



Standard Test Method for Evaluation of the Type and Viscoelastic Stability of Water-in-oil Mixtures Formed from Crude Oil and Petroleum Products Mixed with Water¹

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^{ε1} NOTE—The numbering in Section 3 was editorially corrected in May 2016.

1. Scope

1.1 This test method covers a procedure to determine the water-in-oil emulsification tendencies and stabilities in the laboratory. The results of this test method can provide oil behavior data for input into oil spill models.

1.2 This test method covers a specific method of determining emulsion tendencies and does not cover other procedures which may be applicable to determining emulsion tendencies.

1.3 The test results obtained using this test method are intended to provide baseline data for the behavior of oil and petroleum products at sea and input to oil spill models.

1.4 The test results obtained using this test method can be used directly to predict certain facets of oil spill behavior or as input to oil spill models.

1.5 The accuracy of the test method depends very much on the representative nature of the oil sample used. Certain oils can form a variety of water-in-oil types depending on their chemical contents at the moment a sample is taken. Other oils are relatively stable with respect to the type formed

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

1.7 *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. Summary of Test Method

2.1 Oil is mixed with 33‰ (3.3%) saline water for 12 h in a standard rotating apparatus. The resulting mixture is characterized after this shaking period.

¹ This test method is under the jurisdiction of ASTM Committee F20 on Hazardous Substances and Oil Spill Response and is the direct responsibility of Subcommittee F20.16 on Surveillance and Tracking.

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2.2 The resulting mixture as created in step 2.1, is characterized visually, by measuring water content and by rheological measurements. The mixture is then classified as a stable, meso-stable, unstable emulsion or an entrained water mixture. Each of these four types of mixtures has different characteristics affecting the oils behavior once spilled.

3. Terminology

3.1 Definitions:

3.1.1 *complex modulus*—One of the results of viscoelastic measurement, a measure of the resistance of a viscoelastic substance to flow under an applied dynamic stress, combining both the non-reversible (viscous) flow of the test substance and the reversible (elastic) deformation of the test substance.

3.1.2 *emulsion*—A type of colloid, specifically, a dispersion of small droplets of one liquid in another.

3.1.2.1 *meso-stable emulsions*—Emulsions which lack one or more of the compositional factors necessary to form a stable emulsion, but which are sufficiently stable to persist for short periods, typically a few days.

3.1.2.2 *stable emulsions*—Emulsions that persist indefinitely, consisting of fine droplets with a rigid film interface which resists coalescence.

3.1.2.3 *unstable emulsions*—Mixtures of water and oil which resolve rapidly into two phases, usually within a few minutes to hours. There may be residual water remaining in low percentages.

3.1.2.4 *water-in-oil emulsion*—An emulsion consisting of a continuous phase of oil containing a dispersed phase of water.

3.1.3 *entrained water*—This is not an emulsion but a mechanical mixture of oil and water which has not separated due to the physical properties of the water and oil.

3.1.3.1 *Discussion*—Typically, the oil and water have similar densities and the oil phase has a high viscosity.

3.1.4 *rag*—The remnant of a broken water-in-oil emulsion.

3.1.4.1 *Discussion*—Rag will not reform an emulsion. Rag is thought to consist of tightly bound asphaltenes and resins.

3.1.5 *stability index*—An index describing the stability of an emulsion.

3.1.5.1 *Discussion*—In this standard, it is calculated using data derived from rheological measurements.

3.1.6 *storage modulus*—One of the results of viscoelastic measurement, a measure of the elastic (reversible) deformation behavior of a viscoelastic substance under an applied dynamic stress.

4. Significance and Use

4.1 A standard test is necessary to establish a behavior pattern for spilled oils or petroleum products at different oil weathering stages.

4.2 Water-in-oil mixtures vary with oil type and oil conditions such as weathering. Results from this test method form a baseline, and usually are a measure of behavior at sea.

4.3 This test has been developed over many years using standardized equipment, test procedures, and to overcome difficulties noted in other test procedures.

4.4 This test should be performed at the temperatures and degrees of weathering corresponding to the spill conditions of interest.

5. Interferences and Sources of Error

5.1 Interferences can be caused by contaminants, particularly residual oil or surfactants on labware, and other sample handling supplies and apparatus that lead to irregular results. All glassware must be thoroughly cleaned. The cleaning process includes rinsing with dichloromethane to remove the oil, followed by rinsing three times each with tap water, purified water (reverse osmosis), and acetone. Once cleaned, precautions must be taken to minimize contact of the labware with contaminants to prevent interferences.

5.2 Emulsion formation is somewhat susceptible to energy levels. The rotational speed of the shaker should be checked with a tachometer every day. The specified direction of rotation should be followed (vessel cap leads rotation on start-up).

5.3 The specified fill volumes of the test vessels must be observed as the energy level varies with the amount of fill.

5.4 Temperature is a factor in emulsification, so it is important that all components (salt water, pre-mix, and temperature controlled chamber) are stable at 15°C or the selected test temperature, before starting.

5.5 The handling of the samples after the mixtures are formed is important. Care must be taken to take a representative sample. Excess water should be avoided when sampling.

5.6 Since the test results may be affected by salinity, thorough mixing of the salt water is required. Salinity should be verified using a salinity meter before use.

5.7 Oils sources, especially crude oil sources, vary much with production time and conditions. Oil samples must be treated as unique and are not necessarily representative of the source. Some oils are near the threshold of two different water-in-oil types. Depending on the actual conditions under

which this oil was sampled, different results may occur. Other oils are not as sensitive.

5.8 Additives introduced in the production and transport of oils can change their emulsification behavior. Some oils have added asphaltene suspenders or emulsion inhibitors. These may significantly alter the outcome of this test. Information on the oil treatment should be obtained before making the test.

6. Apparatus

6.1 2.2-litre fluorinated HDPE wide-mouth bottles, approximately 24 cm in height and 6 cm in radius (Nalgene or equivalent), used as the test vessel. These vessels match the shaker as described below.

6.2 Variable speed end-over-end rotary mixer capable of maintaining 55 RPM, with a radius of rotation of 15 cm (7.5 cm from center of vessel) (Associated Design or equivalent).²

6.3 *Automated Karl Fischer titration analyser*; This device is used to measure the water content of the resulting water-in-oil mixture.

6.4 *Rheometer*, with a 35 mm parallel-plate geometry, capable of functioning in forced-oscillation mode. This device is used to measure the rheological properties of the resulting water-in-oil mixture.

6.5 Circulating bath with a range from 0 to 25 °C (±0.1).

6.6 *Salinometer or water quality meter*, SensIon 745 or equivalent.

6.7 Oil mixing devices including a shaker for mixing the small samples prior to use and devices to mix the oil contained in drums.

6.8 The following is a list of other necessary supplies. Equivalent supplies are acceptable.

6.8.1 Disposable 30- and 1-mL plastic syringes,

6.8.2 20-L plastic carboy, stirring plate and stir bar.

6.8.3 Spatulas and wide-mouth bottles for sample handling and storage,

7. Reagents³

7.1 *Reagents*—Water purified by reverse osmosis or equivalent means is used for the test water. Fine granular sodium chloride or table salt, non-iodized, is used for making the salt water. The brine solution of 33‰ (3.3%) NaCl prepared from salt and purified water, is stored in a 20-L carboy at ambient temperatures until needed. Fresh water may also be used for the test to mimic non-saline conditions.

² These devices are described in EPA standards for use in extraction tests: EPA Method 1310 Extraction Procedure (EP) Toxicity Test Method And Structural Integrity Test, EPA Method 1311 Toxicity Characteristic Leaching Procedure (TCLP), and EPA 1312 Synthetic Precipitation Leaching Procedure (SPLP). Environmental Protection Agency 1200 Pennsylvania Avenue, N.W. Washington, DC 20460. <http://www3.epa.gov/>

³ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For Suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

7.1.1 *Oil*—is used as received, but is shaken for 30 minutes prior to use and is maintained at the test temperature of 15°C.

7.1.2 *Karl Fischer reagent*, 5 mg/mL H₂O, single component, pyridine free.

7.1.3 *Toluene*, methanol and chloroform, reagent grade, as solvent for the Karl-Fischer titration.

7.1.4 *Dichloromethane and acetone*, as clean-up solvents, and RO purified water

8. Procedure

8.1 *Crude Oil Sample Collection and Storage*—The bulk oil is mechanically mixed for 1 to 2 h prior to obtaining a working sample. Working samples are stored in 2-L high-density polyethylene bottles with polypropylene screw closures. The working sample is mechanically shaken for 30 min at 15°C or the selected operating temperature prior to removing a sub-sample for testing. When not in use, all samples should be stored in a temperature controlled room at 5°C.

8.2 *Generating the water-in-oil mixture*—In summary, water-in-oil mixtures are formed in 2.2-litre fluorinated vessels on an end-over-end rotary mixer (Associated Design, VA or equivalent) at a rotational speed of 55 RPM.

8.2.1 Each 2.2 L mixing vessel is filled with 600 mL of water, either salt or fresh water as selected for the test. The water should be at the test temperature at the time of addition.

8.2.2 Oil is introduced at a ratio of 1:20 oil:water by adding 30 mL of the test oil to the vessel.

8.2.3 The vessels are sealed and mounted in the rotary mixer such that the cap of each mixing vessel leads the direction of rotation to maximize the turbulence of mixing.

8.2.4 The rotary mixer and vessels are held at 15°C or the selected operating temperature in a temperature controlled cold room for the duration of the experiment. This temperature (15°C) or the selected operating temperature is the standard temperature for measuring oil properties. If the predicted temperatures the time of a spill are different the test should be performed at those predicted temperatures as well. Testing at different temperatures necessitate that the entire study be performed at the new chosen temperature.

8.2.5 The vessels and their contents are allowed to stand for 4 h to thermally equilibrate.

8.2.6 The mixing is initiated using an electronic timer switch. The vessels are mixed continuously for 12 h at a rotation speed of 55 RPM.

8.2.7 After 12 h mixing, the water-in-oil mixtures are collected from the vessels and transferred to appropriately sized glass wide-mouthed jars for observation and analysis.

8.2.8 The emulsions are stored in the cold room at 15°C or the selected operating temperature for one week, followed by additional observation and analysis.

8.2.9 Each oil is tested in triplicate.

8.2.10 The visual observations, viscosity, viscoelastic properties and water content of the starting oil and the resulting water-in-oil mixture are measured for comparison as outlined in the procedures described below.

8.3 *Sampling and analysis*—A small sample is withdrawn from each wide-mouth jar for further analysis as described below. Analysis is performed twice, immediately after mixing and after one week.

8.4 *Sample Analysis for Water Content*—Water content is measured using a Metrohm 784 KFP Titrino Karl Fischer volumetric titrator (or equivalent) and Metrohm 703 Ti Stand (or equivalent). The titre reagent is Aquastar Comp 5 (or equivalent) and the solvent is 1:1:2 methanol:chloroform:toluene. A set of three measurements are made for each sample.

8.5 *Viscosity Measurement of oils*—Dynamic viscosities of the oils are measured at 15°C using a VT550 with viscometer using concentric cylinder geometry. The appropriate cup and spindle combination is selected on the basis of the valid viscosity range for each type, as provided by the manufacturer. The highest suitable shear rate is selected from the manufacturer's guidance manual. The measurement protocol follows a one minute ramp up to the target shear rate, holding for five minutes, then ramping back down to zero to evaluate thixotropy. The reported value for the oil is the average viscosity over the five minutes hold period. Triplicates are performed for each sample.

8.6 *Viscoelastic Measurements of the water-in-oil mixtures*—The viscoelastic properties are determined on a ThermoHaake RheoStress RS6000 rheometer with RheoWin software (or equivalent) using 35 mm plate-plate geometry in forced oscillation mode. The sample stage height is set for a 2.00-mm gap. The sample is measured at 15°C in forced oscillation mode using a stress sweep from 0.100 to 10.0 Pa at a frequency of one reciprocal second. Values of the complex modulus, storage modulus, loss modulus, and tan (δ) are obtained in the linear viscoelastic range (stress independent region of the stress response curve). Samples are measured in duplicate.

8.7 *Data recording of the measurements*—The visual observations and the data on the water content and the viscoelastic measurements are recorded for the water-in-oil mixtures on the test day following the 12-h mixing and again after one week. The water content and viscosity measurements are taken of the starting oil. All values are recorded to 3-significant-figure accuracy. For the viscoelastic measurements, it is necessary to record the complex modulus (mPa), storage modulus (mPa). Viscosity modulus (mPa) and tan delta (V/E). The water content is measured as recorded as percentage water in oil by weight. Three oil samples are taken for the tests, the water content and viscosity are measured in triplicate and the viscoelastic measurements are taken in duplicate.

8.8 Calibration Standards and Methods:

8.8.1 The mixing apparatus is checked daily with a tachometer to ensure a rotational rate of 55 RPM \pm 2 RPM.

8.8.2 The salinity of the salt solution is verified using a water quality meter (SensIon 745 or equivalent), 3.3%0.05 degrees salinity or ppt.

8.8.3 The rheometer calibration is checked with certified viscosity standards. If the rheometer reading is out of the manufacturer's specification (5% mPa.s of certified value), the instrument is to be serviced by certified technicians.

8.8.4 The Karl-Fischer titrant is calibrated following each addition to the titrant reservoir following the manufacturer’s protocol using purified water. The relative standard deviation is acceptable if less than 1%.

8.8.5 The Karl-Fischer titration apparatus is checked daily using purified Type 1 water (Ultrapure water as defined by laboratory water standards) in Sample Mode. A response of 100% ± 1% water (by weight) is acceptable.

8.9 *Cleaning Labware*—A thorough cleaning program is undertaken throughout the procedure to reduce possible cross-contamination and accumulation of contaminants on the labware. Labware is thoroughly rinsed with, DCM, tap and purified (RO) water, between each experimental run. Glassware is dried at 180°C while plastic ware is air dried. Rheometer spindles are cleaned with DCM and acetone.

9. Calculation and Reporting

9.1 The values of viscosity, water content and the values from the viscoelastic measurements are evaluated. The measurements, and repeatabilities are summarized in **Table 1**. Three oil samples are taken for the tests, the water content and viscosity or the starting oil are measured in triplicate. The viscoelastic measurements on the resulting mixture are taken in duplicate.

9.1.1 The values for the replicate sets within each measurement on the oil and on the resulting mixtures should agree within the percentage specified:

Water content - ± 2%

Viscosity - ± 5%

Viscoelasticity measurements - ± 15%

A sample measurement is valid if it is within the specified tolerance compared with the average values of other individual measurements.

Water content - ± 5%

Viscoelasticity measurements - ± 30%

9.2 The stability is calculated using:

$$Stability = \ln \left[\left(\frac{\frac{complex\ modulus}{starting\ oil\ viscosity} \times \frac{storage\ modulus}{starting\ oil\ viscosity}}{10000} \right)^2 \right] \quad (1)$$

where:

complex and storage modulus = mPa

Starting oil viscosity = mPa.s, and

ln = is the natural logarithm

9.3 The data taken are compared to values in **Table 2** to classify the oil type.

9.4 Data reports should include the data in three significant figures, and the average of these three points. Presentation of data should also be made in accordance with **Table 2** showing how the oil was classified as either one of the four water-in-oil mixtures. To capture oil changes due to weathering, it is advised to perform this test with several (three is suggested) weathered samples of the oil in addition to the fresh oil.

10. Keywords

10.1 emulsions; emulsion stability; water-in-oil emulsions; water-in-oil mixtures; oil spills; entrained water

TABLE 1 Measurement Table

Target	Measurement	Timing	Repetitions	Target
Starting oil	Viscosity	before mixing	3	± 5%
	Water content	before mixing	3	± 2%
Mixing experiment		after mixing	3	
Water-in-oil Mixture	Viscoelastic Measurement (Complex Modulus and Storage Modulus)		2	± 15%
	Water content		3	± 2%
	Viscoelastic Measurement (Complex Modulus and Storage Modulus)	after one week	2	± 15%
	Water content		3	± 2%
	Comparison between 3 mixing runs			
	Water content			± 5%
	Viscoelastic Measurement			± 15%

TABLE 2 Classification of Water-in-Oil Mixtures

	Type of Mixture			
	Does not form or Unstable ^A	Entrained ^A	Meso-Stable	Stable
Before mixing				
Density	<0.96 or >1.0 and	>0.96 and <1.0		
viscosity	<50 or >200,000	>2300 <200,000	50 to 2300	50 to 2300
After Mixing - on day of test				
Appearance				
Color	black	black	red	red
Viscosity appearance	as before mixing	as before mixing	viscous liquid	viscous to semi-solid
Measurements				
Water Content	~ 5%	~20-50%	~55-70%	~70-85%
Viscosity	as before mixing	~ 2 × original	~1.5 X original	~ 1000 X original
Stability	~-20 to -4	~-20 to 3	-10 to 5	4 to 30
After Mixing - one week later				
Appearance				
Color	black	black	broken, black separated	red
Viscosity appearance	as before mixing	as before mixing		viscous solid
Measurements				
Water Content	~ 5%	~10-20%	~10-20%	~70-85%
Viscosity	as before mixing	~ 2 X original	~ 7 X original	~ 400 X original
Stability	~-20 to -4	~-10 to 3	-10 to 4	4 to 30

^A Overlap in stability between the water-in-oil types can be reduced by using the density and viscosity criteria noted in the first line of Table 2 along with the measured stability. The criteria are applied first to the “Does not form”, and “Entrained” types. The density criteria is applied first and then the viscosity criteria. The “Meso-stable” and “Stable” types are largely discriminated by the use of the stability value.

APPENDIX

X1. BACKGROUND ON THE FORMATION OF WATER-IN-OIL EMULSIONS

(Nonmandatory Information)

X1.1 Background on the Formation of Water-in-oil Emulsions

X1.1.1 Water-in-oil emulsions sometimes form after oil products are spilled. These emulsions, often called “chocolate mousse” or “mousse” by oil spill workers, can make the cleanup of oil spills very difficult. (1)⁴ When water-in-oil emulsions form, the physical properties of oil changes dramatically. As an example, stable emulsions contain from 60 to 80% water, thus expanding the spilled material from two (2) to five (5) times the original volume. Most importantly, the viscosity of the oil typically changes from a few hundred mPa.s to about 100 000 mPa.s, an increase by a factor of 500 to 1000. A liquid product is changed into a heavy, semi-solid material. These emulsions are difficult to recover with ordinary spill recovery equipment.

⁴ The boldface numbers in parentheses refer to a list of references at the end of this standard.

X1.1.2 Four clearly-defined water-in-oil types are formed by crude oil when mixed with water. (2-4) These are summarized in Table X1.1. This was shown by water resolution over time, by a number of rheological measurements, and by the water-in-oil product’s visual appearance, both on the day of formation and one week later. Some emulsions have been observed for over a period of years, with the same results. The types are named stable water-in-oil emulsions, mesostable water-in-oil emulsions, entrained water, and unstable water-in-oil types. The differences among the four types are quite large.

X1.1.3 Stable emulsions are reddish-brown semi-solid substances with an average water content of about 70-80% on the day of formation and about the same one week later.(2). Stable emulsions remain stable for at least 4 weeks under laboratory conditions. All of the stable emulsions studied in the laboratory remained so for at least one year. The viscosity increase following formation averages 400 to 800 times the original viscosity and one week later averages 1000 times the original

TABLE X1.1 Four Types of Water-in-oil Mixtures

Type	Starting Oil Characteristics			After Water Uptake			
	Viscosity mPa.s	Asphaltenes %	Density g/mL	Color	Typical Lifetime	Typical Viscosity Increase ^A	Typical Water Uptake
Unstable or does not uptake water	<50 or >200,00	<2 or >20	<0.96 or >1.00	same as oi		1	—
Meso-stable	50 to 2300	5 to 12	0.87 to 0.96	reddish until broken	3 to 6 days	7	55 to 70%
Stable	50 to 2300	3 to 8	0.85 to 0.96	reddish	months	800 to 1000	70 to 85%
Entrained	2300 to 200,000	10 to 20	0.96 to 1.00	as oil	2 to 10 days	2 to 5	20 to 60%

^A Viscosity increase starting oil (multiplier).

viscosity. The average properties of the starting oil required to form a stable emulsion are: density-0.9 g/mL; viscosity-300 mPa.s; resin content-9%; asphaltene content-5 %; and asphaltene-to-resin ratio-0.6.

X1.1.4 Meso-stable water-in-oil emulsions are reddish-brown viscous liquids with an average water content of 60-65% on the first day of formation and less than 30% one week later. (2) Meso-stable emulsions generally break down to about 20% water content within one week. The viscosity increases over the initial viscosity on the day of formation averages a factor of 7 and one week later averages 5. The average properties of the starting oil required to form a meso-stable emulsion are: density-0.9 g/mL; viscosity-1300 mPa.s; resin content-16%; and asphaltene content-8%; asphaltene-to-resin ratio-0.5. The greatest difference between the starting oils for stable and mesostable emulsions are the ratio of viscosity increases (stable 400, first day and 1000 in one week; mesostable 7, first day and 5 in one week) and resin content (stable - 9%; mesostable - 16%).

X1.1.5 Entrained water-in-oil types are black viscous liquids with an average water content of 40-50% on the first day of formation and less than 28% one week later. (2) The viscosity increase over the day of formation averages a multiple of two and one week later still averages two. The average properties of the starting oil required to form entrained water are: density-0.97 g/mL; viscosity-60,000 mPa.s; resin content-18%; asphaltene content-12%; and asphaltene-to-resin ratio-0.75. The greatest differences between the starting oils for entrained water-in-oil compared to stable and mesostable emulsions are the viscosity of the starting oil (entrained starting oil averages 60,000 mPa.s compared to 200 mPa.s for stable emulsions and 1300 mPa.s for mesostable emulsions) and the ratio of viscosity increase (entrained = 2, first day and 2 in one week; stable 400 to 800, first day and 1000 in one week; mesostable 7, first day and 5 in one week). Entrained water-in-oil types appear to be applicable to viscous oils and petroleum products, but not extremely viscous products.

X1.1.6 Unstable water-in-oil emulsion types are characterized by the fact that the oil-water mixture formed during turbulent mixing tends to be an oil-in-water emulsion rather than water-in-oil, and quickly separates once the energy of mixing is removed leaving very little residual water in the oil layer. The starting oil viscosities are very low, and include the group of light fuels such as gasoline and diesel fuel. Oils that do not form an oil-water mixture by this test are heavy, viscous oil products such as heavy residual oils. These oils are too viscous to entrain water in this test, but may form an entrained water state under different mixing conditions.

X1.1.7 Some researchers reported that asphaltenes were a major factor in water-in-oil emulsions more than 40 years ago. (5) The specific roles of asphaltenes in emulsions were not defined until recently. (3) Currently, the basics of water-in-oil emulsification are now understood to a much better degree.(3-7) The fundamental process is that water-in-oil emulsions are stabilized by the formation of high-strength visco-elastic asphaltene films around water droplets in oil. Resins could also form emulsions, but resins do not form stable

emulsions, and actually aid in asphaltene emulsion stability by acting as asphaltene solvents and by providing temporary stability during the time of the slow asphaltene migration. Overall, scientists have found that oil composition is the key factor in water-in-oil emulsion formation including the amounts and types of asphaltene, resin, and saturate contents.

X1.1.8 Asphaltenes represent a very broad category of substances.(8) Some scientists separate resins and asphaltenes into two classes: binding and non-binding.(9) They found that the binding component formed emulsions, whereas the non-binding did not. Several scientists found that rag, the residual of a broken emulsion, contains high proportions of asphaltenes.(10) They noted that water-in-oil emulsions, solids-in-oil dispersions, oil-in-oil dispersions and oil-in-water-in-oil multiple emulsions coexist in rag.

X1.1.9 Several researchers studied the role of resins in water-in-oil formation.(2, 11) They noted that the main role appears to be solvation of the asphaltenes in the oil solution. Research has shown that the addition of resins at ratios of 1:2(asphaltene:resin) could increase the stability of the water-in-oil emulsions by as much as twice as that without the resins.(11) Others have noted that resins and asphaltenes are somehow correlated in emulsion stability. Some researchers note that with increasing asphaltene:resin ratio, the emulsions in well heads were more stable.(12) The interfacial properties of asphaltenes in several crude oils were studied.(13) Asphaltenes were shown to be the agent responsible for stabilizing the crude oils tested, however the resins were also noted as being important. It was noted that resins can determine whether asphaltenes stabilize or destabilize emulsions depending on the type of resins and asphaltenes.(14)

X1.1.10 The data suggest that the water-in-oil types are stabilized by both asphaltenes and resins, but for greater stability, resin content should exceed the asphaltene content slightly.(2) However, excess resin content (A/R > about 0.6) apparently destabilizes the emulsion. This does not consider the question of different types of asphaltenes or resins. A high asphaltene content (typically > 10%) increases the viscosity of the oil such that a stable emulsion will not form. Viscous oils will only uptake water as entrained water and will slowly lose much of this water over a period of about one week. Viscous oils (typically >2000 mPa.s) will not form stable or meso-stable emulsions. Oils of low viscosity or without significant amounts of asphaltenes and resins have low stability and will retain less than about 6% water. Oils of very high viscosity (typically > 10,000 mPa.s) will also not form any of these water-in-oil types in this test. This is probably due to the inability of water droplets to penetrate the oil mass.

X1.1.11 The different factors involved in the stabilization of water-in-oil types dictate that one simple equation is not adequate to predict formation. It is now known that emulsion formation is a result of surfactant-like action of the polar asphaltene and resin compounds. Emulsions begin to form when there is sufficient sea energy and these emulsions are stabilized when the required chemical and viscosity conditions are met. While resins and asphaltenes are similar compounds that both behave like surfactants when they are not in solution,

asphaltenes form much more stable emulsions. Further, as pointed out above, three different water-in-oil types are formed, depending on the oil type and its composition. Some oils do not form any water-in-oil types or break down as soon as mixing energy is removed, and both these are stated to be a fourth type. Several new models for the prediction of water-in-oil emulsion stability have been developed to predict the formation of emulsions.(15-18) These models used empirical data to predict the formation of emulsions using the physical and chemical properties of oil as input.

X1.1.12 Most crude oils and petroleum products require weathering (evaporation) before they will form any water-in-oil type.(4) The weathering is necessary to increase the

viscosity and the asphaltene/resin content to the point where a water-in-oil type is possible. Weathering to a different degree can result in different water-in-oil types for the same starting oil, however water-in-oil types will not change once formed.

X1.1.13 The effect of temperature on water-in-oil type has been studied.(4) Temperature has a variable effect on the formation of water-in-oil types and depends largely on the specific oil studied. Some oils do not show a significant effect of temperature on water-in-oil formation, while others do. It has been noted that some oils will form more stable water-in-oil types at lower temperatures and that higher temperatures may destabilize these same types. Testing at the predicted spill temperatures and conditions is recommended.

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