



Designation: G205 – 23

Standard Guide for Determining Emulsion Properties, Wetting Behavior, and Corrosion-Inhibitory Properties of Crude Oils¹

This standard is issued under the fixed designation G205; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers some generally accepted laboratory methodologies that are used for determining emulsion forming tendency, wetting behavior, and corrosion-inhibitory properties of crude oil.

1.2 This guide does not cover detailed calculations and methods, but rather covers a range of approaches that have found application in evaluating emulsions, wettability, and the corrosion rate of steel in crude oil/water mixtures.

1.3 Only those methodologies that have found wide acceptance in the industry are considered in this guide.

1.4 This guide is intended to assist in the selection of methodologies that can be used for determining the corrosivity of crude oil under conditions in which water is present in the liquid state (typically up to 100 °C). These conditions normally occur during oil and gas production, storage, and transportation in the pipelines.

1.5 This guide is not applicable at higher temperatures (typically above 300 °C) that occur during refining crude oil in refineries.

1.6 This guide involves the use of electrical currents in the presence of flammable liquids. Awareness of fire safety is critical for the safe use of this guide.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standard-*

ization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:²

- D473 Test Method for Sediment in Crude Oils and Fuel Oils by the Extraction Method
- D665 Test Method for Rust-Preventing Characteristics of Inhibited Mineral Oil in the Presence of Water
- D724 Test Method for Surface Wettability of Paper (Angle-of-Contact Method) (Withdrawn 2009)³
- D1125 Test Methods for Electrical Conductivity and Resistivity of Water
- D1129 Terminology Relating to Water
- D1141 Practice for Preparation of Substitute Ocean Water
- D4006 Test Method for Water in Crude Oil by Distillation
- D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
- G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
- G31 Guide for Laboratory Immersion Corrosion Testing of Metals
- G111 Guide for Corrosion Tests in High Temperature or High Pressure Environment, or Both
- G170 Guide for Evaluating and Qualifying Oilfield and Refinery Corrosion Inhibitors in the Laboratory
- G184 Practice for Evaluating and Qualifying Oil Field and Refinery Corrosion Inhibitors Using Rotating Cage
- G185 Practice for Evaluating and Qualifying Oil Field and Refinery Corrosion Inhibitors Using the Rotating Cylinder Electrode
- G193 Terminology and Acronyms Relating to Corrosion
- G202 Test Method for Using Atmospheric Pressure Rotating Cage

¹ This guide is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.05 on Laboratory Corrosion Tests.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

2.2 *ISO Standard*.⁴

ISO 6614 Petroleum products—Determination of Water Separability of Petroleum Oils and Synthetic Fluids

2.3 *NACE Standard*.⁵

TM0172 Standard Test Method Determining Corrosive Properties of Cargoes in Petroleum Product Pipelines

3. Terminology

3.1 *Definitions*—The terminology used herein, if not specifically defined otherwise, shall be in accordance with terminologies in Guide **G170**, Terminology **G193**, and Terminology **D1129**. Definitions provided herein and not given in terminologies in Guide **G170**, Terminology **G193**, and Terminology **D1129** are limited only to this standard.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *emulsion, n*—a two-phase immiscible liquid system in which one phase is dispersed as droplets in the other phase.

3.2.2 *emulsion-inversion point, n*—the volume percentage of water at which a water-in-oil (W/O) emulsion converts into oil-in-water (O/W) emulsion.

3.2.3 *wettability, n*—tendency of a liquid to wet or adhere on to a solid surface.

3.3 *Acronyms*:

CO ₂	= Carbon dioxide
EIP	= Emulsion inversion point
H ₂ S	= Hydrogen sulfide
NaCl	= Sodium chloride
O/W	= Oil-in-water
W/O	= Water-in-oil

4. Summary of Guide

4.1 This guide describes methodologies for determining three properties of crude oils that are relevant to corrosion processes caused by the presence of water in hydrocarbon transport and handling: (1) the emulsion of the oil and water, (2) the wettability of the steel surface, and (3) the corrosivity of water phase in the presence of oil.

4.2 Conductivity of emulsion can be used to determine the type of emulsion: oil-in-water (O/W) or water-in-oil (W/O). The conductivity of O/W emulsion (in which water is the continuous phase) is high. The conductivity of W/O emulsion (in which oil is the continuous phase) is low.

4.3 The wettability of a steel surface is determined by either contact angle methodology or spreading methodology.

4.4 The corrosiveness of water phase in the presence of crude oil can be determined using several methodologies.

5. Significance and Use

5.1 In the absence of water, the crude oil is noncorrosive. However, trace amounts of water and sediment have the potential to create corrosive situations during crude oil han-

dling or transport if such materials accumulate and persist on steel surfaces. Test Methods **D473** and **D4006** provide methods for determination of the water and sediment content of crude oil.

5.2 The potential for a corrosive situation to develop during the handling and transport of crude oil that contains water can be determined by a combination of three properties (**Fig. 1**) (**1**)⁶: the type of emulsion formed between oil and water, the wettability of the steel surface, and the corrosivity of water phase in the presence of oil.

5.3 Water and oil are immiscible but, under certain conditions, they can form emulsion. There are two kinds of emulsion: oil-in-water (O/W) and water-in-oil (W/O). W/O emulsion (in which oil is the continuous phase) has low conductivity and is thus less corrosive; whereas O/W (in which water is the continuous phase) has high conductivity and, hence, is corrosive (**2**) (see ISO 6614). The percentage of water at which W/O converts to O/W is known as the emulsion inversion point (EIP). EIP can be determined by measuring the conductivity of the emulsion. At and above the EIP, a continuous phase of water or free water is present. Therefore, there is a potential for corrosion.

5.4 Whether water phase can cause corrosion in the presence of oil depends on whether the surface is oil-wet (hydrophobic) or water-wet (hydrophilic) (**1, 3-5**). Because of higher resistance, an oil-wet surface is not susceptible to corrosion, but a water-wet surface is. Wettability can be characterized by measuring the contact angle or by evaluating the tendency of water to displace oil from a multi-electrode array by measuring the resistance (or conductors) between the electrodes (spreading methodology).

5.4.1 In the contact angle methodology, the tendency of water to displace hydrocarbon from steel is determined by direct observation of the contact angle that results when both oil and water are in contact with the steel. Although this contact angle is determined by the interfacial free energies of the phases involved, there is no standard method to determine the steel-oil or steel-water interfacial free energies.

5.4.2 In the spreading methodology of determining wettability, the resistance between isolated steel pins is measured. If a conducting phase (for example, water) covers (wets) the distance between the pins, conductivity between them will be high. If a non-conducting phase (for example, oil) covers (wets) the distance between the pins, the conductivity between them will be low.

5.5 Dissolution of ingredients from crude oils may alter the corrosiveness of the aqueous phase. A crude oil can be classified as corrosive or inhibitory based on how the corrosivity of the aqueous phase is altered by the presence of the oil. Corrosiveness of aqueous phase in the presence of oil can be determined by methods described in Test Method **D665**, Guide **G170**, Practice **G184**, Practice **G185**, Test Method **G202**, and NACE TM0172.

⁴ Available from the American National Standards Institute, 25 W. 43rd St., New York, NY 10036.

⁵ Available from the National Association of Corrosion Engineers, 1440 S. Creek Dr., Houston, TX 77084-4906.

⁶ The boldface numbers in parentheses refer to a list of references at the end of this standard.

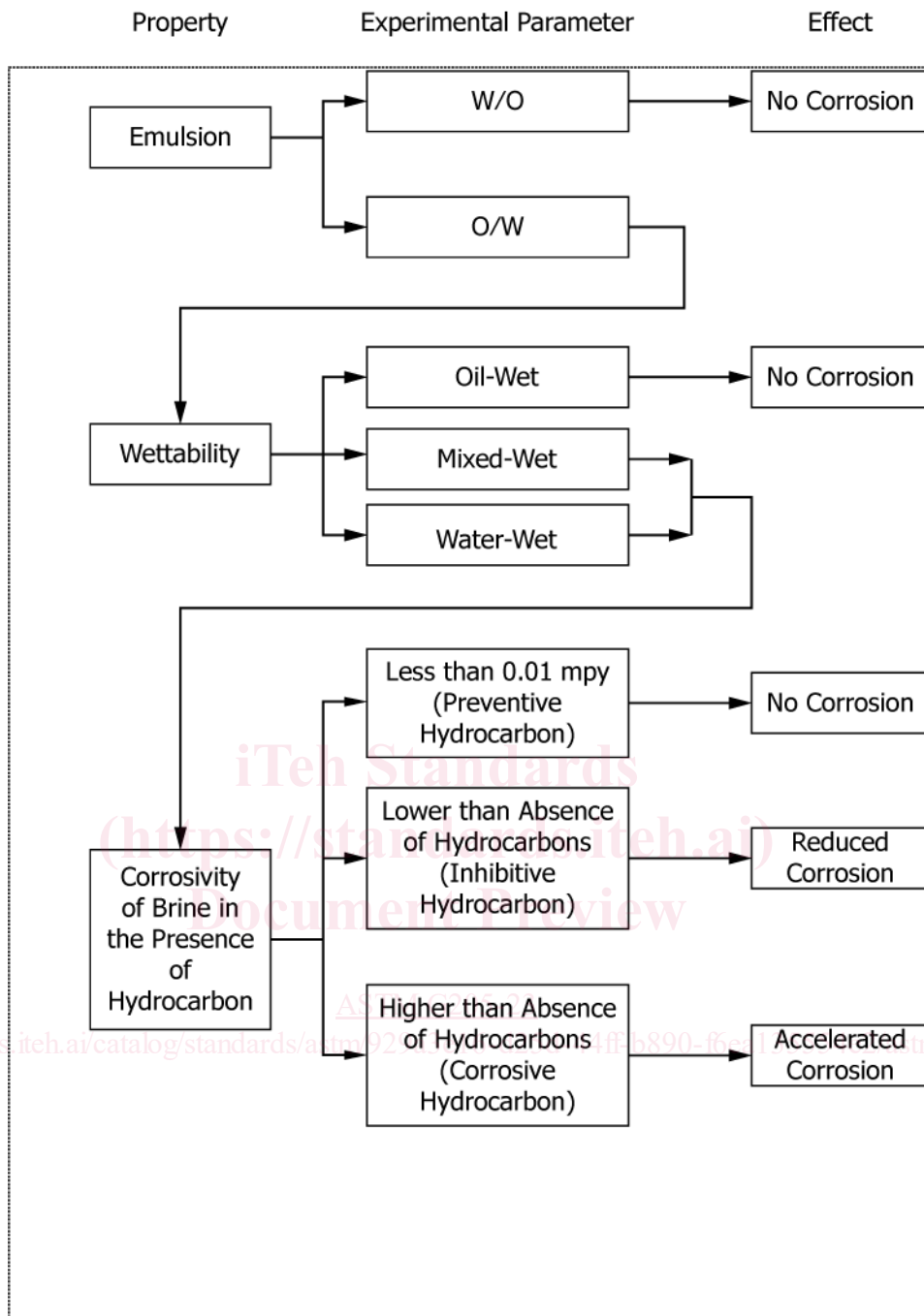


FIG. 1 Predicting Influence of Crude Oil on the Corrosivity of Aqueous Phase

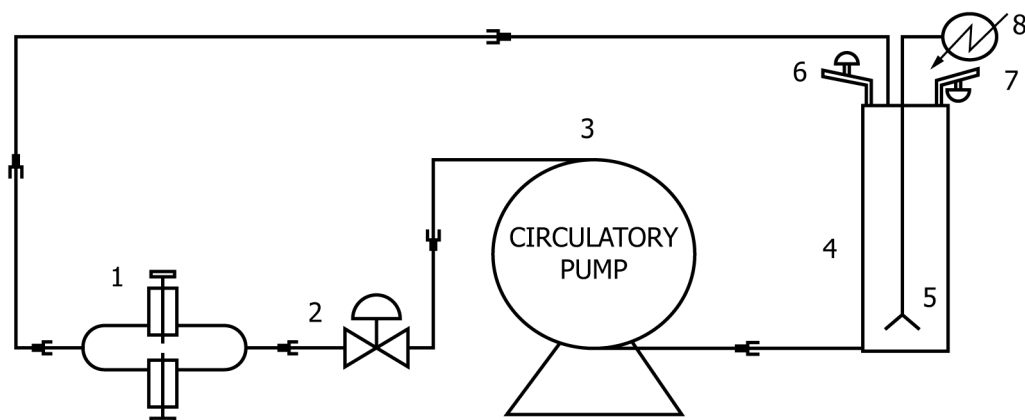
6. Materials

6.1 Methods for preparing coupons and probes for tests and for removing coupons after the test are described in Practice G1. Standard laboratory glassware should be used for weighing and measuring reagent volumes.

6.2 The coupons/probes should be made of the same metallographic material as the carbon steel that is used in the service components. The probes for wettability and EIP measurements should be ground to a surface finish of 600 grit. Preparation of coupons for corrosion measurements is described in Guide G170, Practice G184, Practice G185, and Test Method G202.

7. Preparation of Test Solutions

7.1 Oil should be obtained from the field that is being evaluated. Practice D4057 provides guidelines for collecting crude oil. It is preferred that live fluids do not contain externally added contaminants, for example, corrosion inhibitors, biocides, and surfactants to allow measurement of Guide G205 parameters on the “base” crude. A water sample should also be obtained from the field. A synthetic aqueous solution could be used; the composition of which should be based on field water analysis. Alternatively, use of 3 % NaCl aqueous solution composed of purified water and reagent grade sodium chloride or synthetic brine of a composition provided



- 1—Experimental section (see Fig. 3)
- 2—Flow controller
- 3—Circulatory pump
- 4—Reservoir (volume = 7 L)
- 5—Impeller
- 6—Gas inlet
- 7—Gas outlet
- 8—Power source to operate the impeller

FIG. 2 Schematic Diagram of a Flow Loop of an EIP Apparatus

in Practice D1141 (substitute ocean water, note brine stability is approximately one day) may be used. Their composition should be specified in the work plan and recorded in the laboratory logbook. The solutions should be prepared following good laboratory practice.

7.2 The solutions (oil and water phases) should be deaerated by passing nitrogen (or any other inert gas) and kept under deaerated conditions. Solutions should be transferred with minimal contact with air. Procedures to transfer the solutions are described in Test Method G202.

7.3 Procedures to deoxygenate and saturate the solutions with acid gases are presented in Test Method G202. To simulate field operating conditions, the solution is often required to be saturated with acid gases such as hydrogen sulfide (H₂S) and carbon dioxide (CO₂). H₂S and CO₂ are corrosive gases. H₂S is poisonous and shall not be released to the atmosphere. The appropriate composition of gas can be obtained by mixing H₂S, CO₂, and methane streams from the standard laboratory gas supply. Nitrogen or any other inert gas can be used as a diluent to obtain the required partial pressures of the corrosive gases. Alternatively, gas mixtures of the appropriate compositions can be purchased from suppliers of industrial gases. The composition of gas depends on the field gas composition. The oxygen concentration in solution depends on the quality of gases used to purge the solution. The oxygen content of nitrogen or the inert gas should be less than 10 ppm by volume. Any leaks through the vessel, tubing, and joints should be avoided.

7.4 The test vessels should be heated slowly to avoid overheating. The thermostat in the heater or thermostatic bath should be set not more than 20 °C above the solution temperature until the test temperature is reached. The pressure in the vessel should be monitored during heating to make sure it does not exceed the relief pressure. If necessary, some of the gas in

the vessel may be bled off to reduce the pressure. The test temperature should be maintained within +2 °C of the specified temperature. Once the test temperature is reached, the test pressure should be adjusted to the predetermined value. The pressure should be maintained within +10 % of the specified value for the duration of the test.

7.5 A general procedure to carry out experiments at elevated pressure and elevated temperature is described in Guide G111. For elevated temperature and elevated pressure experiments using individual gases, first the autoclave is pressurized with H₂S to the required partial pressure and left for 10 min. If there is a decrease of pressure, the autoclave is repressurized. This process is repeated until no further pressure drop occurs. Then, the autoclave is pressurized with CO₂ by charging with CO₂ from a high pressure gas cylinder at a pressure equal to the CO₂ + H₂S partial pressure and left for 10 min. If there is a decrease in pressure, the autoclave is repressurized with CO₂ gas. This process is repeated until no further pressure drop is observed. Finally, the autoclave is pressurized with an inert gas (for example, methane) to the total pressure at which the experiments are intended to be carried out.

8. Laboratory Methodologies

8.1 Determination of Emulsion Type:

8.1.1 A schematic diagram of the equipment used for determining the emulsion type is presented in Figs. 2 and 3. The apparatus consists of an experimental section (Fig. 3), a reservoir, a circulating pump, and a flow controller.

8.1.2 The experimental section (Fig. 3) is a 15.2 cm long horizontal pipe section of 1.6 cm in diameter containing two vertically placed electrically isolated measuring pins (typically made from carbon steel). The distances between the pins can be varied with a screw arrangement. For optimal measurements, a pin distance of 1 mm to 2 mm is suggested.

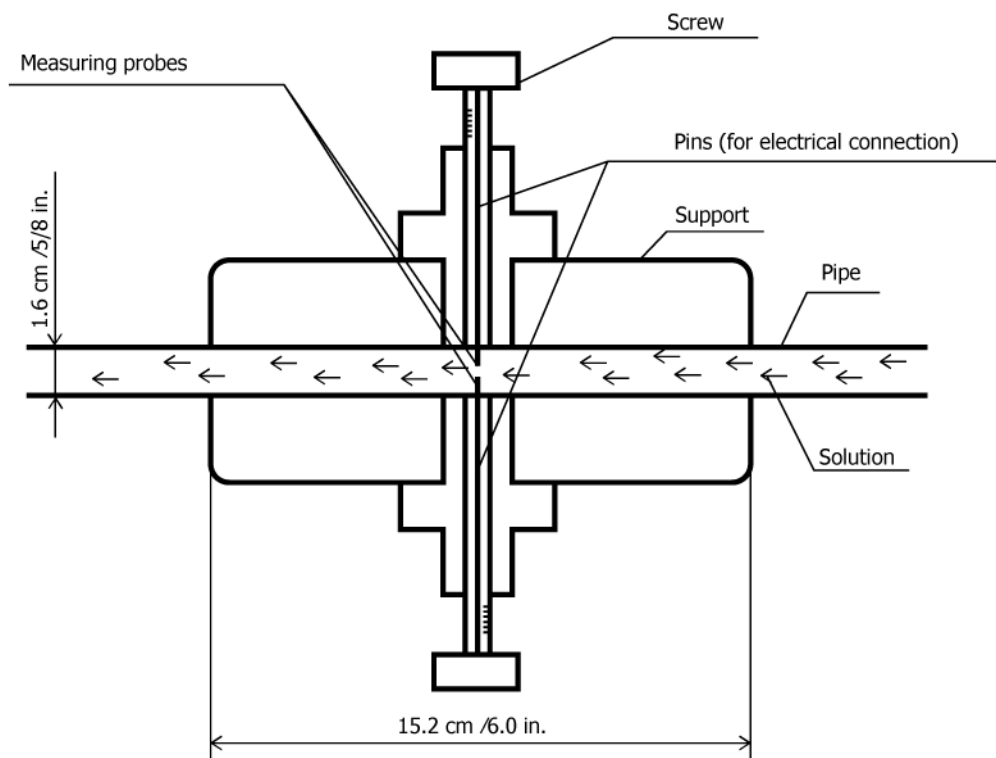


FIG. 3 Schematic Diagram of the Experimental Section of the EIP Apparatus

8.1.3 The reservoir (typically 7 L capacity) may be an autoclave (for higher pressure measurements) or a glass container (for atmospheric pressure measurements). The top cover of the reservoir is fitted with an inlet, an outlet, and an impeller. For higher pressure experiments, the reservoir is also fitted with a pressure gauge to monitor the pressure. The impeller should be capable of rotating at annular rotation speeds higher than 1000 rpm. A homogenous solution may also be created without an impeller by designing the reservoir inlet with horizontal flow and adjustable height to the top of the liquid level that provides sufficient turbulence to mix the test fluids.

8.1.4 The circulating pump is used to circulate the emulsion between the reservoir and the experimental section. The pump should be capable of pumping fluids at a speed of 50 cm/s through the experimental section across the measuring pins. The flowrate is achieved with a flow controller or variable speed pump.

8.1.5 The apparatus should be cleaned before each experiment. The measuring pins should be washed as described in Practice G1 to remove any corrosion products.

8.1.6 An appropriate volume of oil (typically 1 L) is poured into the reservoir and the entire EIP apparatus is deoxygenated using an inert gas (and presaturated with gases (typically CO₂, H₂S, and methane) when necessary), as described in Section 7. Note that proper deoxygenation of the apparatus may be critical for fire safety.

8.1.7 The initial 1 L of crude is circulated through the apparatus to remove residual cleaning fluids and then discarded. A second reservoir charge of 900 mL crude and 100 mL brine (10 %) is added to the reservoir. The impeller is

started to thoroughly mix the fluids. The rotation speed of the impeller and the duration of rotation depend on the characteristics of oil. Alternatively the test solution can be mixed within the apparatus during fluid circulation by releasing the returning fluids within the reservoir at an angle to create a vortex. A homogenous mixture of water and crude oil, is required during the conductivity measurements.

8.1.8 Once a homogenous mixture of brine and crude oil is circulating through the experimental section, the electrical resistance of the solution is measured using the two probes as described in Test Method D1125.

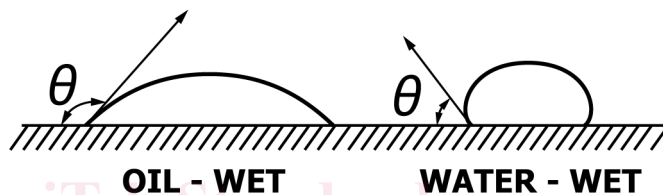
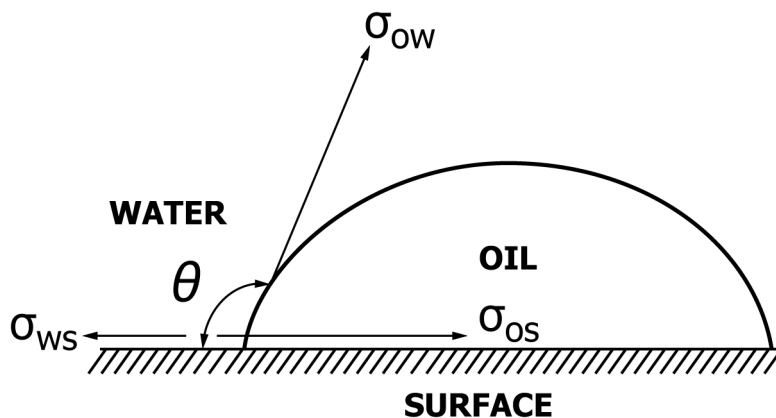
NOTE 1—The DC method of measuring electrical resistance may be used with a low voltage (1.5 V to 3 V battery) multi-meter. However, care should be taken to avoid electrolysis of the measuring probes by restricting the duration of the measurement (typically five seconds) and by taking several measurements (typically three) at regular intervals (with at least 1 min between each measurement (during which time the DC power source is turned off).

8.1.9 After measuring the electrical resistance of 90 % oil, circulation is stopped and an additional 10 % increment of brine is added to the reservoir. Subsection 8.1.7 is repeated after each 10 % addition of brine. This process is repeated until conductivity measurements indicate the inversion of the emulsion by a significant increase in the measured conductivity.

8.1.10 The emulsion inversion point is determined from a plot of conductivity versus oil-water ratio as being the first point on the graph at which the conductivity starts to increase significantly.

8.2 Determination of Wettability:

8.2.1 Contact Angle Method:



θ = contact angle
 σ_{os} = surface tensions of oil-steel interface
 σ_{ow} = surface tensions of oil-water interface
 σ_{ws} = surface tensions of water-steel interface

FIG. 4 Contact Angle Measurements through Water Phase (Exterior Contact Angle)

8.2.1.1 The contact angle of the water-oil system on steel can be measured using two different sequences: adding water first and the oil drop next (Sequence #1; 8.2.1.4 – 8.2.1.7) or adding oil first and the water drop next (Sequence #2; 8.2.1.8, 8.2.1.9). Sequence #1 is experimentally easier but does not simulate the sequence in an oil and gas pipeline (in which the surface will be first contacted with oil and then with water). Sequence #2 is more relevant to the pipeline operating conditions, but measuring contact angle through dark oil background is relatively difficult (such measurements require illumination).

8.2.1.2 Contact angle reported depend on whether the water phase is advancing or receding over the steel surface. This phenomenon is known as contact angle hysteresis and is caused by surface roughness or absorption of surface active agents on the surface (6). In order to account for this phenomenon the oil drop volume (Sequence #1; 8.2.1.4 – 8.2.1.7) or water drop volume (Sequence #2; 8.2.1.8 and 8.2.1.9) needs to be varied in order to determine the maximum and minimum contact angles. Average of both contact angles should be determined and reported.

8.2.1.3 The contact angle can be measured as interior angle or exterior angle.

Sequence #1

8.2.1.4 In Sequence #1, the steel surface is first in contact with water, a drop of oil is then added, and the contact angle is measured through the water phase. A water-steel interface will be replaced by an oil-steel interface if the surface free energy of the system decreases as a result of this action. In order to account for contact angle hysteresis the minimum and maximum contact angles need to be determined by increasing and decreasing the size of the oil droplet. The average of minimum and maximum contact angles should be determined and reported.

8.2.1.5 Figs. 4 and 5 provide examples of different contact angles of oil drop and water on a steel surface. In Fig. 4, σ_{os} , σ_{ow} , and σ_{ws} are surface tensions of oil-steel, oil-water, and water-steel interfaces, respectively. In Figs. 4 and 5, θ is the contact angle. If σ_{ws} is much larger than σ_{os} , θ will approach 180° , and the surface will be completely oil wet (7, 3). Different methods of measuring and reporting the contact angle are provided in Table 1.

8.2.1.6 The steel sample is placed horizontally in a beaker. The beaker is filled with aqueous phase so as to immerse the steel surface completely. A drop of oil is then injected using a needle (typical diameter 21G (0.8 mm)). The photograph of the