INTERNATIONAL

Designation: G208 − 12 (Reapproved 2020)

Standard Practice for Evaluating and Qualifying Oilfield and Refinery Corrosion Inhibitors Using Jet Impingement Apparatus[1]

This standard is issued under the fixed designation G208; 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 practice covers a generally accepted procedure to use the jet impingement (JI) apparatus for evaluating corrosion inhibitors for oilfield and refinery applications in defined flow conditions.

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

1.3 *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.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization 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]

D1141 Practice for the Preparation of Substitute Ocean Water
D1193 Specification for Reagent Water
D4410 Terminology for Fluvial Sediment
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements
G16 Guide for Applying Statistics to Analysis of Corrosion Data
G31 Guide for Laboratory Immersion Corrosion Testing of Metals
G46 Guide for Examination and Evaluation of Pitting Corrosion
G59 Test Method for Conducting Potentiodynamic Polarization Resistance Measurements
G96 Guide for Online Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)
G102 Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements
G106 Practice for Verification of Algorithm and Equipment for Electrochemical Impedance Measurements
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

3. Terminology

3.1 The terminology used herein shall be in accordance with Terminology D4410, Guide G170, and Terminology G193.

4. Summary of Practice

4.1 This practice provides a method for evaluating corrosion inhibitor efficiency in jet impingement (JI) apparatus. The method uses a well-defined impinging jet set up and mass loss or electrochemical techniques to measure corrosion rates. Measurements are made using three different experimental designs and at several flow rates to evaluate the inhibitor performance under increasingly severe hydrodynamic conditions.

5. Significance and Use

5.1 Selection of corrosion inhibitor for oilfield and refinery applications involves qualification of corrosion inhibitors in the laboratory (see Guide G170). Field conditions should be simulated in the laboratory in a fast and cost-effective manner.

[1] This practice 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.

Current edition approved Nov. 1, 2020. Published November 2020. Originally approved in 2012. Last previous edition approved in 2016 as G208 – 12 (2016). DOI: 10.1520/G0208-12R20.

[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.

TABLE 1 Parameters to be Reported Along with Test Results

Parameter	Units	Remarks
Solution chemistry		
Material chemistry		
Solution density		
Solution viscosity		
Temperature	C or F or K	
Pressure	psi or kPa	For elevated pressure experiments
Jet velocity	m/s or cm/s or inch/s	
Specimen type	ring or disc	
Disc diameter	mm or cm or m	For disc electrodes only
ring diameter (inner)	mm or cm or m	For ring electrodes only
ring diameter (outer)	mm or cm or m	For ring electrodes only
radial distance	mm or cm or m	
Distance between jet and the nozzle	mm or cm or m	
Rotation speed	RPM	
Electrode diameter or radius	mm or cm or m	
Volume of container	cm^3	
Volume of solution	cm^3	
Tafel constants, anodic, cathodic	For electrochemical measurements	
Description of counter electrode (size, shape, and distance from the working electrode)	For electrochemical measurements	
Initial mass	mg or g	For mass loss measurements
Final mass	mg or g	For mass loss measurements
Corrosion rate in absence of inhibitor	mpy or mm/yr	
Inhibitor efficiency, at each inhibitor concentration	%	
Number of specimens		
Volume of solution/surface area of the electrode	cm	
Inhibitor type	continuous or batch	
Inhibitor concentration	ppm or vol/vol or mass/volume or mass/mass	
Description of EIS model	Provide the model and elements (for electrochemical measurements)	
Solution conductivity	Siemens	For electrochemical measurements
Presence of oil	yes or no	
If oil is present, volume of oil	cm^3	
Duration of experiments	Minutes, hour, day	
Type of reference electrode		For electrochemical measurements
Number of specimens		

5.2 Oilfield and refinery corrosion inhibitors should provide protection over a range of flow conditions from stagnant to that found during typical production conditions. The inhibitors are not equally effective over all flow conditions, so it is important to determine the flow conditions in which they are effective.

5.3 Severity of hydrodynamic conditions depends on the type of laboratory methodology. Typically, rotating cylinder electrode is effective up to 20 Pa of wall shear stress, rotating cage (RC) is effective between 20 and 200 Pa of wall shear stress, and jet impingement (JI) is effective at wall shear stress above 200 Pa (**1**)[3] of wall shear stress.

5.4 The JI test system is relatively inexpensive and uses simple flat specimens.

5.5 In this practice, a general procedure is presented to obtain reproducible results using JI simulating the effects of different types of coupon materials; inhibitor concentrations; oil, gas, and brine compositions; temperature; pressure; and flow. Erosive effects predominate when the flow rate is very high (typically above 500 Pa) or when sand or solid particles are present; however, this practice does not cover the erosive effects.

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

6. Apparatus

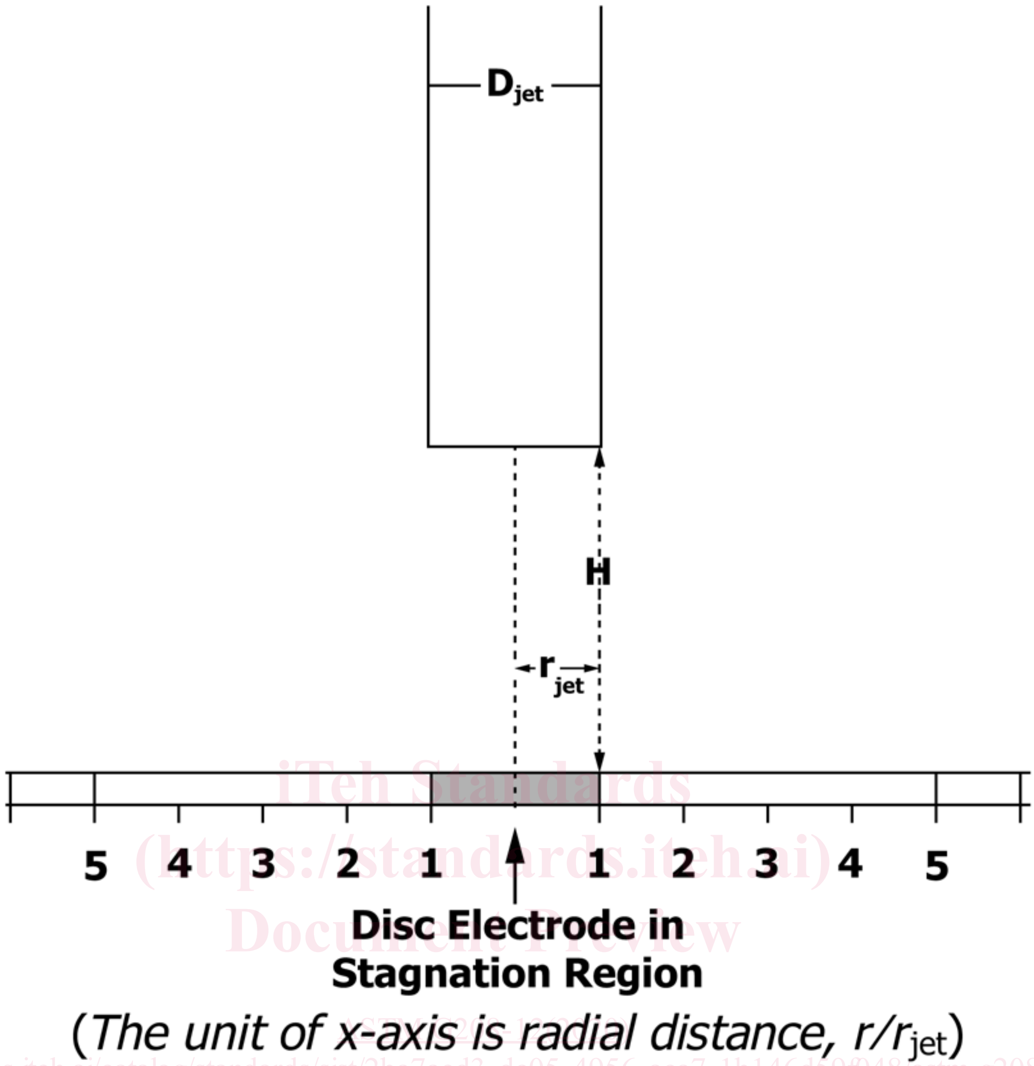
6.1 The actual hydrodynamic conditions in the tests must be known to enable comparison of results with those obtained in other tests or predictions of inhibitor performance in practical operating systems. Hydrodynamic parameters in jet impingement are described in Annex A1. These hydrodynamic relationships are valid only for a specific range and are influenced by the geometry and orientation of specimen and apparatus. A minor change in any one parameter drastically alters the hydrodynamic parameters.

6.2 A proper experimental design must consider the jet velocity, radial distance, radius of the electrode (ring or disc), distance between jet nozzle and the electrode, and jet nozzle diameter. Some typical parameters for describing jet impingement apparatus are listed in Table 1. A good laboratory practice would be to control, record, and report all the system specifications.

6.3 Depending on the geometry of apparatus and size and shape of the specimens there are three jet impingement apparatus designs.

6.3.1 *Design 1:*

6.3.1.1 In this design, the working electrode is a disc and is exposed only to the stagnation region (Fig. 1) (**2-4**). Typical diameter of the jet nozzle is 0.6 cm and is placed axis-symmetric to the specimen (working electrode). The diameter



NOTE 1—r/r_{jet} is less than 2 (D_{jet} is the diameter of the jet, r_{jet} is the radius of the jet, *r* is the radius of the specimen, and *H* is the distance between the jet tip and the specimen surface). Shaded area indicates the location of the specimen.

FIG. 1 Schematic Diagram (Side View) of Impinging Jet on a Specimen in Stagnation Region

of the specimen is equal to or less than the diameter of the jet nozzle. The typical distance between the jet nozzle tip and specimen is 3 cm (that is, five times the diameter of the jet nozzle).

6.3.1.2 The jet system is a submerged type and it impinges at 90° onto the specimen. Both the counter electrode and the reference electrode are placed adjacent to the nozzle, so that they are not in the path of the jet impinging on the working electrode (Fig. 2).

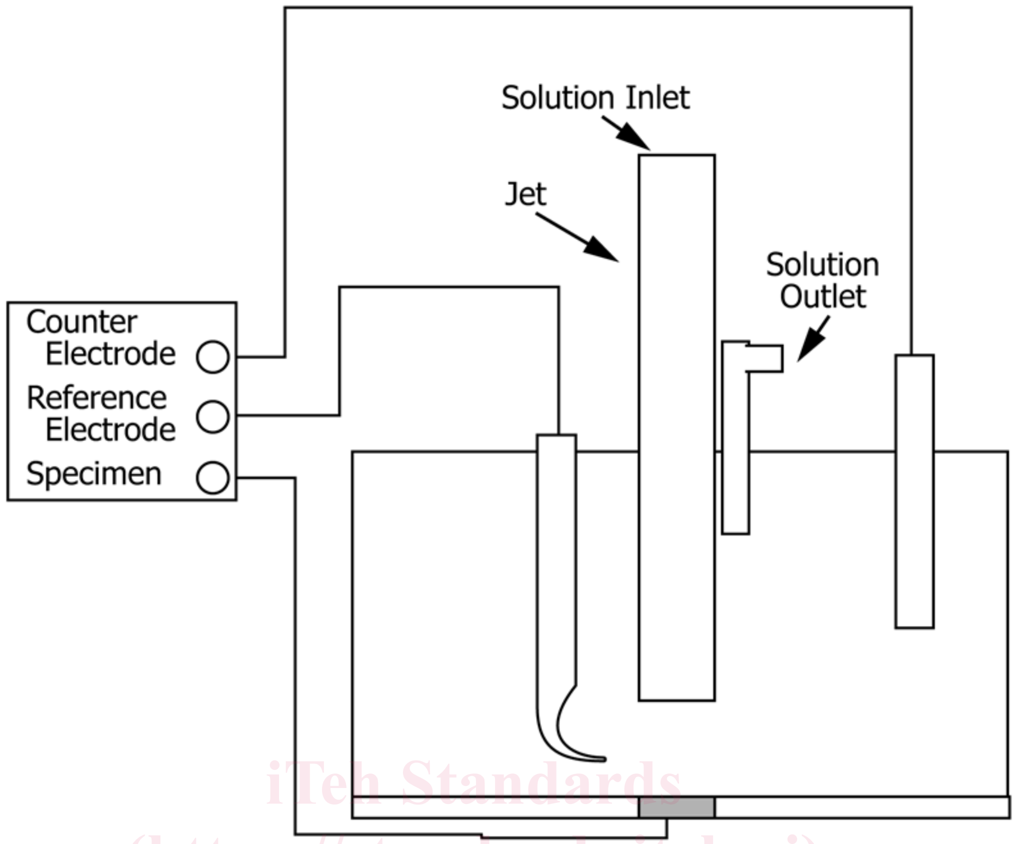
6.3.2 *Design 2:*

6.3.2.1 In this design, the specimen is a ring and is exposed only to the jet region (Fig. 3 and Fig. 4) (**5, 6**). The diameter of the jet nozzle is 0.2 cm. The diameter of the specimen is three times the diameter of the jet nozzle (measured to the centerline of the ring). The inner and outer diameters of the ring specimen are within the jet region. Typical distance between the jet nozzle tip and the specimen is 0.4 cm (that is, two times the diameter of the jet).

6.3.2.2 The jet nozzle is manufactured using a nonmetallic cylinder (typically of 1.25 cm of outer diameter with a 0.2 cm inlet hole in the center). The length of the cylinder (typically 20 cm) is long enough so that the fluid flow stabilizes before exiting through the nozzle. The counter electrode is placed at the end of the jet nozzle (Fig. 5). The reference electrode is placed adjacent to the counter electrode.

6.3.3 *Design 3:*

6.3.3.1 In this design, the specimen is a disc and is exposed to all three regions of jet (stagnant, jet, and hydrodynamic regions) (see Fig. 6). This design facilitates occurrence of



NOTE 1—Figure not to scale. Shaded area indicates the location of the specimen.

FIG. 2 Schematic Diagram of Experimental Test Cell (Design 1)

localized corrosion as the specimen is under the influence of various regions (stagnation, wall jet, and hydrodynamic regions).

6.3.3.2 The diameter of the jet nozzle is 0.64 cm. The diameter of the specimen is five times the diameter of the jet nozzle. Typical distance between the jet nozzle tip and the specimen is 3.2 cm (that is, five times the diameter of the jet) (**7, 8**).

NOTE 1—The larger size of the specimen may also enable it to be used as a mass loss coupon.

6.3.3.3 The counter electrode is placed on the return path of the jet to avoid interference with the jet flow (Fig. 7). Reference electrode is placed in the side of the jet arm.

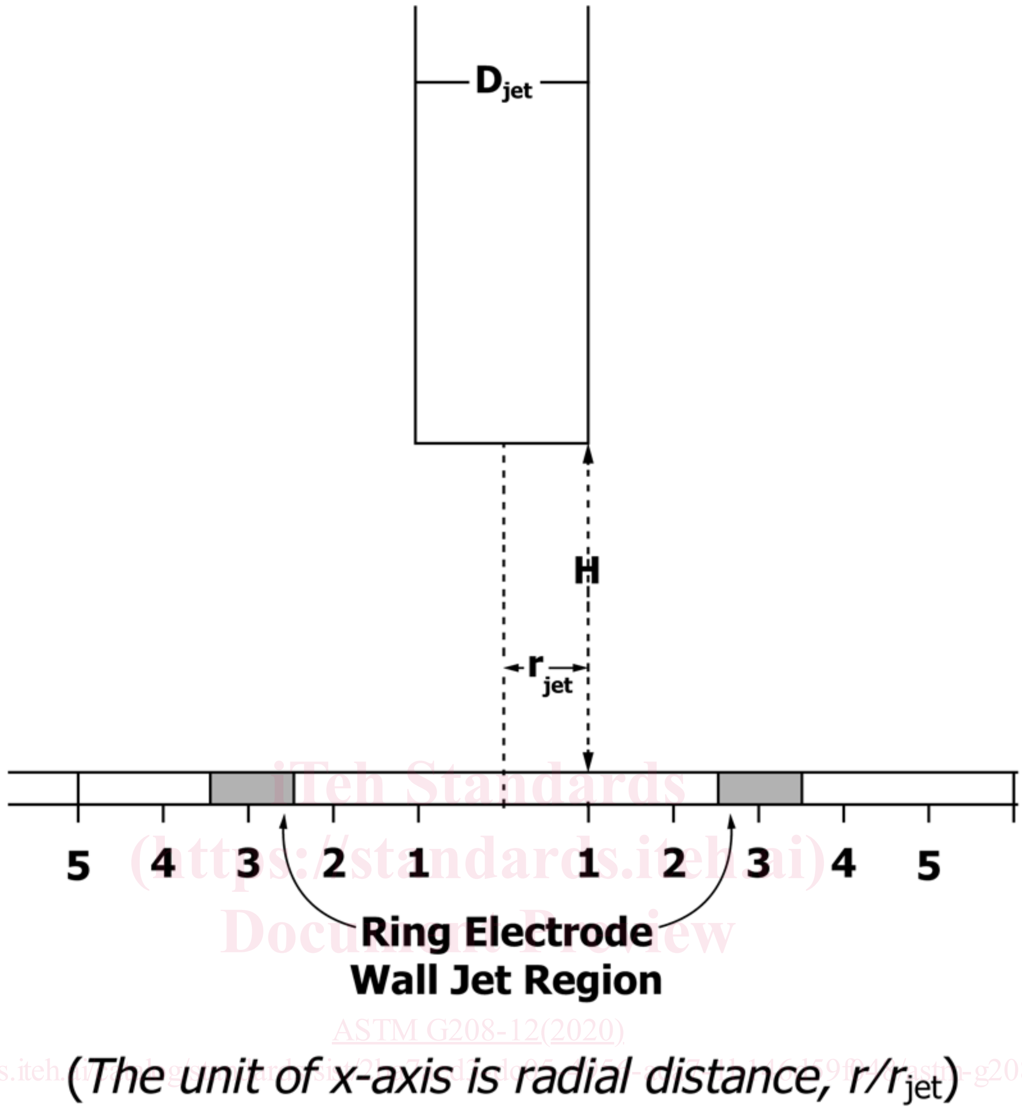
6.3.3.4 This design uses multiple specimens (typically four) (Fig. 8). The jet is created in a central cell with four arms containing four nozzles. The impeller is housed in the cell body and is driven by a motor magnetically coupled to the impeller shaft. Fluid from the cell is forced by the impeller through the nozzles and is recirculated to the cell. All moving parts of the pump are located inside the central cell (**7**).

6.4 For all designs, the relationship between the motor speed that creates the jet and the flow rate shall be established. A procedure to establish such a relationship is described in Annex A2.

6.5 For atmospheric pressure experiment, an apparatus constructed from acrylic, PFTE, or an inert material shall be used. For experiments above atmospheric pressure, an apparatus that can withstand high pressure without leakage must be used. Such high-temperature, high-pressure jet impingement (HTHPJI) system is constructed using corrosion-resistant alloy (CRA).

6.6 For all designs, the apparatus must contain ports for specimen, counter electrode, reference electrode, inlet and outlet. Additional ports enable measurement of pH and temperature during the experiment and draining of the test solution after the experiment. Both inlet and outlet ports should be fitted with a **Y** joint, so that the apparatus is connected to both a gas cylinder and the preparation apparatus. In Design 1 and 2, a pump that creates the jet should be placed between the preparation and experimental apparatus. In Design 3, the pump should be placed inside the apparatus itself.

6.7 The suggested components can be modified, simplified, or made more sophisticated to fit the needs of a particular investigation. The suggested apparatus is basic and the apparatus is limited only by the judgment and ingenuity of the investigator.



NOTE 1—(r_{jet} is the radius of jet, D_{jet} is the diameter of jet nozzle, and H is the distance between jet nozzle and the specimen). Shaded area indicates the location of the specimen.

FIG. 3 Schematic Diagram (Side View) of Impinging Jet on a Specimen in Wall Jet Region

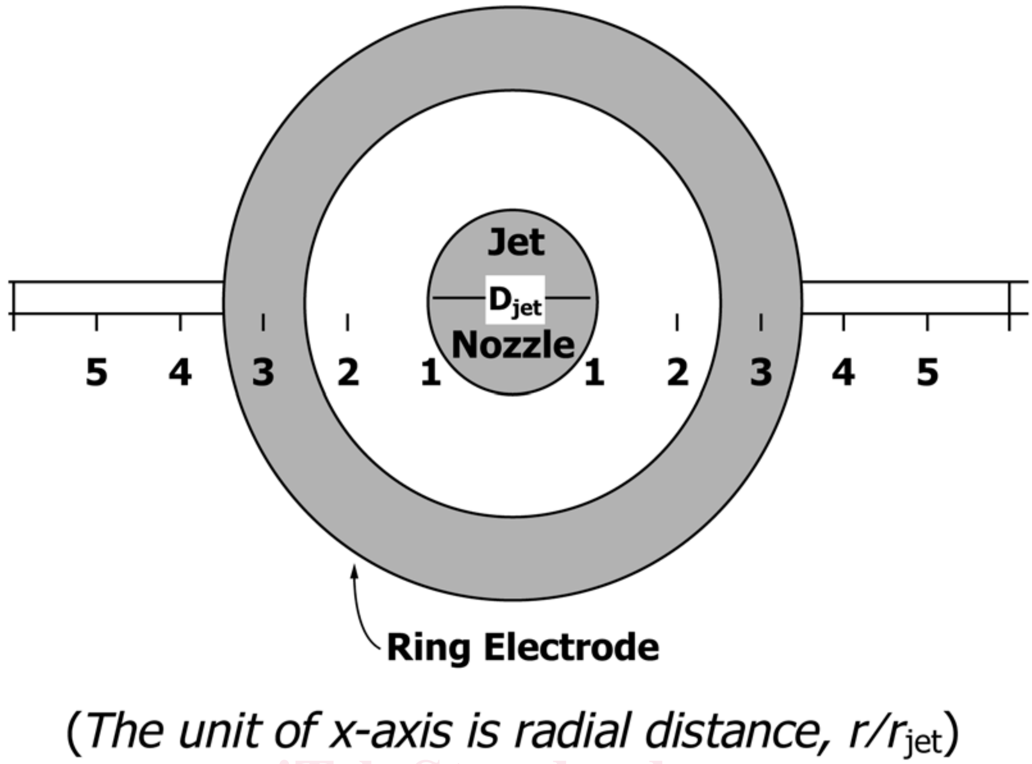
7. Preparation of Test Specimens

7.1 Methods for preparing specimens for tests and for removing specimens after the test are described in Practice G1.

7.2 The specimen shall be made of the material (for example, carbon steel) for which the inhibitor is being evaluated. Corrosion rates and inhibitor performance change by several orders of magnitude as surface roughness changes from rough to fine. The surface roughness shall be kept the same during inhibitor screening and, if possible, the surface roughness of specimens used in the laboratory experiments shall be related to that of field pipe. The specimens shall be ground to a specified surface finish. The grinding shall produce a reproducible surface finish, with no rust deposits, pits, or deep scratches. All sharp edges on the specimen shall be ground. All loose dirt particles shall be removed.

7.3 The appropriate ring or disc specimen shall be machined and snugly fitted into the PTFE sample holder or sample holder made from any other appropriate material, with no gap between the sample and the holder. If necessary, a very small amount of epoxy should be used to fit the specimen into the holder. The presence of a gap will create crevice corrosion as well as change the flow pattern. The end cap is screwed in or attached tightly so that only the disc or ring of known area is exposed to the solution. Electrical connection shall be provided at the back of the specimen through spring connections.

7.4 The specimens shall be rinsed with distilled water; degreased by immersing in acetone or methanol or any other suitable solvent; ultrasonically cleaned (typically for about 1 min); and then dried by blowing air. The surface of the specimens shall not be touched with bare hands. The specimen



NOTE 1—(D_{jet} is the diameter of jet nozzle). Shaded ring area indicates the location of the specimen.

FIG. 4 Schematic Diagram (Top View) of Impinging Jet on a Specimen in Wall Jet Region

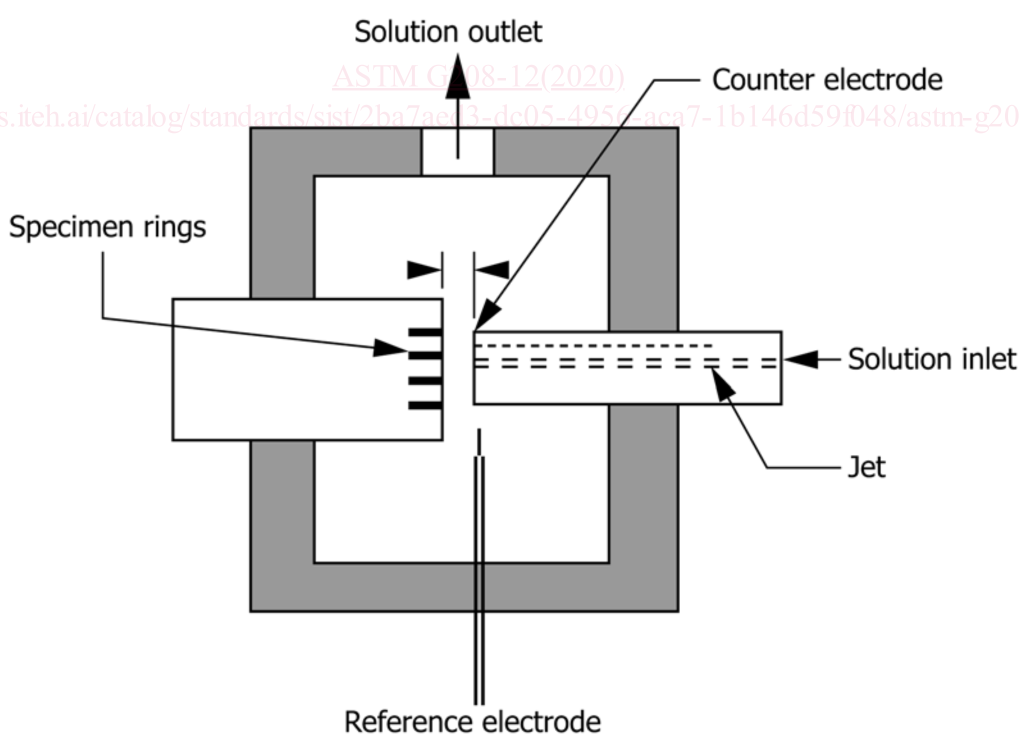
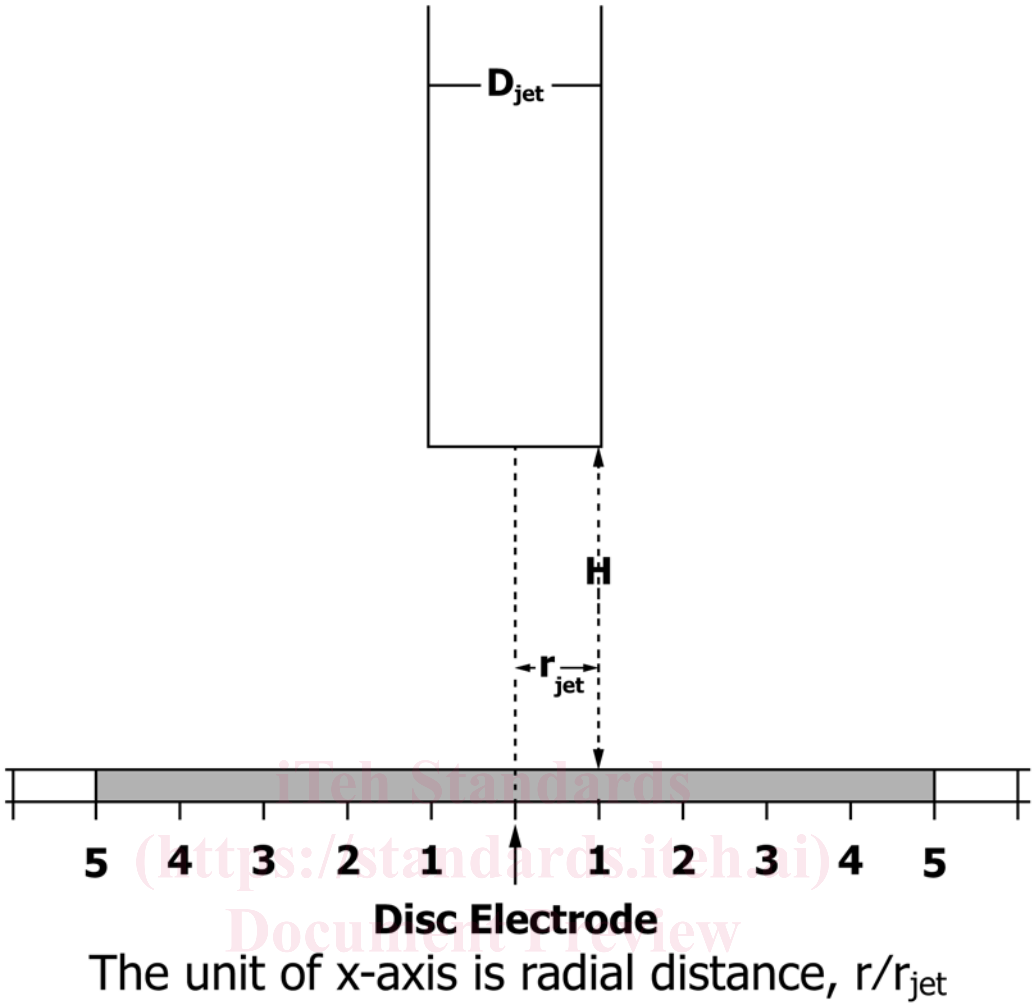


FIG. 5 Schematic of Experimental Test Cell (Design 2) (6)



NOTE 1—(r_{jet} radius of jet, D_{jet} diameter of jet nozzle, and *H* distance between jet nozzle and specimen). Shaded area indicates the location of the specimen.

FIG. 6 Schematic Diagram of Impinging Jet on a Specimen Covering Stagnation, Wall Jet, and Hydrodynamic Boundary Regions

shall be weighed to the nearest 0.1 mg. The dimensions shall be measured to the nearest 1 mm and the surface area calculated.

7.5 The specimen shall be placed into the experimental apparatus within 1 h of preparing the surface and the lid of the apparatus closed immediately.

7.5.1 Specimen to be treated with batch inhibitor shall be exposed to inhibitor containing oil phase for a certain amount of time (usually 30 min). 8.8 describes the preparation of inhibitor containing oil phase. The specimen shall be removed and introduced into the experimental apparatus immediately.

8. Preparation of Test Solution

8.1 Test solution shall be prepared in a separate container (preparation apparatus). Ideally, all phases (oil and aqueous) of test solution shall be obtained from the field for which the inhibitor is being evaluated. It is important that live fluids do not already contain corrosion inhibitor.

8.1.1 If the field crude oil is not available, heptane, kerosene, or any suitable hydrocarbon can be used as oil phase.

8.2 If aqueous phase is not available, synthetic aqueous phase shall be used; the composition of which, however, shall be based on field water analysis. The composition of the aqueous phase shall be determined and reported. Alternatively, standard brine (such as in accordance with Practice D1141) shall be used. The aqueous phase shall be prepared following good laboratory practice. Their composition shall be specified in the work plan and recorded in the laboratory logbook. The aqueous phase shall be prepared using analytical grade reagents and deionized water (Specification D1193). If other grades of chemicals are used, their purity or grade shall be recorded in the laboratory logbook.

8.3 The test solution shall be deaerated by passing nitrogen or any other inert gas or CO_2 and kept under deaerated conditions.

8.4 The test solution shall be heated to the predetermined temperature (that is, temperature at which experiments will be conducted). Depending on the size of apparatus, heating unit (mantle, bath, or wrapper around the apparatus), difference