	0.887		2.21	0.01
	1500	30	45.35	13.85	**13.9**	0.0	0.887		1.34	0.00
	1500	10	15.00	13.74		-0.3	0.887		0.45	0.00
										0.00
	1000	50	72.30	13.25		0.3	0.885		2.33	0.01
93	1000	30	43.05	13.14	**13.1**	0.0	0.885	20 020	1.41	0.00
	1000	10	14.25	13.05		-0.3	0.885		0.47	0.00
										0.00
	500	50	68.50	12.55		0.3	0.882		2.45	0.01
	500	30	40.85	12.47	**12.5**	0.0	0.882		1.48	0.00
	500	10	13.50	12.37		-0.3	0.882		0.50	0.00
										0.00
	1500	130	63.30	4.31		0.4	0.852		17.89	0.06
	1500	80	38.65	4.28	**4.28**	0.0	0.852		11.10	0.04
	1500	40	19.20	4.25		-0.4	0.852		5.59	0.02
										0.00
	1000	130	60.80	4.14		0.5	0.849		18.56	0.06
149	1000	80	36.95	4.09	**4.10**	-0.1	0.849	20 020	11.57	0.04
	1000	40	18.40	4.07		-0.4	0.849		5.81	0.02
										0.00
	500	130	57.85	3.94		0.5	0.845		19.43	0.06
	500	80	35.20	3.89	**3.90**	-0.1	0.845		12.09	0.04
	500	40	17.50	3.87		-0.4	0.845		6.08	0.02

Table A 43 Experimental Data of Viscosity Measured by Capillary Viscometer – High Viscous Oil / Heptane Mixture with 0.310 wt/wt of Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	50	72.60	13.74		0.0	0.867		2.20	0.01
	1500	30	43.25	13.64	**13.6**	0.0	0.867		1.33	0.00
	1500	10	14.30	13.53		0.0	0.867		0.45	0.00
										0.00
	1000	50	69.30	13.11		0.0	0.865		2.30	0.01
38	1000	30	41.25	13.01	**13.0**	0.0	0.865	20 020	1.39	0.00
	1000	10	13.60	12.87		0.0	0.865		0.47	0.00
										0.00
	500	50	65.90	12.47		0.0	0.862		2.41	0.01
	500	30	39.15	12.35	**12.4**	0.0	0.862		1.46	0.00
	500	10	13.00	12.30		0.0	0.862		0.49	0.00
										0.00
	1500	150	58.40	3.57		0.1	0.829		24.28	0.08
	1500	100	38.60	3.54	**3.54**	0.0	0.829		16.33	0.05
	1500	50	19.15	3.51		-0.1	0.829		8.23	0.03
										0.00
	1000	150	56.05	3.42		0.1	0.826		25.21	0.08
93	1000	100	37.05	3.39	**3.40**	0.0	0.826	20 020	16.95	0.06
	1000	50	18.45	3.38		-0.1	0.826		8.51	0.03
										0.00
	500	150	53.80	3.29		0.1	0.823		26.17	0.09
	500	100	35.60	3.26	**3.26**	0.0	0.823		17.57	0.06
	500	50	17.65	3.23		-0.1	0.823		8.86	0.03
										0.00
	1500	350	63.55	1.61		0.2	0.792		120.05	0.40
	1500	250	44.95	1.59	**1.59**	0.0	0.792		86.59	0.29
	1500	150	26.65	1.57		-0.2	0.792		52.58	0.18
										0.00
	1000	350	60.70	1.53		0.3	0.788		125.07	0.42
149	1000	250	42.90	1.52	**1.51**	0.1	0.788	20 020	90.29	0.30
	1000	150	25.10	1.48		-0.4	0.788		55.55	0.19
										0.00
	500	350	58.20	1.47		0.3	0.783		129.72	0.43
	500	250	40.70	1.44	**1.45**	-0.1	0.783		94.64	0.32
	500	150	24.20	1.43		-0.3	0.783		57.30	0.19

Table A 44 Experimental Data of Viscosity Measured by Capillary Viscometer – Xylenes

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	90	68.80	0.53		0.2	0.854		202	0.34
	1500	60	45.80	0.53	**0.53**	0.1	0.854		135	0.22
	1500	30	22.80	0.53		-0.3	0.854		68	0.11
	1000	90	68.00	0.52		0.6	0.852		204	0.34
38	1000	60	45.10	0.52	**0.52**	0.0	0.852	20 010	136	0.23
	1000	30	22.40	0.52		-0.6	0.852		69	0.11
	500	90	66.60	0.51		0.2	0.849		207	0.35
	500	60	44.40	0.51	**0.51**	0.2	0.849		138	0.23
	500	30	22.10	0.51		-0.3	0.849		69	0.12
	1500	120	58.50	0.33		0.5	0.808		411	0.69
	1500	80	38.85	0.33	**0.33**	0.1	0.808		275	0.46
	1500	40	19.30	0.33		-0.6	0.808		138	0.23
	1000	120	57.80	0.32		0.8	0.805		414	0.69
93	1000	80	38.20	0.32	**0.32**	0.0	0.805	20 010	279	0.46
	1000	40	18.95	0.32		-0.8	0.805		140	0.23
	500	120	57.05	0.32		0.9	0.801		418	0.70
	500	80	37.60	0.32	**0.32**	-0.2	0.801		282	0.47
	500	40	18.70	0.32		-0.7	0.801		142	0.24
	1500	140	51.20	0.24		3.2	0.759		619	1.03
	1500	100	35.20	0.23	**0.23**	-0.6	0.759		459	0.77
	1500	60	20.70	0.23		-2.6	0.759		281	0.47
	1000	140	50.50	0.24		3.3	0.755		624	1.04
149	1000	100	34.75	0.23	**0.23**	-0.5	0.755	20 010	462	0.77
	1000	60	20.35	0.22		-2.9	0.755		284	0.47
	500	140	49.40	0.23		3.2	0.750		633	1.06
	500	100	34.05	0.22	**0.22**	-0.4	0.750		469	0.78
	500	60	19.95	0.22		-2.8	0.750		288	0.48

Table A 45 Experimental Data of Viscosity Measured by Capillary Viscometer – Heptane

Temperature (°C)	Pressure (psia)	Q (mL/Hr)	Δ P (psia)	Viscosity (mPa•s)	Avg. Viscosity (mPa•s)	% Diff	Density g/mL	Coil	Re= ρuD/μ	De
	1500	120	64.00	0.37		0.2	0.959		433	0.72
	1500	80	42.45	0.37	**0.37**	-0.2	0.959		290	0.48
	1500	40	21.30	0.37		0.0	0.959		144	0.24
	1000	120	62.50	0.36		0.2	0.957		442	0.74
38	1000	80	41.65	0.36	**0.36**	0.2	0.957	20 010	295	0.49
	1000	40	20.65	0.36		-0.4	0.957		149	0.25
	500	120	61.00	0.35		0.3	0.955		452	0.75
	500	80	40.60	0.35	**0.35**	0.2	0.955		302	0.50
	500	40	20.10	0.35		-0.5	0.955		152	0.25
	1500	150	53.80	0.24		1.3	0.924		798	1.33
	1500	100	35.05	0.24	**0.24**	-0.4	0.924		544	0.91
	1500	50	17.40	0.23		-0.9	0.924		274	0.46
	1000	150	52.50	0.24		1.5	0.921		816	1.36
93	1000	100	34.20	0.23	**0.23**	-0.2	0.921	20 010	557	0.93
	1000	50	16.85	0.23		-1.3	0.921		282	0.47
	500	150	51.20	0.23		2.0	0.919		834	1.39
	500	100	33.10	0.22	**0.22**	-0.2	0.919		573	0.96
	500	50	16.20	0.22		-1.7	0.919		293	0.49
	1500	150	39.60	0.17		3.2	0.887		1073	1.79
	1500	100	25.15	0.16	**0.17**	-0.4	0.887		751	1.25
	1500	50	12.15	0.16		-2.8	0.887		389	0.65
	1000	150	38.60	0.17		3.5	0.884		1097	1.83
149	1000	100	24.25	0.16	**0.16**	-0.7	0.884	20 010	776	1.29
	1000	50	14.10	0.15		-2.8	0.884		400	0.67
	500	150	37.10	0.16		3.8	0.881		1137	1.90
	500	100	23.30	0.15	**0.15**	-0.4	0.881		805	1.34
	500	50	11.15	0.15		-3.3	0.881		420	0.70