Designation: D6561 – 06 (Reapproved 2016)

Standard Test Method for Determination of Aerosol Monomeric and Oligomeric Hexamethylene Diisocyanate (HDI) in Air with (Methoxy-2–phenyl-1) Piperazine (MOPIP) in the Workplace[1]

This standard is issued under the fixed designation D6561; 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 test method covers the determination of aerosol hexamethylene diisocyanate (HDI) in air samples collected from workplace and ambient atmospheres. The method described in this test method collects separate fractions. One fraction will be dominated by vapor, and the other fraction will be dominated by aerosol. It is not known at the present time whether this represents a perfect separation of vapor and aerosol, and in any case, there are not separate exposure standards for vapor and aerosol. Therefore, in comparing the results for isocyanate against a standard, results from the two fractions should be combined to give a single total value. The reason for splitting the sample into two fractions is to increase analytic sensitivity for the vapor fraction and also to give the hygienist or ventilation engineer some information concerning the likely state of the isocyanate species. The analyses of the two fractions are different, and are provided in separate, linked, standards to avoid confusion. This test method is principally used to determine short term exposure (15 min) of HDI in workplace environments for personal monitoring or in ambient air. The analysis of the vapor fraction is performed separately, as described in Test Method D6562.

1.2 Differential air sampling is performed with a segregating device.[2] The aerosol fraction is collected on a polytetrafluoroethylene (PTFE) filter.

1.3 Immediately after sampling, the PTFE filter is transferred into a jar containing a (methoxy-2 phenyl-1) piperazine (MOPIP) solution in toluene.

1.4 The analysis of the aerosol fraction is performed by using a high performance liquid chromatograph (HPLC) equipped with an ultraviolet (UV) detector. The range of application of the test method has been validated from 0.052 to 1.04 µg of monomeric HDI/mL, which corresponds, based on a 15 L air sample, to concentrations from 0.004 to 0.070 mg/m^3 of HDI. Those concentrations correspond to a range of aerosol phase concentrations from 0.5 ppb (V) to 10 ppb (V) and cover the established threshold limit valve (TLV) value of 5 ppb (V).

1.5 The quantification limit for the monomeric HDI is 0.041 µg per mL, which corresponds to 0.003 mg/m^3 for a 15 L sampled air volume. This value is equivalent to ten times the standard deviation obtained from ten measurements carried out on a standard solution in contact with the PTFE filter whose concentration of 0.1 µg/mL is close to the expected detection limit.

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.* See Section 9 for additional hazards.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1193 Specification for Reagent Water

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D1357 Practice for Planning the Sampling of the Ambient Atmosphere

D5337 Practice for Flow Rate Adjustment of Personal Sampling Pumps

[1] This test method is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.04 on Workplace Air Quality.

Current edition approved Nov. 1, 2016. Published November 2016. Originally approved in 2000. Last previous edition approved in 2011 as D6561 – 06 (2011). DOI: 10.1520/D6561-06R16.

[2] The sampling device for isocyanates is covered by a patent held by Jacques Lesage et al, IRSST, 505 De Maisonneuve Blvd. West, Montreal, Quebec, Canada. If you are aware of an alternative to this patented item, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[3] 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.

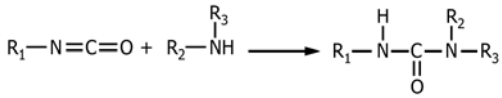

FIG. 1 MOPIP Solution

D6562 Test Method for Determination of Gaseous Hexamethylene Diisocyanate (HDI) in Air with 9-(N-methylaminomethyl) Anthracene Method (MAMA) in the Workplace

2.2 *Other Standard:*[4]

Sampling Guide for Air Contaminants in the Workplace

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology D1356.

4. Summary of Test Method

4.1 Vapor and aerosol fractions are sampled simultaneously by using a segregating sampling device. The aerosols are collected on PTFE filter while the gaseous fraction is being adsorbed on a second filter made of glass fiber, impregnated with a 9-(N-methylaminomethyl) anthracene (MAMA).

4.2 The analysis of the monomer in the gaseous fraction is performed separately in accordance with the procedure described in Test Method D6562.

4.3 Diisocyanates present as aerosols are collected on the PTFE filter and derivatized in a MOPIP solution (**1, 2**).[5] See Fig. 1.

4.3.1 The solution is then evaporated to dryness and redissolved, using the acetic anhydride solution (see 8.11). Monomeric and oligomeric HDI are separated by using a reversed phase HPLC column, and detection is made by using an HPLC equipped with UV detection.

4.4 Concentration of monomeric and oligomeric diisocyanates contained in a sample is calculated by using an external standard of the monomeric HDI.

5. Significance and Use

5.1 HDI is mostly used in the preparation of paints. For the last ten years, the use of isocyanates and their industrial needs have been in constant growth.

5.2 Diisocyanates and polyisocyanates are irritants to skin, eyes, and mucous membranes. They are recognized to cause respiratory allergic sensitization, asthmatic bronchitis, and acute respiratory intoxication (**3-6**).

5.3 The American Conference of Governmental Industrial Hygienists (ACGIH) has adopted a threshold limit value - time weighted average (TLV – TWA) of 0.005 ppm (V) or 0.034 mg/m^3 for monomeric HDI (**7**). The Occupational Safety & Health Administration of the U.S. Department of Labor (OSHA) has not listed a permissible exposure limit (PEL) for HDI (**8**).

5.4 Due to its low LOD and low required volume (15 L), this test method is well suited for monitoring of respiratory and other problems related to diisocyanates and polyisocyanates. Its short sampling times are compatible with the duration of many industrial processes, and its low detection limit with the concentrations often found in the working area.

6. Interferences

6.1 Any substance, including strong oxidizing agents, that can be deposited on the PTFE filter and react with MOPIP reagent can affect the analysis efficiency.

6.2 Any compound that has the same retention time as the HDI-MOPIP derivative and contributes to UV response is an interference. Chromatographic conditions can sometimes be changed to eliminate an interference.

7. Apparatus

7.1 *Sampling Equipment:*

7.1.1 *Personal Sampling Pump,* equipped with a flow-monitoring device (rotameter, critical orifice) or a constant-flow device capable of drawing 1.0 L/min of air through the sampling device for a period of at least 4 h.

7.1.2 *Double Filter Sampling Device,* 37 mm in diameter, three-piece personal monitor, plastic holder loaded with a PTFE filter close to the mouth, followed by a glass fiber filter (GFF) impregnated with MAMA and a plastic back-up pad.[6] The GFF is impregnated with an amount of MAMA in the range from 0.07 to 0.25 mg.

7.1.3 *Flow Measuring Device,* used in accordance with Practice D5337.

7.2 *Analytical Equipment:*

7.2.1 *Liquid Chromatograph,* HPLC, equipped with a UV detector (242 nm wavelength), connected in series with a diode detector, and equipped with an automatic or manual sampling port injection.

7.2.2 *Liquid Chromatographic Column,* an HPLC stainless steel column, capable of separating the urea derivatives. This test method recommends a 150 by 3.2-mm internal diameter stainless steel column packed with 3 µm C-18, or an equivalent column.

7.2.3 *Electronic Integrator,* or any other effective method for determining peak areas.

7.2.4 *Analytical Balance,* with a precision of ±0.0001 g.

7.2.5 *Microsyringes and Pipets*—Microsyringes are used in the preparation of urea derivatives and standards. An automatic pipet, or any equivalent equipment, is required for sample preparation.

[4] Available from Institut de recherche en sante et en securite du travail du Quebec, Laboratory Division, Montreal, IRSST.

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

[6] The sole source of supply of the apparatus known to the committee at this time is Omega Specialty Instrument, Chelmsford, MA and is prepared in accordance with Patent No. 4 961 916 (**9**). If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

7.2.6 *pH Meter,* or any equivalent device capable of assaying a pH range between 2.5 and 7.

7.2.7 *Culture Tubes,* 16 by 100 mm, disposable, in borosilicate glass for evaporation of derivatized samples.

7.2.8 *Glass Jars,* 30 mL, and lids, capable of receiving 37-mm filters, used for derivatization of samples.

7.2.9 *Vacuum Filtration System,* filter 47 mm, with 0.22-µm pore size polyamide filters, or any equivalent method.

7.2.10 *Syringe Operated Filter Unit,* syringes with 4 mm, polyvinylidene fluoride 0.22-µm pore size filter unit, or any equivalent device.

7.2.11 *Injection Vials,* 1.5-mL vials with PTFE-coated septums.

7.2.12 *Bottle,* amber colored bottle with cap and PTFE-coated septum for conservation of stock and diluted standard solutions of HDI.

7.2.13 *Vacuum Evaporator,* capable of heating to 55°C, or any equivalent device.

7.2.14 *Vortex Movement Mixer,* or any equivalent device.

8. Reagents and Materials

8.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. All reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[7] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water*—Unless otherwise indicated, water shall be reagent water as defined by Type 2 of Specification D1193. HPLC grade.

8.3 *Acetic Acid,* glacial (CH_3COOH), HPLC grade.

8.4 *Acetic Anhydride* $(CH_3CO)_2O$), certified by American Chemical Society (ACS).

8.5 *Acetonitrile,* HPLC grade.

8.6 *Buffer*—In a 1-L volumetric flask, dissolve 12.5 g sodium acetate ($NaC_2H_3O_2$) (see 8.12) in water and dilute to volume. Add glacial acetic acid (CH_3COOH) (see 8.11) to acidify to pH = 6.0. Under vacuum, filter the buffer with a 0.22-µm pore size filter.

8.7 *Derivatization Solution*—Weigh 50 mg of MOPIP (see 8.9), and dilute to 500 mL in a volumetric flask with toluene (see 8.13). This solution is equivalent to 0.1 mg MOPIP/mL.

8.8 *Hexamethylene Diisocyanate (HDI),* (F.W. 168), 98 % purity.

8.9 *(Methoxy-2-phenyl-1) Piperazine (MOPIP),* (F.W. 192.2). 98 % purity.

8.10 *Mobile Phase,* a solvent mixture of 60 % (v/v) acetonitrile (see 8.5) and 40 % (v/v) buffer (see 8.6).

8.11 *Redissolution Solution*—Dilute 500 µL of acetic anhydride ($(CH_3CO)_2O$) (see 8.4) to 100 mL with acetonitrile (see 8.5.)

8.12 *Sodium Acetate ($NaC_2H_3O_2$),* certified ACS.

8.13 *Toluene,* HPLC grade.

9. Hazards

9.1 **Warning—**Diisocyanates are potentially hazardous chemicals and are extremely reactive. Refer to material safety data sheets for reagents.

9.2 **Warning—**Avoid exposure to diisocyanate and solvents. Sample and standard preparations should be done in an efficient operating hood. For remedial statement, see Ref **(10)**.

9.3 **Warning—**Wear safety glasses at all times and other laboratory protective equipment if necessary.

10. Sampling

10.1 Refer to Practice D1357 for general information on sampling.

10.2 This test method recommends sampling in accordance with the method described in Refs **(9-11)**.

10.3 Equip the worker, whose exposure is to be evaluated, with a filter holder connected to a belt-supported sampling pump. Place the filter holder pointing downward, if possible, at an optimum angle of 45° from horizontal in the breathing zone of the worker. Draw air through the sampling device, and collect 15 L at a rate of approximately 1.0 L/min.

10.4 For stationary monitoring, use a tripod or any other support to locate the sampler in a general room area at a height equivalent to the breathing zone.

10.5 A field blank is used to monitor contamination during the combined sampling, transportation, and storage process. Open the field blanks in the environment to be sampled and immediately close them. Process field blanks in the same manner as samples. Submit at least one field blank for every ten samples.

10.6 Immediately after sampling, open the cassette, withdraw the PTFE filter, place it in a glass jar containing 5 mL of MOPIP derivatization solution (see 8.7), and close the jar. This filter is used to analyze the aerosol fraction of diisocyanates.

10.7 Close the cassette leaving the GFF and the plastic pad support. The GFF is used to analyze the gaseous fraction of diisocyanates (see Test Method D6562).

10.8 Send the jars and the cassettes to be analyzed to the laboratory. Keep away from light.

11. Calibration and Standardization

11.1 For general information on sampling, refer to Practice D1357.

11.2 *Sample Pump Calibration*—Calibrate the sampling pump (see 7.1.1) with a sampling device (see 7.1.2) between the pump and the flow measuring device, in accordance with Practice D5337. Calibrate the pump before and after sampling. If the flow rate after sampling differs by more than 5 % from the flow rate before sampling, invalidate the sample.

[7] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, D.C. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar 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.

11.3 *Reference Standards:*

11.3.1 *Stock Standard Solution of HDI*—Using a microsyringe, transfer 10 µL of HDI to a 100-mL volumetric flask and dilute to volume with toluene. To prevent standard degradation, prepare a fresh solution daily.

11.4 *Blanks:*

11.4.1 The field blank described in 10.5 is prepared and analyzed as a sample (see 12.1).

11.4.2 A laboratory blank is used to check contamination that may occur during laboratory manipulations. Use a laboratory blank and process as a sample (see 12.1).

11.4.3 Use derivatization solution as a solution blank and process as a sample (see 12.1).

11.5 *Calibration Curve:*

11.5.1 To prepare working standards, prepare at least three dilutions from the standard stock solution (see 11.3.1) within the concentrations range from 0.05 to 1.04 µg of monomeric HDI/mL. This corresponds to 0.004 to 0.070 mg/m^3 of HDI for an air sampled volume of 15 L.

11.5.2 Transfer 1 mL of the different working standard solutions into identified disposable culture tubes containing 5 mL of the derivatization solution (see 8.7). Mix gently.

11.5.3 Process as samples (see 12.1.3).

11.5.4 Analyze by high performance liquid chromatography in accordance with the conditions described in 12.2.

11.5.5 Prepare the calibration curve by plotting peak area values against micrograms of monomeric HDI per millilitre of solution. A coefficient of correlation equal or greater than 0.995 must be achieved.

11.5.6 In daily routine procedures, inject one working standard every ten samples to check the stability of the instrument response.

12. Procedure

12.1 *Sample Preparation:*

12.1.1 Using tweezers, remove the PTFE filter from the cassette and transfer into a glass jar containing 5 mL of derivatization solution (see 8.7). Process field and laboratory blanks in the same manner as samples.

12.1.2 Transfer the solution from the glass jar to a disposable culture tube (see 7.2.7). Rinse at least three times with about 1 mL of toluene.

12.1.3 Evaporate to dryness with a heating (50°C) vacuum evaporation (see 7.2.13).

12.1.4 Add 1 mL of redissolution solution (see 8.11) to the tube, and mix with a vortex movement. (see 7.2.14)

12.1.5 Filter the resulting solution with a polyvinylidene fluoride filter (see 7.2.10) mounted on a disposable syringe. Transfer a fraction of the standard to an injection vial (see 7.2.11).

12.1.6 Analyze sample, blank, quality control, and external standard solutions in accordance with the conditions described in 12.2. Use the same injection technique and injection volume for samples, blanks, quality controls, and external standards.

12.1.7 Calculate the HDI monomer and oligomer concentrations in the sample, as specified in Section 13.

12.2 *HPLC Conditions:*

12.2.1 Analyze by high performance liquid chromatography, using a suitable column (see 7.2.2) and the mobile phase described in 8.10. Typical conditions are as follow:

Column Temperature	Room Temperature
Flow rate:	0.6 mL/min.
Ultraviolet:	242 nm
Injection volume:	40 µL

Analytical conditions serve as a guideline and may need to be modified depending on instrumentation, column conditions, detectors, and so forth.

13. Calculation

13.1 Monomeric determination in this test method is done by using a calibration curve. The two following equations are used to obtain the concentration of the monomer in the samples.

$$M_{mono} = (A - b)/m \quad (1)$$

$$C_{mono} = M_{mono}/V \quad (2)$$

where:

A = HDI monomer peak area,
b *and* m = Y intercept and slope, respectively, obtained from the linear regression,
M_{mono} = mass of HDI monomer in sample (µg),
V = volume of air sampled (L), and
C_{mono} = concentration of HDI monomer in air (mg/m^3).

13.2 Calculate the concentration of the oligomers, using the following equation:

$$M_{mono\ eq} = \left(\sum A - b\right)/m \quad (3)$$

$$M_{NCO\ eq} = \left(M_{mono\ eq} * M_n * N\right)/M_i \quad (4)$$

$$C_{NCO\ eq} = M_{NCO\ eq}/V \quad (5)$$

where:

$\sum A$ = summation of all oligomeric peak areas,
b *and* m = Y intercept and slope, respectively, obtained from the linear regression,
$M_{mono\ eq}$ = mass of oligomer in monomer equivalent (µg),
M_n = molecular weight of NCO function,
N = numbers of isocyanate groups (functions)/molecule,
M_i = molecular weight of the isocyanate,
$M_{NCO\ eq}$ = mass of oligomer in NCO function equivalent (µg),
V = volume of air sampled (L), and
$C_{NCO\ eq}$ = concentration in air of oligomer in NCO equivalent (mg NCO/m^3).

14. Report

14.1 Report the following information:

14.1.1 For monomeric HDI: concentration of HDI in mg/m^3 obtained from Eq 2, which is added to the result of monomeric HDI obtained in the same sample by Test Method D6562.

14.1.2 For oligomeric HDI, report concentration of oligomer in mg NCO/m^3 obtained from Eq 5.

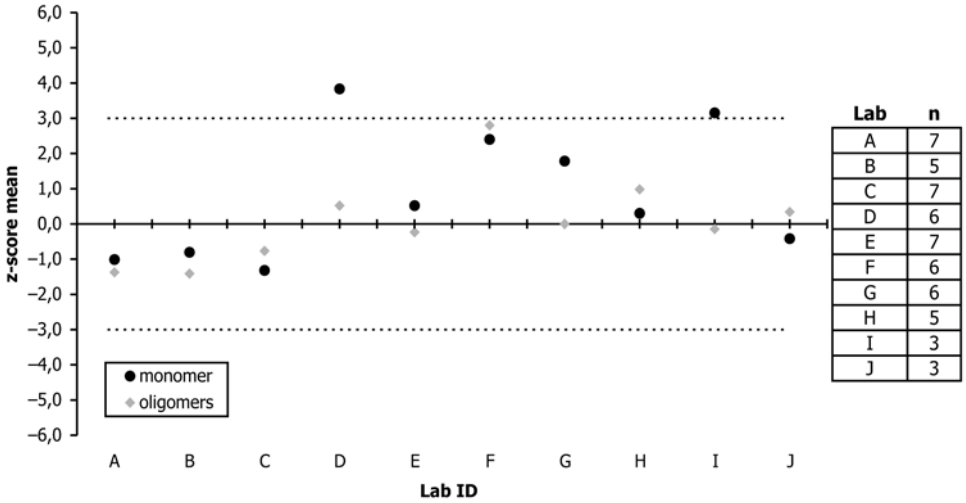

FIG. 2 Means of the Z-Scores Obtained by Ten Laboratories After n ≥ 3 Participations to an Interlaboratory Evaluation—Test Method D6561

15. Precision and Bias

15.1 *Precision:*

15.1.1 *Precision on a Complete Calibration Curve (Same Lab, Different Operators)*—To measure the relative standard deviation (RSD) and the recovery percentage, five concentration levels were tested six times. A PTFE filter was placed in the standard solution to evaluate the possibility of potentially interfering compounds being extracted from the filter, or isocyanate becoming irreversibly bound to the filter. The calibration curve was prepared covering the following range: 0.052, 0.13, 0.26, 0.52, and 1.04 µg/mL. Using a UV detector, the RSD for concentrations within the range from 0.004 to 0.070 mg/m^3 has been measured as 0.07.

15.1.2 *Recovery Percentage*—To evaluate the recovery percentage, the standard solutions and equivalent standard solutions that were in contact with the PTFE filter were analyzed. The average recovery percentage (n=24) for all four HDI concentrations is 94.3 ± 11 % for the UV detector.

15.1.3 The precision of the UV detector has been calculated from ten measurements carried out on a concentration of 0.052 mg/m^3. RSD measured 0.08.

15.1.4 *Results of an Interlaboratory Evaluation for the Monomer*—The RSD calculated from an average of seven participating laboratories over seven rounds is 0.25 (n = 58).

15.2 *Accuracy*—Fig. 2 contains the average of the z-scores of ten different laboratories that participate to an on-going interlaboratory evaluation using this test method. The evaluation is performed once a year.

16. Keywords

16.1 air monitoring; dual filter sampling system; hexamethylene diisocyanate; high-performance liquid chromatography; (methoxy-2–phenyl-1) piperazine; sampling and analysis; workplace atmospheres

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