

TECHNICAL SPECIFICATION

Guidance on the measurement of hydrophobicity of insulator surfaces

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TECHNICAL SPECIFICATION

Guidance on the measurement of hydrophobicity of insulator surfaces

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

GUIDANCE ON THE MEASUREMENT OF HYDROPHOBICITY OF INSULATOR SURFACES

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62073, which is a technical specification, has been prepared by IEC technical committee 36: Insulators.

This second edition cancels and replaces the first edition published in 2003. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Changed wettability to hydrophobicity throughout the document
- b) Redefined the criteria for the determination of hydrophobicity class in paragraph 3.4;

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
36/363/DTS	36/367/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The wetting properties of a surface by water are commonly described by the terms hydrophobic (or hydrophobicity) and hydrophilic (or hydrophilicity). A hydrophobic surface is water-repellent, while a surface that is easily wetted by water is hydrophilic.

The wetting phenomenon of a surface is complex and many different parameters can influence its hydrophobic properties. Some important parameters include: type of insulator material, surface roughness, heterogeneities of the surface, chemical composition (e.g. due to ageing) and presence of pollution. For insulator materials in common use, the hydrophobic properties can change over time, due to the influence of the ambient conditions. This change can be either reversible or irreversible. Thus, the result of the measurement of the hydrophobicity may be influenced by the ambient conditions and the HV corona or dry-band arcing to which the insulator has been previously exposed. This dynamic behaviour of the hydrophobicity is more or less specific to different insulator materials. These types of materials, which have an ability to retain and transfer hydrophobicity, are commonly called Hydrophobicity Transfer Materials (HTM).

The dynamic behaviour of the hydrophobicity exhibited by insulator materials is due to their chemical composition. Different processes such as oxidation, hydrolysis, migration of low molecular weight compounds, formation of complex compounds between e.g. siloxanes and water, rotation of flexible polymer chains, inter- and intra-molecular rearrangements, microbiological growth, deposition of contaminants, adhesion and encapsulation of contaminant particles, may take place at different rates, depending on material and ambient conditions. Thus hydrophobicity along and around an insulator can vary, due to differences in the exposure to solar radiation, rain, corona discharges, deposited pollution, etc. Therefore, hydrophobicity of insulators is usually measured on several separate areas of the insulator.

Measurement of the hydrophobicity of a surface is readily performed in the laboratory on well defined, homogeneous, smooth and planar surfaces of prepared specimens. In the case of insulators, for which non-destructive measurements are usually required (and where cut-out of material samples is usually not desired), these conditions do not exist and measurement with high precision is a difficult task. This is especially true when the measurement has to be performed on an insulator installed in an overhead line, substation or even in a high voltage test set-up in the laboratory.

Previously wettability class (WC) was used as equivalent technology.

GUIDANCE ON THE MEASUREMENT OF HYDROPHOBICITY OF INSULATOR SURFACES

1 Scope

The methods described in this technical specification can be used for the measurement of the hydrophobicity of the shed and housing material of composite insulators for overhead lines, substations and equipment or ceramic insulators covered or not covered by a coating. The obtained value represents the hydrophobicity at the time of the measurement.

The object of this technical specification is to describe three methods that can be used to determine the hydrophobicity of insulators. The determination of the ability of water to wet the surface of insulators may be useful to evaluate the condition of the surface of insulators in service, or as part of the insulator testing in the laboratory.

2 Terms and definitions

For the purposes of this document, the following definitions apply.

2.1

hydrophobicity

state of a surface with a low surface tension and thus is water-repellent

2.2

hydrophilicity

state of a surface with a high surface tension and thus is wetted by water (in the form of a film)

2.3

surface tension

region of finite thickness (usually less than 0,1 µm) in which the composition and energy vary continuously from one bulk phase to the other

Note 1 to entry: The pressure (force field) in the interfacial zone has a gradient perpendicular to the interfacial boundary. A net energy is required to create an interface (surface) by transporting the matter from the bulk phase to the interfacial (surface) zone. The reversible work required to create a unit interfacial (surface) area is the surface tension and is defined thermodynamically as follows:

$$\gamma = \left(\frac{\partial G}{\partial A} \right)_{T,P,n}$$

where

γ is the surface (interfacial) tension or surface energy;

G is the Gibbs free energy of the total system;

A is the surface (interfacial) area;

T is the temperature;

P is the pressure;

n is the total number of moles of matter in the system.

The surface tension (γ) is usually expressed in mN/m (1 mN/m = 1 dyn/cm).

2.4

static contact angle

angle of a drop of liquid resting on the surface of a solid, and a gas is in contact with both, the forces acting at the interfaces are in balance

Note 1 to entry: These forces are due to surface tensions acting in the direction of the respective surfaces. From Figure 1 it follows that:

$$\gamma_{GL} \cos \theta_s = \gamma_{GS} - \gamma_{SL}$$

where

θ_s is the static contact angle of the edge of the drop with the solid surface,

γ_{GL} is the surface tension of the gas-liquid interface,

γ_{GS} is the surface tension of the gas-solid interface, and

γ_{SL} is the surface tension of the solid-liquid interface.

Note 2 to entry: The above equation (Young's equation) is only valid for ideal and smooth surfaces.

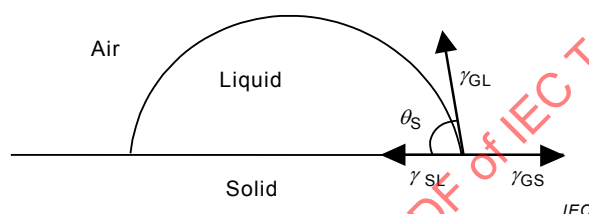


Figure 1 – Definition of the static contact angle

The right side of the above equation (the difference between the surface tensions of the gas-solid and the solid-liquid interfaces) is defined as the surface tension of the solid surface. It is not a fundamental property of the surface but depends on the interaction between the solid and a particular environment.

When the gas is air saturated with vapour of the liquid, γ_{GL} will be the surface tension of the liquid. If the contact angle is 0° , the liquid is said to just wet the surface of the solid, and in this particular case (since $\cos \theta_s = 1$), the surface tension of the solid will be equal to the surface tension of the liquid.

2.5

advancing and receding contact angle (dynamic contact angles)

angles of a droplet on an inclined solid surface that exhibits two different angles

Note 1 to entry: The advancing contact angle (θ_a) is the angle inside the water droplet between the solid surface and the droplet surface at the lower part of the droplet on the inclined surface (see Figure 2). The receding contact angle (θ_r) of a droplet on an inclined surface is the angle inside the droplet between the solid surface and the droplet surface at the droplet rear (highest part on the inclined surface). If the receding contact angle is zero, a completely wetted trace of water is formed as the drop moves along the solid inclined surface (see Figure 2). The general physical relation between the advancing and receding contact angle and the static contact angle defined in 2.4 is: $\theta_r \leq \theta_s \leq \theta_a$.

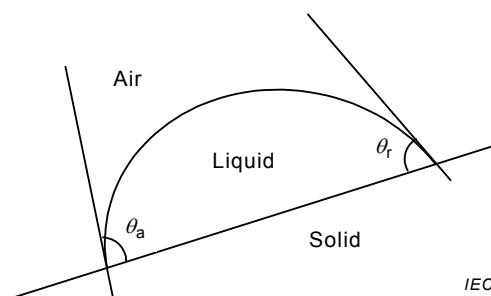


Figure 2 – Definition of the advancing angle (θ_a) and the receding angle (θ_r) inside a liquid drop resting on an inclined solid surface

2.6

hydrophobicity class

HC

specific level of the scale used in the spray method (Method C)

Note 1 to entry: Seven classes, HC/1 to HC/7, have been defined. HC/1 corresponds to the most hydrophobic surface and HC/7 to the most hydrophilic surface.

3 Methods for measurement of hydrophobic properties

3.1 General

Three methods for measurement of the hydrophobicity, differing in accuracy, simplicity, size of measured surface area and applicability, are described in this technical specification and are as follows:

- a) the contact angle method;
- b) the surface tension method;
- c) the spray method.

Guidance relative to the specific use of the three methods is found in Annex A.

3.2 Method A – Contact angle method

3.2.1 General

The contact angle method is a measurement that involves the evaluation of the contact angle formed between the edge of a single droplet of water and the surface of a solid material. If done on a horizontal surface, the advancing and receding contact angles can be measured by adding water to or withdrawing water from the droplet.

The contact angles depend strongly on the surface roughness and contact angles measured on polluted surfaces may differ significantly from contact angles measured on smooth, clean and planar surfaces.

3.2.2 Equipment

Different commercial equipment for measuring the contact angle is available. Simple measurements are made using a magnifying device with a graduated reticle (goniometer) fixed on a frame with a syringe for application of the droplet on the test specimen. Another method involves magnifying the droplet using a light projector (behind the droplet) and projecting an image of the droplet onto a graduated background. Some equipment includes camera, display and computer for analysis of the measurements.

3.2.3 Measurement procedure

3.2.3.1 General recommendations

General recommendations include:

- a) the receding contact angle (θ_r) reflects the hydrophobic properties of an insulator more than the advancing contact angle (θ_a) and the static contact angle (θ_s);
- b) it is often necessary to cut out a test specimen from the insulator under investigation. The test specimen selected should be as planar as possible and the size should allow for the application of at least three droplets on separate surface areas adjacent to each other. The surface to be measured should not be touched and the specimen should be carefully stored until the measurement has been performed. The measurement should be performed as soon as possible;
- c) the water used should not contain impurities affecting the water surface tension (e.g. tensides, solvents, oil residues, etc.). De-ionized water is suitable;

- d) the volume of water in the droplet is not very critical. Volumes in the range 5 μl to 50 μl may be used. 50 μl is the recommended volume. For rough surfaces, a larger droplet volume may be needed. To limit a possible influence of the water droplet volume, the volume should be kept as constant as possible when comparing different specimens;
- e) the measurement of the contact angles should be performed as soon as possible (within a minute) after the application of the droplet on the surface. This is especially important when the ambient temperature is high and the relative humidity is low, which increases the rate of evaporation of the droplet. If the measurement is performed in a chamber with saturated water vapour, it eliminates the influence of evaporation.

NOTE Small droplet volumes have the advantage that the contact angle is less influenced by gravity. On the other hand, for rough surfaces and other surfaces that could have high advancing contact angles and low receding angles, a too small droplet volume makes the measurement of the dynamic contact angles very difficult. A small droplet volume will also be more sensitive to evaporation, which could affect the measurement. The optimal droplet volume may thus be dependent on type of surface and ambient temperature and humidity.

3.2.4 Static contact angle measurements

The measurement of the static contact angle (θ_s) can be performed by applying a water droplet to the horizontal surface of a test specimen, using a pipette or a syringe with a scale.

3.2.5 Dynamic contact angle measurements

The measurement of the receding contact angle (θ_r) can be performed on a horizontal plane by withdrawing water from the droplet by using a syringe with a scale (see Figure 3). θ_r is the angle at the moment when the liquid front recedes. Measurement of θ_r should be performed on both projected sides of the droplet. At least three measurements on droplets applied on adjacent areas on the test specimen shall be performed. If three droplets are applied, this gives a total of six values.

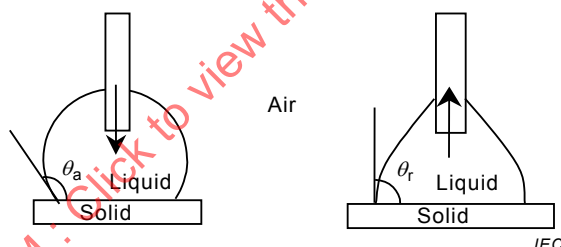


Figure 3 – Measurements of the advancing angle (θ_a) and the receding angle (θ_r) by adding or withdrawing water from a droplet

It is recommended to keep the capillary pipette of the syringe immersed in the droplet during the entire measurement in order to avoid vibrations and distortions of the droplet that otherwise may affect the result.

There exist other methods to measure the dynamic contact angles. Examples of such methods are given in Annex B.

NOTE Prior to the measurement of θ_r the advancing contact angle (θ_a) can be measured by adding water to the droplet. θ_a is the angle at the moment when the water droplet front starts to advance on the surface.

3.2.6 Evaluation

To obtain a good indication of the hydrophobicity of the whole insulator, several contact angle measurements should be performed on different areas along and around the insulator. Low or zero receding angles on all measured areas indicate a hydrophilic insulator, especially if also the advancing angles are low or zero. On the contrary, high receding (and advancing) angles indicate that the insulator is hydrophobic. Measurement on a single spot of the insulator surface is only valid for that location and is not sufficient to draw conclusions on the hydrophobicity of the whole insulator.

3.3 Method B – Surface tension method

3.3.1 General

The determination of the surface tension of an insulator surface is based on the phenomenon that drops of a series of organic liquid mixtures, with gradually increasing surface tension, have different ability to wet the insulator surface. Any trace of surface-active impurities in the liquid reagents or on the surface may affect the results. It is, therefore, important that the surface to be tested should not be touched or rubbed, that all equipment is clean and that reagent purity is carefully controlled.

This method is an extension of IEC 60674-2:1988, *Specification for plastic films for electrical purposes – Part 2: Methods of test*, which is used for the determination of the surface tension of polyethylene and polypropylene films. In particular this method implies the adoption of a larger number of liquids to cover a wider range of surface tension, which is needed to perform measurements on both hydrophobic and hydrophilic insulators. There may be restrictions in using this method on polluted insulator surfaces (see Annex A).

3.3.2 Safety precautions

The organic liquids used as reagents may affect health if not used properly. Formamide (HCONH_2) may cause skin irritation and is particularly dangerous in direct contact with eyes. Ethylene-glycolmonoethyl-ether ($\text{CH}_3\text{OCH}_2\text{CH}_2\text{OH}$) (or ethyl cellosolve) is a highly flammable solvent. Both formamide and ethyl cellosolve are toxic. Adequate safety precautions should be adopted, e.g. safety goggles should be worn and there should be adequate ventilation when handling these liquids and performing the measurements.

3.3.3 Equipment and reagents

3.3.3.1 Preparation of reagents

Tables C.1, C.2 and C.3 are used for the preparation of the required mixtures. For surface tension outside the range 30 mN/m to 56 mN/m, reference is made to mixtures in Tables C.2 and C.3. Commercially available marker pens already prepared with solutions of different surface tension may be an alternative to making own mixtures.

If desired, add dye (e.g. Victoria Pure Blue BO at a maximum concentration of 0,03 %) to each of the different reagent mixtures. The dye used should be of such a colour as to make drops clearly visible on the surface of the organic material considered. Furthermore, the dye shall be of such a chemical composition that it will not measurably affect the wetting tension of the liquid mixtures. It is recommended that the surface tension of the liquid mixture be checked weekly. Any surface tension method applied in the laboratory is suitable. Although the shown liquid mixtures are relatively stable, exposure to temperatures above 30 °C and a relative humidity in excess of 70 % should be avoided.

3.3.3.2 Equipment

Three different applicators are available to apply the reagent solutions on the insulator surface:

- cotton-tipped wooden applicators;
- small soft paintbrushes fixed into the caps of the bottles with the reagents;
- commercially available marker pens already prepared with solutions of different surface tension.

For applicators a) and b), additional equipment is required:

- two graduated bottles of 50 ml;
- other bottles, 100 ml with caps and labels. The bottles should be cleaned with chrome-sulfuric acid and rinsed with distilled water.

3.3.4 Measurement procedure

Wet the extreme tip of the cotton applicator (if cotton applicators are used) with one of the reagent mixtures or remove the soft paintbrush fixed into the cap of the bottle with the reagent. Use only a minimum amount of liquid as an excess of reagent may affect the result.

The same measurement procedure is then used with any of the three applicators.

Spread the liquid lightly over an area of approximately 5 cm² (25 mm of diameter) of the insulator surface at the selected location. Note the time required for the continuous liquid coverage formed on the surface to break up into droplets. If the continuous liquid coverage holds for more than 2 s, proceed to a higher surface tension mixture, but if the continuous liquid coverage breaks into droplets in less than 2 s proceed to a lower surface tension mixture. For each application of a new reagent mixture, a new adjacent surface should be selected to avoid contamination from the previously applied reagent. If measurements on the same surface area are desirable and possible without disturbance, the surface may be gently cleaned with a dry cloth (without the use of any detergent) to remove the remaining reagent previously applied. If cleaning is not performed, it is recommended to start with the lower surface tension mixtures and progressively continue to higher surface tension mixtures to minimize erroneous results due to contamination from the previously applied reagent mixture. When a cotton applicator is used, a clean, new applicator shall be used each time to avoid contamination of the solution. If the soft paintbrushes fixed into the caps are used, the brush may be cleaned in a small volume of the reagent before it is re-inserted into the reagent bottle again.

Proceed in the direction indicated above continually repeating the prescribed steps until it is possible to select the right mixture according to the evaluation in 3.3.5.

3.3.5 Evaluation

The mixture is considered as wetting the insulator surface when it remains intact as a continuous coverage of the liquid for at least 2 s. Shrinkage of the periphery of the continuous liquid coverage does not indicate lack of wetting. Only breaking into droplets within 2 s indicates lack of wetting. Severe peripheral shrinking may be caused when too much liquid is placed upon the surface. The surface tension of the applied mixture (in mN/m), which remains intact during 2 s as close as possible, is called the surface tension of the measured insulator surface.

3.4 Method C – The spray method

3.4.1 General

The spray method is based on the response that an insulator surface gives after exposure to a fine water mist for a short period. The hydrophobicity after the mist exposure is evaluated.

NOTE The method will not give exact measurements of the advancing and receding contact angle but is a practical method for an estimation of the hydrophobicity in field. This method is intended to be performed on unenergized insulator

3.4.2 Equipment

The equipment needed is a device that can produce a fine mist, such as a common spray bottle. The spray bottle is filled with water. The water shall not contain any impurities, which could influence the surface tension of the water, such as detergents, solvents, etc. Tap water of high quality does usually not contain impurities that significantly influence the surface tension of the water. Tap water of high quality could thus be used for the measurement. If there are any uncertainties about the water quality, de-ionized water or distilled water should be used

NOTE 1 Additional equipment which may facilitate the measurement include a magnification glass (for an easier judgement of droplet shape) and a lamp.

3.4.3 Measurement procedure

The test area should preferably be approximately 50 cm² to 100 cm². The ratio between the length and width of the test area should not be larger than 1:3. If this requirement cannot be met, this should be noted in the measurement report. Apply the mist from a distance of 20 cm $\pm$ 10 cm. The surface shall be exposed to the mist for a period of 10 s to 20 s. Typically, the amount of water sprayed during the 10 s to 20 s should be sufficient enough so that the water is dripping off the sheds. The measurements of the hydrophobicity shall be performed within 10 s after the spraying has been completed.

The measurement should be performed in such a way that a clear picture of the variation of the hydrophobicity along and around the insulator is obtained.

The measurement might be difficult to perform in high winds. If such difficulties are present it may be necessary to perform the spraying from a shorter distance than 20 cm $\pm$ 10 cm. This should be noted in the measurement report, together with any other possible deviations from given recommendations, e.g. smaller test area.

NOTE 1 For long insulators, it is possible to only examine some selected sheds from the upper, middle and lower part of the insulator.

NOTE 2 If necessary, a photographic camera can be used to record the surface condition.

3.4.4 Evaluation

The appearance on the insulator surface after mist exposure has to be identified with one of the seven hydrophobicity classes (HC), which is a value between 1 and 7. The criteria for the different HCs are given in Table 1. Typical photos of surfaces with different HCs are shown in Annex D.

A surface with the HC value 1 is the most hydrophobic surface and a surface with the HC value 7 is the most hydrophilic surface.

Two visual criteria are used to judge the HC value:

- a) the shape of droplets;
- b) the percentage part of the surface which is wetted.

NOTE The uncertainty in the visual evaluation is usually not larger than ± 1 hydrophobicity class.

Table 1 – Criteria for the determination of hydrophobicity class (HC)

HC	Description	Approximate receding contact angle θ_r
1	Only discrete droplets are formed. Their shape when viewed perpendicular to the surface is practically circular.	$>60^\circ$
2	Only discrete droplets are formed. The major part of the surface is covered by droplets with a shape, as seen perpendicular to the surface, still regular but deviates from circular form.	40 to 60°
3	Only discrete droplets are formed. The major part of the surface is covered by droplets with an irregular shape.	10 to 40°
4	Both discrete droplets and wetted traces from the water runnels or water film are observed (i.e. $\theta_r = 0^\circ$ for some of the droplets). Less than 10 % of the observed area is covered by water runnels or film.	0 to 10°
5	Both discrete droplets and wetted traces from the water runnels or water film are observed (i.e. $\theta_r = 0^\circ$ for some of the droplets). More than 10 % but less than 90 % of the observed area is covered by water runnels or film.	0 to 10°
6	More than 90 % but less than 100 % of the observed area is covered by water runnels or film (i.e. small non-wetted areas/spots/traces are still observed).	0 to 5°
7	Continuous water film is formed over the whole-observed area.	0°

3.5 Documentation

The measurement report should include the following information:

a) General information

- 1) location, station, line or laboratory conditions;
- 2) method used (A, B or C);
- 3) date and time of the measurement and sample collection date and droplet volume for method A;
- 4) weather conditions (temperature, wind, precipitation);
- 5) who performed the test.

b) Test object

- 1) type of insulator or apparatus;
- 2) insulator material and shed profile;
- 3) identity (item No., position in substation or tower No.);
- 4) voltage class, arcing distance, creepage distance;
- 5) date of installation or application of coating (type of coating);
- 6) installation position (vertical, horizontal, angle);
- 7) information on the pollution state of the insulator.

c) Result

The results of the measurement performed at different positions should be documented, e.g. along the insulator (shed No.), along the surface within each shed sequence (top, bottom, large shed, small shed, trunk, etc.), and differences (if any) around the insulator circumference should be noted.

Annex A

(normative)

Guidelines regarding the applicability and comments on the limitations of the different methods described in this technical specification

A.1 General

The suitability of each method and its applicability depends not only on its associated procedure but also on the specific case to be evaluated. All three methods are well suited for hydrophobicity measurements in the laboratory. In the field, it may be difficult to use method A. Method B can be used without too much difficulty while Method C can readily be used. Some considerations relevant to each method are outlined below:

a) **Method A:** Contact angle measurement

- gives an accurate value of the hydrophobicity of the area measured,
- is more accurately performed in the laboratory than in the field,
- the measurement is easily performed on practically flat surfaces,
- if aging has affected the surface morphology, i.e. presence of cracks, fissures or filler, the measurement may be adversely affected, and
- requires many measurements if a complete evaluation of the insulator surface is required.

b) **Method B:** Surface tension measurement

- gives an accurate value of the hydrophobicity of the area measured provided the spatial variation in the hydrophobicity is compatible with the area required for the measurement,
- is fairly easy to perform,
- requires certain safety precautions,
- may be difficult to use if the surface is covered with a layer of loosely adhering pollution,
- may be affected by interaction between certain types of surface pollution and the measuring agents may occur, and
- requires many measurements if a complete evaluation of the insulator surface is required.

c) **Method C:** Spray method

- gives a global assessment of the hydrophobicity of the insulator surface and its variation along and around the insulator,
- is easy to perform and requires simple equipment,
- depends on subjective visual examination of the surface,
- can be used to evaluate bare and polluted surfaces, and
- may be affected by an interaction between certain types of surface pollution and the spray water (i.e. modification of the equivalent salt deposit density (ESDD) level of the surface contaminant applied for laboratory pollution tests).

A.2 Typical results obtained with the three methods

Typical results obtained with the three methods are as follows:

a) Hydrophobic surface

- high value of receding contact angle ($>80^\circ$),
- low value of surface tension (<30 mN/m),
- low HC value (HC = 1 or HC = 2).

b) Intermediate surface

- intermediate value of receding contact angle (10° to 80°),
- intermediate value of surface tension (30 mN/m to 60 mN/m),
- intermediate HC value (HC = 3 to HC = 5).

c) Hydrophilic surface

- low value of receding contact angle ($<10^\circ$),
- high value of surface tension (>60 mN/m),
- high HC value (HC = 6 or HC = 7).

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Annex B (normative)

Method A – Contact angle method

There are several different methods to measure the dynamic contact angles. The captive bubble technique is illustrated in Figure B.1. In this technique the specimen is immersed in water. An air bubble (or a liquid immiscible with water) is formed by injecting air (or liquid) on the lower side of the immersed specimen. Young's equation, as given in 2.4, is also valid in this case.

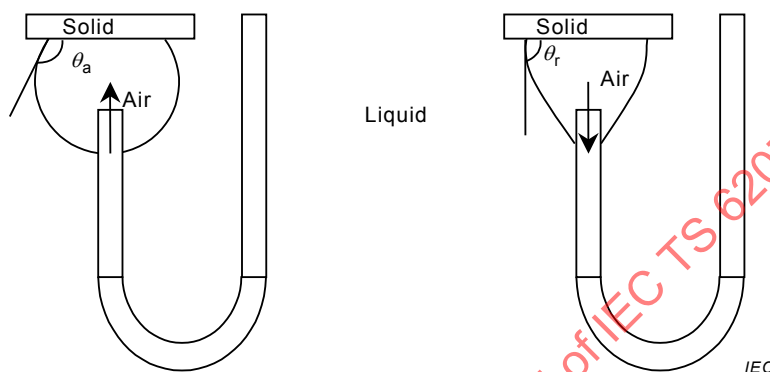


Figure B.1 – Measurement of the advancing angle (θ_a) and the receding angle (θ_r) by using the captive bubble technique

It is also possible to measure the advancing and receding contact angles (θ_a and θ_r , respectively) on an inclined surface. This method, the tilting base technique, uses a water droplet that is placed on the surface, which is tilted at a progressively higher angle until the droplet starts to move, allowing the determination of advancing and receding contact angles. The tilting base technique is illustrated in Figure 2.