



# Standard Guide for Determining Emulsion Properties, Wetting Behavior, and Corrosion-Inhibitory Properties of Crude Oils<sup>1</sup>

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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This guide presents 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 and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- D96 Test Method for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure) (Withdrawn 2000)<sup>3</sup>
- 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)<sup>3</sup>
- D1125 Test Methods for Electrical Conductivity and Resistivity of Water
- D1129 Terminology Relating to Water
- D1141 Practice for the Preparation of Substitute Ocean Water
- D1193 Specification for Reagent Water
- D4006 Test Method for Water in Crude Oil by Distillation
- D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
- D4377 Test Method for Water in Crude Oils by Potentiometric Karl Fischer Titration
- 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

<sup>1</sup> 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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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

## G202 Test Method for Using Atmospheric Pressure Rotating Cage

2.2 ISO Standard.<sup>4</sup>

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

2.3 NACE Standard.<sup>5</sup>

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 <sub>2</sub>	= Carbon dioxide
EIP	= Emulsion inversion point
H <sub>2</sub> S	= Hydrogen sulfide
KOH	= Potassium hydroxide
NaCl	= Sodium chloride
Na <sub>2</sub> CO <sub>3</sub>	= Sodium carbonate
NaHCO <sub>3</sub>	= Sodium bicarbonate
NaOH	= Sodium hydroxide
Na <sub>2</sub> S	= Sodium sulfide
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 handling or transport if such materials accumulate and persist on steel surfaces. Test Methods D96, D473, D4006, and D4377 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)<sup>6</sup>: 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

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

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

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

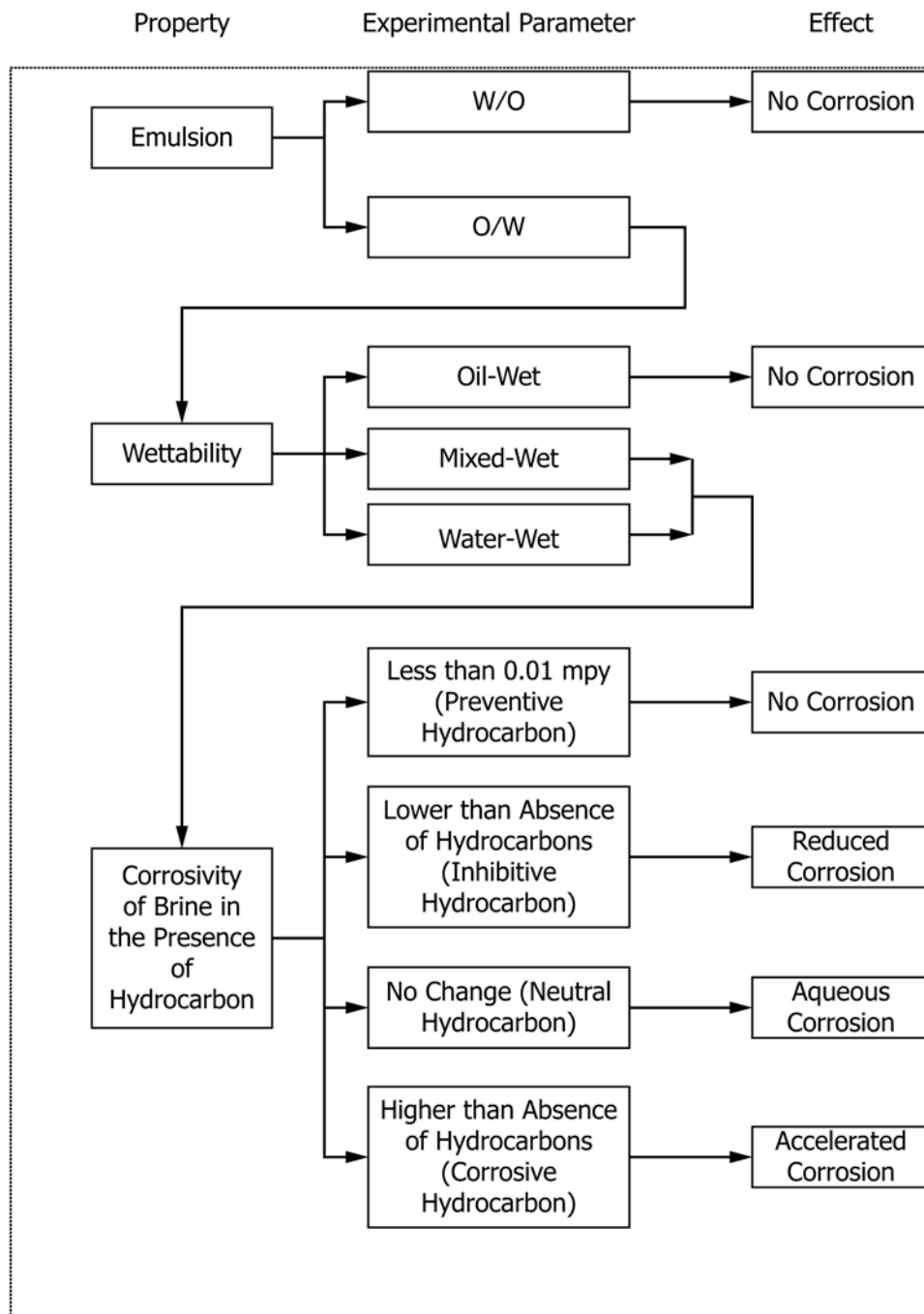


FIG. 1 Predicting Influence of Crude Oil on the Corrosivity of Aqueous Phase

classified as corrosive, neutral, 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.

## 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 field material (such as carbon steel) and have the same metallographic structure as that 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 important that live fluids do not contain

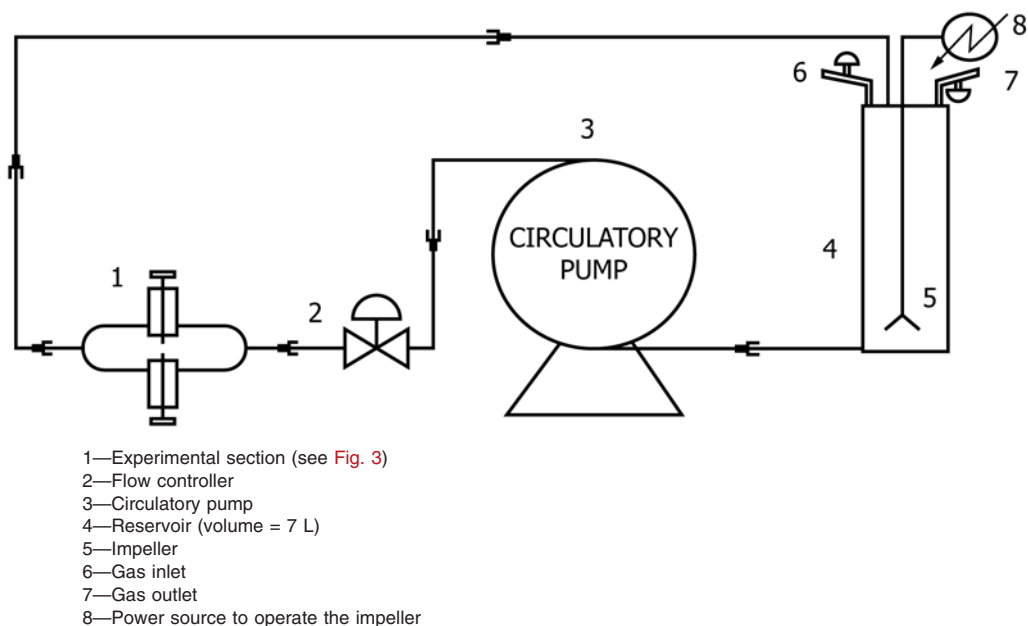


FIG. 2 Schematic Diagram of a Flow Loop of an EIP Apparatus

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 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 (H<sub>2</sub>S) and carbon dioxide (CO<sub>2</sub>). H<sub>2</sub>S and CO<sub>2</sub> are corrosive gases. H<sub>2</sub>S is poisonous and shall not be released to the atmosphere. The appropriate composition of gas can be obtained by mixing H<sub>2</sub>S, CO<sub>2</sub>, 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 H<sub>2</sub>S to the required partial pressure and left for 10 minutes. 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 CO<sub>2</sub> by opening the CO<sub>2</sub> gas cylinder at a pressure equal to the CO<sub>2</sub> + H<sub>2</sub>S partial pressure and left for 10 minutes. If there is a decrease in pressure, the autoclave is repressurized with CO<sub>2</sub> gas. This process is repeated until no further pressure drop is observed. Finally, the autoclave is pressurized with an inert gas (for example, methane) by opening the appropriate cylinder at the total gas pressure at which the experiments are intended to be carried out.

## 8. Laboratory Methodologies

### 8.1 Determination of Emulsion Type:

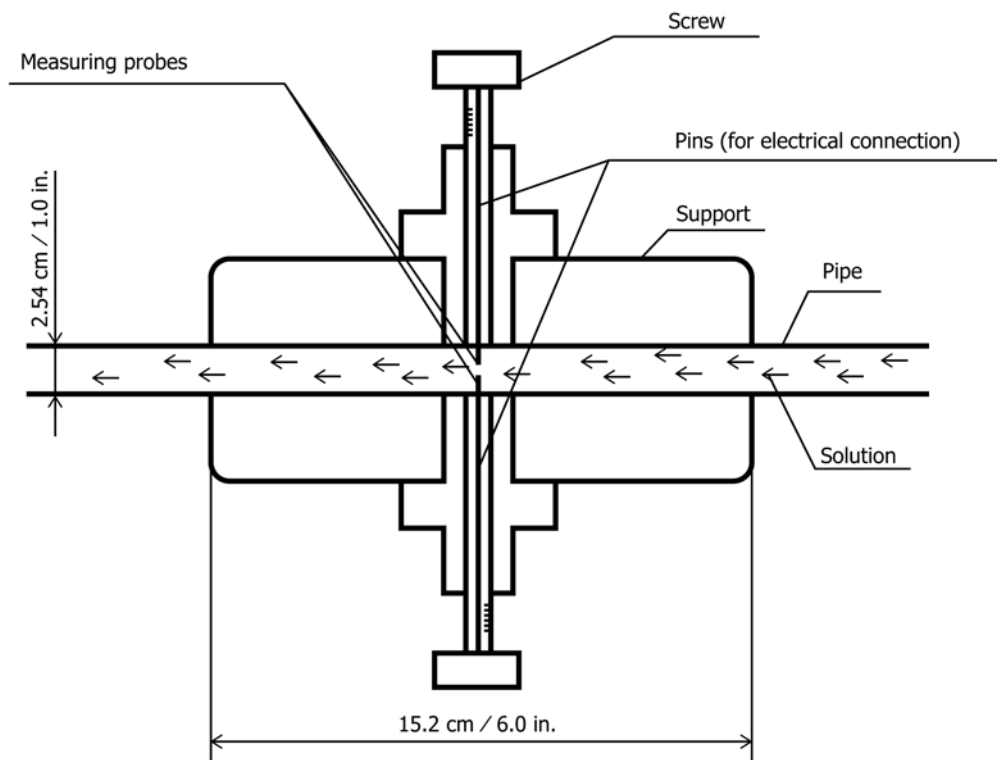


FIG. 3 Schematic Diagram of the Experimental Section of the EIP Apparatus

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 2.5 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 0.25 cm is suggested.

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 up to a speed of 50 cm/s.

8.1.5 The flow controller controls the velocity of the fluids through the experimental section. The flow controller should be capable of controlling fluids up to a linear velocity of 50 cm/s.

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

8.1.7 An appropriate volume of oil (typically 4 L) is poured into the reservoir and the entire EIP apparatus is deoxygenated using an inert gas (and presaturated with gases (typically CO<sub>2</sub>, H<sub>2</sub>S, and methane) when necessary), as described in Section 7. Note that proper deoxygenation of the apparatus may be critical for fire safety.

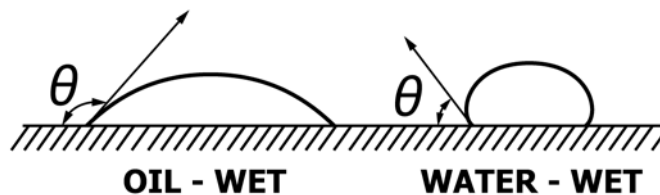
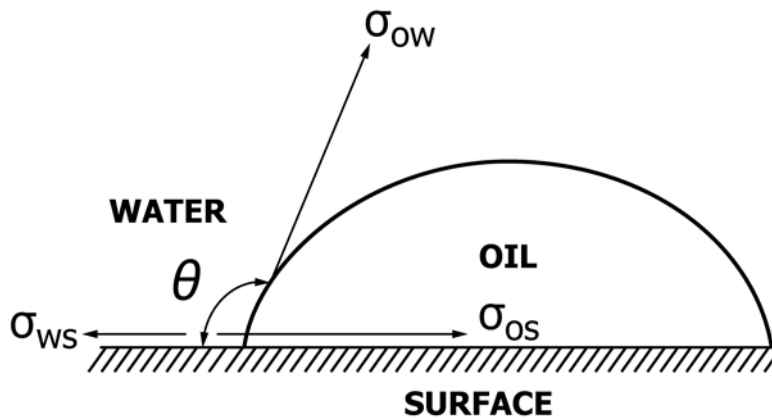
8.1.8 The impeller is started to thoroughly mix the fluids. The rotation speed of the impeller and the duration of rotation depend on the characteristics of oil. To create a homogenous mixture of water and crude oil, a minimum impeller speed of 1000 rpm and rotation for up to 30 minutes is sufficient.

8.1.9 Once a homogenous mixture of brine and crude oil is created in the reservoir, the circulating pump is started and the flow controller is adjusted. For most crude oil-water systems, a flow velocity of about 20 cm/s at the experimental section provides reproducible results.

8.1.10 The electrical resistance of the solution passing through the experimental section 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 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 5 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).

8.1.11 After measuring the electrical resistance of 100 % oil, the circulating pump and impeller are stopped. 400 mL oil (10 % of the original volume) is pumped out and replaced with 400 mL of 3 % NaCl brine and 8.1.8 to 8.1.10 are repeated. After measuring with 90 % oil the water and oil are allowed to separate and 400 mL of the oil is removed (10 % of the



$\theta$  = contact angle  
 $\sigma_{OS}$  = surface tensions of oil-steel interface  
 $\sigma_{OW}$  = surface tensions of oil-water interface  
 $\sigma_{WS}$  = surface tensions of water-steel interface

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

volume) to be replaced with 3 % NaCl solution. This process is repeated until 100 % water is reached or until it becomes impossible to remove oil without also removing water/oil emulsion. If the oil cannot be removed in 10 % aliquots then separate mixtures will need to be prepared and inserted in the apparatus.

NOTE 2—Procedures for converting the measured resistance to resistivity are described in Test Method D1125. Resistivity (in ohms-cm) is numerically the inverse of conductivity (in Siemens per cm).

8.1.12 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:

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,  $\sigma_{OS}$ ,  $\sigma_{OW}$ , and  $\sigma_{WS}$  are surface tensions of oil-steel, oil-water, and

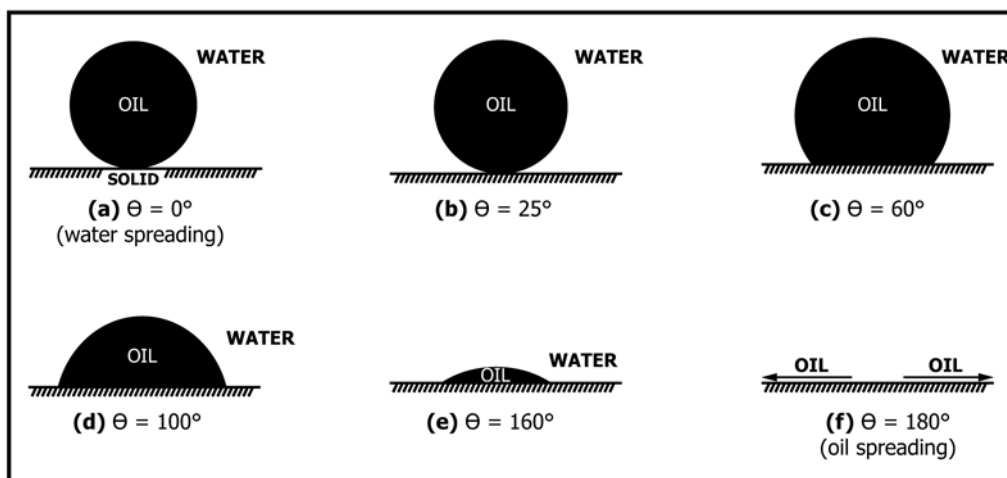


FIG. 5 Contact Angle Measurements through Water Phase (Exterior Contact Angle)

water-steel interfaces, respectively. In Figs. 4 and 5,  $\theta$  is the contact angle. If  $\sigma_{ws}$  is much larger than  $\sigma_{os}$ ,  $\theta$  will approach  $180^\circ$ , 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 oil droplet on the steel surface is taken. On a printed photograph, a horizontal line is drawn at the base of the droplet. At the point of contact of the droplet with the steel surface, two tangents to the curve are drawn at the two points of contact with the baseline. The two exterior angles between the base and the tangents are measured with a protractor. Alternatively, the tangent can be drawn using the tools in software.

8.2.1.7 The angle is measured exterior to the oil droplet on the metal surface; the surface is considered oil wet when the contact angle is more than  $120^\circ$ , mixed wet when the contact angle is between  $60$  and  $120^\circ$ , and water wet when the contact angle is less than  $60^\circ$  (Table 1, Figs. 4 and 5).

### Sequence #2

8.2.1.8 In Sequence #2, the steel surface is first in contact with oil, a drop of water is then added, and the contact angle is measured through the oil phase. Determining the contact angle through the oil phase with a dark oil background is difficult experimentally. Therefore, the surface is illuminated. Test Method D724 provides the procedure to measure contact angle using Sequence #2. 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 water droplet. The average of minimum and maximum contact angles should be determined and reported.

8.2.1.9 In Test Method D724, the interior angle is measured. Using interior angle (measured through the oil phase), the surface is considered oil wet when the contact angle is more than  $120^\circ$ , mixed wet when the contact angle is between  $60$  and

$120^\circ$ , and water wet when the contact angle is less than  $60^\circ$  (Table 1 and Test Method D724).

### 8.2.2 Spreading Methodology:

8.2.2.1 The schematic diagram of an apparatus to determine wettability by the spreading methodology under pipeline operating conditions is presented in Fig. 6. A measuring probe containing twenty one (21) measuring pins (Fig. 7) is placed at the bottom of the apparatus. The pins are electrically isolated from one another by an insulator material (PTFE is found to be suitable). Electrical connections to the pins are provided through the imbedded back of the pins. Typically the measurements are made first using (the innermost) A series of pins, followed by using (the middle) B series of pins, and finally using (the outermost) C series of pins. All measurements are made in reference to the central pin. Typical diameter of the central holding part of the apparatus is 36 mm and typical height is 12 mm. The top cover is fitted with a gas inlet and outlet and a plugged port for introduction of the test brine in 8.2.2.4. For elevated pressure experiments the apparatus requires a pressure rating sufficient for its use at room temperature, normal operating pressure is 690 kPa.

8.2.2.2 The apparatus is cleaned, leveled, and the measuring pins are polished before each experiment. The test crude is poured into the apparatus such that all 21 pins are covered and a minimum height of oil is present above the pins (4.5 mL). The apparatus is closed and sealed, then the headspace is purged to deaerate for 10 minutes (at a rate greater than one volume of the apparatus every 2 minutes). Excessive purging may evaporate light ends of the crude sample. The apparatus is then saturated (for an atmospheric pressure experiment) with appropriate test gases for 30 min or is pressurized (for an elevated pressure experiment) with the appropriate test gases. The apparatus is left undisturbed for 24 hours. Note that proper deoxygenation of the apparatus may be critical for fire safety.

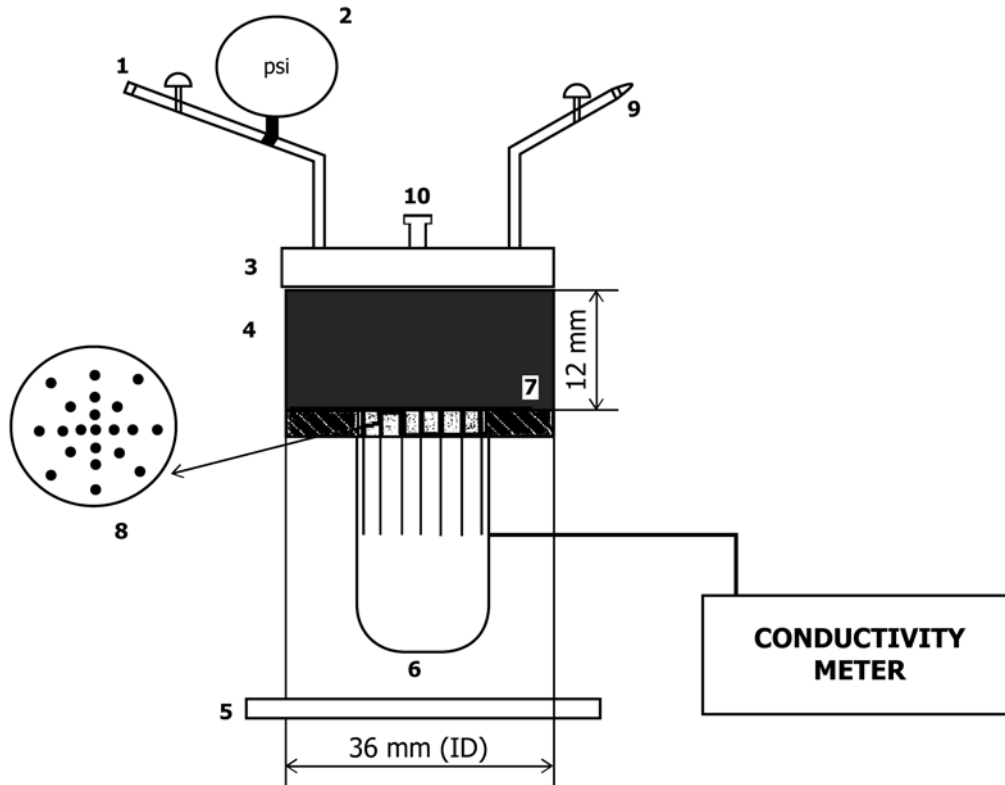
8.2.2.3 The electrical resistance (see Notes 3 and 4) between the pins is then measured with the central pin as one of the two measuring pins. Typically, the measurements are made first using (the innermost) A series of pins, followed by using (the

TABLE 1 Methods for Measuring and Reporting Contact Angles

First Phase Added onto the Steel Surface	Second Phase Added onto the Steel Surface	Angle Measured	Range of Contact Angle under Oil-Wet Condition	Range of Contact Angle under Water-Wet Condition	Range of Contact Angle under Mixed-Wet Condition
Water	Oil	Interior	0-60°	120-180°	60-120°
Water	Oil	Exterior <sup>A</sup>	120-180°	0-60°	60-120°
Oil	Water	Interior <sup>B</sup>	120-180°	0-60°	60-120°
Oil	Water	Exterior	0-60°	120-180°	60-120°

<sup>A</sup> In Fig. 4 and Fig. 5, this sequence is illustrated

<sup>B</sup> This sequence of measurement may require illumination (see Test Method D724 for details).



- 1—Gas inlet
- 2—Pressure gauge
- 3—Cover
- 4—Corpus
- 5—Support
- 6—Electrical connections to the conductivity meter
- 7—Test solution
- 8—Measuring pins (see Fig. 7 for details)
- 9—Gas outlet
- 10—Injection port

FIG. 6 Schematic Diagram of an Apparatus to Determine Wettability by Spreading

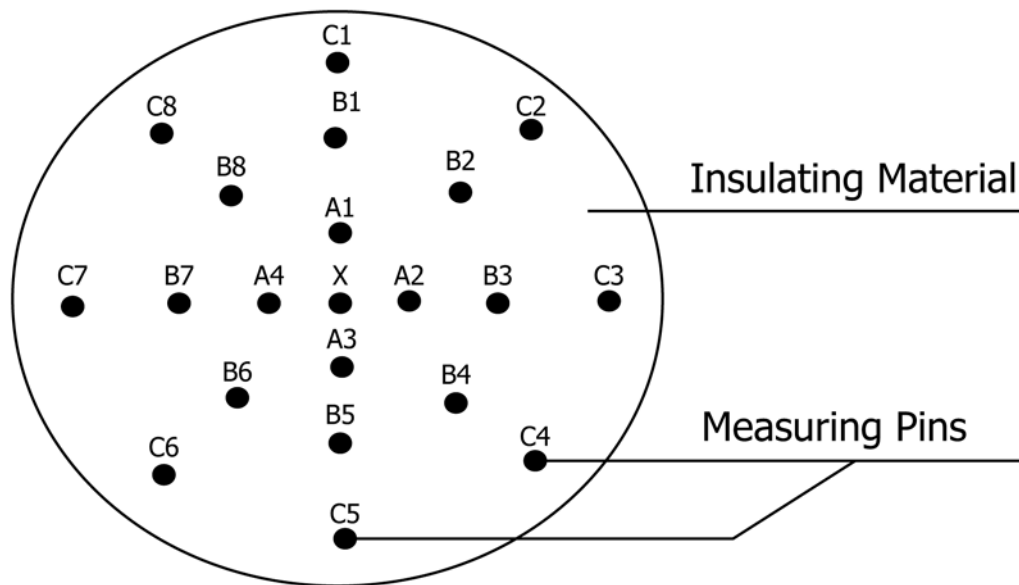
middle) B series of pins, and finally using (the outermost) C series of pins to the central reference pin. The resistance in all of the measurements should be higher than 200 KΩ. After recording data for all 20 pins the pressure is released.

NOTE 3—Although the word “resistance” is used in anticipation that a DMM (digital multimeter) is the most likely instrument to be used to measure inter-pin resistance, this guide does not exclude the use of conductivity meters (that measure siemens), or CMAS (Coupled Multi-Electrode Array Sensors) technologies (that measure current). The intent of the spreading methodology wettability test is to establish the number of pins within the test head that become wetted by water over the course of procedure 8.2.2.4.

NOTE 4—Low frequency AC impedance measurements (less than 100 Hz) can be used to minimize polarization or electrolysis of the measuring pins. DC resistance measurements may be used provided that polarization and electrolysis of the measuring pins is minimized. This may be achieved by restricting the duration of the measurement to just a few seconds, in conjunction with taking the average of two reversed polarity resistance measurements for each measuring pin-pair (that is, by changing the polarity of the DC ohm-meter).

8.2.2.4 The injection port in the lid of the apparatus is opened and 4.5 mL of deaerated test brine is injected so that the water to oil volume ratio is 1:1. The apparatus is resealed and repressurized, following the procedure described in 8.2.2.2.





Dimensions:  
 Pin diameter = 2.4 mm  
 Distances center to center:  
 X-A = 4.5 mm  
 X-B = 9.3 mm  
 X-C = 14.0 mm

FIG. 7 Schematic Diagram Indicating the Positions of Measurement Pins in the Wettability Apparatus (Spreading Method)

After 30 minutes of saturation (in the atmospheric pressure experiment) or 30 min of pressurization (in the elevated pressure experiment), the resistance between the pins is measured in accordance with procedures described in 8.2.2.3.

NOTE 5—For resistance measurements using the center pin as reference, it is essential that the center pin be wetted by the brine. This is typically accomplished by manufacturing the top cover of the apparatus with a brine injection port immediately ovetop and in close proximity to the center pin. Failure to wet the center pin with brine may result in an erroneous result of “0 pins conducting” even if other pins are water-wet.

8.2.2.5 The ability of the oil phase to continue wetting the pins in the presence of brine provides a measure of the crude oils ability to preferentially wet a steel surface. A low number (<5) of conducting pins (<200 kΩ) indicates that the surface is preferentially oil wetted, and a high number (>15) of conducting pins indicates that the surface is preferentially water wetted. Water wetted surfaces are more likely to experience corrosion.

8.2.2.6 “0 pins conducting” results should be validated by re-checking inter-pin resistances using the innermost “B” ring of pins as reference. If a conducting pin pair is found; re-measure all inter-pin resistances in a similar fashion to 8.2.2.3 using one of the two conducting pins as reference and report the number of pins conducting to that reference as per 8.2.2.5.

NOTE 6—For the accuracy of differentiating wettability of surfaces, the 200 kΩ resistance cut off point is sufficient. Procedures for converting the measured resistance to resistivity (and conductivity) are described in Test Method D1125.

NOTE 7—The resistance may be measured between any of the 21 pins against the rest of the 20 pins connected together in a coupling joint. The coupling joint will electrically connect all pins together except for the one

pin that is being measured.

### 8.3 Determination of the Effect of Crude Oil on the Corrosiveness of the Aqueous Phase:

8.3.1 Under water-wet conditions, the corrosivity of the aqueous phase may be altered by the dissolution of chemical components from the crude oil into the aqueous phase.

8.3.2 The effect of crude oil on the corrosiveness of the deaerated aqueous phase can be determined by two methods (8). The two methods consist of determining the corrosion rate on the test specimen either after the aqueous phase has been exposed to the crude or after the test specimen is pretreated with the crude oil.

8.3.2.1 In the first method the corrosion rate of steel in brine (typically 3 % NaCl) under standardized anaerobic conditions is established and then compared with the corrosion rate of steel in the same brine after it has been exposed to the crude oil being assessed. Methods described in Test Method D665, Practice G184, Practice G185, Test Method G202, and NACE TM0172 may be used to determine the corrosion rate. The corrosion rate obtained should be compared under the same experimental conditions. This method would involve partitioning of a water sample from the crude.

8.3.2.2 In the second method, the coupon is pretreated with crude oil and the experiment is conducted in the aqueous phase only (typically 3 % NaCl). Guide G170 provides procedure to pretreat the coupons or probes with oil. The corrosion rate of pretreated coupon is compared with that of an untreated coupon under the same test conditions.

8.3.3 Based on the comparison of corrosion rates in the aqueous phase, the crude oil may be classified as inhibitory, neutral, or corrosive (Fig. 1).

## 9. Report

9.1 All information and data shall be recorded as completely as possible.

9.2 The following checklist is a recommended guide for reporting important information.

### 9.3 Emulsion Inversion Point:

9.3.1 Volumes of oil and aqueous phases used at various stages during the experiments,

9.3.2 Rotating speed of the impeller in the reservoir,

9.3.3 Flow rate at the experimental chamber,

9.3.4 Percentage of the water cut at emulsion inversion point.

### 9.4 Wettability Measurement:

#### 9.4.1 Contact Angle Methodology:

9.4.1.1 Phase through which the contact angle was measured,

9.4.1.2 Method of measuring the contact angle (interior or exterior),

9.4.1.3 Contact angle, °,

9.4.1.4 Type of wettability.

#### 9.4.2 Spreading Methodology:

9.4.2.1 Volumes of oil and aqueous phase used,

9.4.2.2 Total pressure,

9.4.2.3 Partial pressures of acid gases (CO<sub>2</sub> and H<sub>2</sub>S),

9.4.2.4 Resistivity values at each of the 20 measurements,  
9.4.2.5 Number of measurements at which the resistivity is lower than 200 KΩ,

9.4.2.6 Type of wettability.

### 9.5 Corrosivity Measurement:

9.5.1 Reporting Section of Practices G31 and G184 provide a checklist for reporting corrosion data,

9.5.2 Standard used to determine the corrosion rate,

9.5.3 Method of simulating the effect of crude oil (by pretreating the sample or by conducting the experiment in brine that was partitioned from the crude oil),

9.5.4 Percentage of crude oil and aqueous phase (for experiments conducted in the presence of both oil and water),

9.5.5 Corrosion rates of carbon steel in aqueous phase and crude oil-aqueous phase mixture,

9.5.6 Corrosion rates of untreated and pretreated with crude oil carbon steel coupons in aqueous phase,

9.5.7 Type of crude: corrosive, neutral, inhibitive, or preventive.

## 10. Keywords

10.1 corrosivity; crude oil; emulsion; inhibitory oil; mixed-wet; oil-in-water emulsion; oil wet; water-in-oil emulsion; water-wet; wettability

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