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INVESTIGATION OF THE ABILITY OF MDHS METHOD 25 TO DETERMINE URETHANE-BOUND ISOCYANATE GROUPS

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Method 25 for the Determination of Hazardous Substances (MDHS 25) of the Health and Safety Executive of the United Kingdom attempts to identify and quantify all isocyanate species in an air sample. Isocyanate species are derivatized with 1-(2-methoxyphenyl)piperazine (MOPP) and analyzed by high-performance liquid chromatography (HPLC) with tandem ultraviolet/electrochemical (UV/EC) detection. The method identifies peaks as being isocyanate-derived if the EC/UV detector response ratio is between 0.75 and 1.5 times that of the derivatized monomer. This investigation sought to determine if the method correctly identifies and accurately quantifies intermediates created during polyurethane formation that possess free isocyanate groups. Model compounds derived from 2,4-toluene diisocyanate (2,4-TDI) and ethylene glycol were prepared. These urethane species contained two ("dimer") and three ("trimer") TDI units and terminal MOPP-derivatized isocyanate groups. Like monomeric 2,4-TDI/MOPP urea, each contained two derivatized isocyanate groups per molecule. This investigation found that neither the UV nor the EC response is proportional to the number of isocyanate groups present in the model compounds. Therefore, it is concluded that MDHS 25 is neither capable of correctly identifying TDI-urethane intermediates possessing MOPP-derivatized isocyanate groups nor is it capable of accurately quantifying these isocyanate groups. The proposed solution to this problem is the utilization of a derivatizing reagent that yields derivatized isocyanate species whose detector responses come more exclusively from the derivatized isocyanate moiety and, therefore, are more proportional to the number of derivatized isocyanate groups.

Monomeric and polymeric isocyanates are widely used in the manufacture of polyurethane plastics and coatings. Exposure to airborne monomeric isocyanates is known to cause a range of respiratory disorders in laboratory animals and humans.[1] Because respiratory disorders may develop after exposure to very low levels of isocyanate, the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit for several isocyanate monomers has been set at 5 ppb.[2,3] But workers also may be exposed to a variety of nonmonomeric isocyanates. These include prepolymers used as starting materials; urethane-bound, urea-bound, and partially hydrolyzed isocyanate species generated during polyurethane formation; as well as species generated during thermal breakdown of polyurethane. It has been observed that inhalation of aerosols of nonvolatile isocyanate species causes the same type of respiratory effects as inhalation of monomeric isocyanate vapors.[4] This observation has led the Health and Safety Executive of the United Kingdom to create a common standard encompassing all organic isocyanate species based on the number of reactive isocyanate groups (-NCO) per unit volume of air. The standard was set at 20 μg NCO m^{-3} for an 8-hour time-weighted average and 70 μg NCO m^{-3} for a 10-min time-weighted average.[4] The analytical method devised to measure compliance with this standard is Method 25 for the Determination of Hazardous Substances (MDHS 25).[5]

The majority of analytical methods for isocyanates developed over the last 15 years utilize the same basic strategy.[6,7] These methods typically involve collection of the isocyanate

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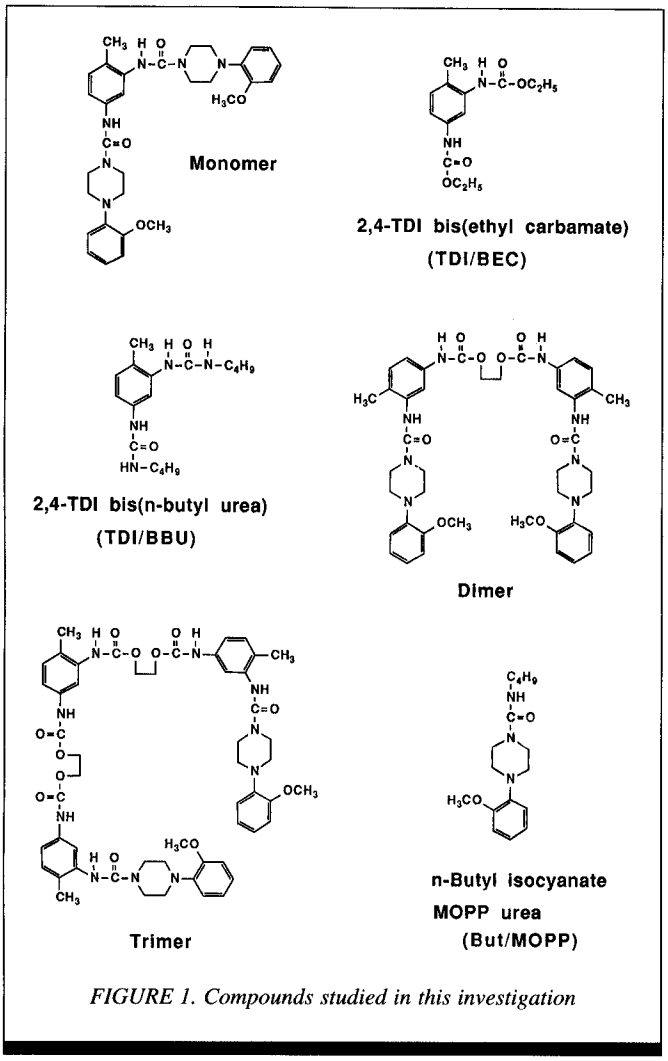

FIGURE 1. Compounds studied in this investigation

species by drawing air through a sampler (impinger, bubbler, filter, or some solid sorbent) containing an amine reagent. The reagent reacts with the isocyanate to form a stable urea derivative. A portion of the sample is injected into a high-performance liquid chromatograph (HPLC) with an ultraviolet (UV) absorbance detector. The chromatographic retention time serves as a means of identification of the urea derivative. Quantification is achieved by comparing the area of the sample peak with areas of peaks generated by injecting known quantities of the urea derivative.

These methods are suitable only for determination of isocyanate monomers. This is because they require analytical reference standards for identification and quantification, and these standards generally are available only for isocyanate monomers. Products containing prepolymeric starting materials have limited utility as reference standards. Although they can provide qualitative identification of species likely to be found in an air sample, it cannot be assumed that all species observed in these products are isocyanates, nor can quantification of these species be accomplished accurately. Obviously, no reference standards are available for even qualitative identification of nonmonomeric isocyanate species generated during polyurethane formation or breakdown.

Without analytical reference standards, chromatographic retention time cannot be used as a means of identification. For accurate total isocyanate group determination, there must be some mechanism to correctly identify a chromatographic peak as being derived from an isocyanate. The use of a highly selective detector and appropriate derivatizing reagent may accomplish this. A single nonselective detector (such as a UV detector) cannot. However, if two nonselective detectors are placed in series, the ratio of their responses for a particular compound is characteristic of that compound. Moreover, it is conceivable that structurally similar compounds will have similar detector response ratios, enabling a class of compounds to be recognized using the detector response ratio for one member of the class. Once a peak is recognized as being a member of the class, one of the two detectors is used for quantification. This is the strategy utilized in MDHS 25 for the identification and quantification of total isocyanate group. Details about the operation of NIOSH Method 5521[8] (a modification of MDHS 25), along with a description of problems encountered in the analysis of field samples from an environment where an HDI-based prepolymer was used, are given in a paper presented elsewhere in this issue.[9]

For the detector response ratio technique to work, in the strictest sense, the response of each detector must be directly proportional to the quantity of isocyanate group present. For this proportionality to be achieved, two conditions must be met. First, the total detector response for a particular compound must come from the derivatized isocyanate moiety. In other words, no other portion of the molecule can contribute to the detector response. Second, all derivatized isocyanate moieties derived from the same monomeric isocyanate must have the same detector response factor.

In practice, a detector response ratio window must be used to determine if an unknown is a derivatized isocyanate species. Even if the detector response ratios of the derivatized isocyanate species were expected to be identical to that of the derivatized monomer, a window would have to be used to account for run-to-run variability, such as slight changes in detector sensitivity over time. In reality the window also must be wide enough to account for the fact that the detector responses may not be exactly proportional to the number of derivatized isocyanate groups present. Of course, the window cannot be so wide that nonisocyanate species are identified as isocyanates.

In the present study, urethanes have been prepared that consist of two and three 2,4-TDI groups linked by ethylene glycol units and containing terminal 1-(2-methoxyphenyl)piperazine (MOPP)-derivatized isocyanate moieties. The UV absorbance of these compounds at 242 nm is compared to the absorbance of the derivatized 2,4-TDI monomer. Also, the relative responses of these compounds for UV and EC detectors in HPLC analysis are examined. The results of these investigations enable evaluation of the ability of MDHS 25 to correctly identify and quantify 2,4-TDI urethane-bound isocyanate species.

EXPERIMENTAL MATERIALS AND METHODS

The compounds studied in this investigation are shown in Figure 1.

All solvents were Burdick and Jackson HPLC grade (Baxter Healthcare Corp., Muskegon, Mich.). Butylamine (99+%), dibutyltin dilaurate (98%), ethylene glycol (99+%), 1-(2-methoxyphenyl)piperazine (98%), silica gel (high-purity grade, 70–230 mesh), and triethylamine (99%) were purchased from Aldrich (Milwaukee, Wis.). Butyl isocyanate was from Pfaltz and Bauer (Waterbury, Conn.). Tolylene 2,4-diisocyanate (2,4-TDI) was purchased from Sigma (St. Louis, Mo.). 2,4-TDI bis(ethyl carbamate) (TDI/BEC) was obtained from the Alfred Bader Library of Rare Chemicals, a division of Aldrich (Milwaukee, Wis.). The 1-(2-methoxyphenyl)piperazine urea derivative of 2,4-TDI (hereafter referred to simply as "monomer") was prepared as described in NIOSH Method 5521.[8] Procedures for the preparation of the other compounds shown in Figure 1 can be obtained by writing to the authors. These compounds include the 1-(2-methoxyphenyl)piperazine urea of n-butyl isocyanate (But/MOPP), 2,4-TDI bis(n-butyl urea) (TDI/BBU), the 1-(2-methoxyphenyl)piperazine urea of 2,4-TDI/ethylene glycol urethane dimer (referred to hereafter simply as "dimer"), and the 1-(2-methoxyphenyl)piperazine urea of 2,4-TDI/ethylene glycol urethane trimer (referred to hereafter simply as "trimer").

Mass spectrometry was utilized to verify the identity of synthesized products described above. A VG MicroMass 7070HS mass spectrometer with a VG model 11–250J data system (VG Analytical, Ltd, Manchester, UK) was used for the analyses. Two different ionization techniques were employed depending on the nature of the compound. Compounds of relatively low molecular weight were analyzed by desorption probe.[10] High molecular weight compounds were analyzed by field desorption.[11]

Combustion analyses for determination of elemental composition were performed by M-H-W Laboratories (Phoenix, Ariz.).

UV Analyses

The UV analyses were performed on a Hewlett-Packard Model 8452A Diode Array Spectrophotometer (Hewlett-Packard, Avondale, Pa.). The solvent used in the analyses was the HPLC mobile phase (see "HPLC Analyses"). Stock solutions were prepared at 1×10^{-3} moles/liter (M) in methanol. Aliquots of these stocks were spiked into flasks containing mobile phase to give solutions of 1×10^{-5} M and 2×10^{-5} M for But/MOPP and 5×10^{-6} M and 1×10^{-5} M for TDI/BEC, TDI/BBU, monomer, dimer, and trimer. These solutions were analyzed in a quartz cuvette over the wavelength range 190–820 nm. Integration time was set at 25 sec.

HPLC Analyses

The HPLC system utilized two Waters Model M-6000A pumps and a Waters WISP 710B autosampler (Millipore, Milford, Mass.). The analytical column was a Supelco LC-8-DB (amine-deactivated octyldimethylsilyl), 150 × 4.6 mm, 5-μm particle size (Supelco, Bellefonte, Pa.). Detection was accomplished by an ABI Analytical Spectroflow 783 Programmable Absorbance Detector/Gradient Controller (Applied Biosystems, Foster City, Calif.) connected in series to an ESA Coulochem Model 5100A Electrochemical Detector with a Model 5010 analytical cell (ESA, Bedford, Mass.).

The mobile phase was 60% buffer (0.1 M sodium acetate/acetic acid in 1:1 methanol:water, pH 6)/40% acetonitrile,[8] isocratic, run at a flow rate of 1 mL/min. The UV detector was set at a wavelength of 242 nm and a sensitivity of 0.05 absorbance units full scale (AUFS). The analytical electrochemical cell and the guard cell were set at +0.8 V and +0.75 V, respectively.

Separate standard solutions of TDI/BEC, monomer, dimer, and trimer were prepared at a concentration of 1×10^{-5} M in methanol. Each analysis involved injection of 10 μL of one of these solutions. The analysis of each of the four compounds a single time comprised a set. Each set was followed by running a methanol blank. A total of 16 sets were run. The order of the analyses within each set was randomized.

RESULTS AND DISCUSSION

Synthesized Standards

Based on HPLC analyses, the standards of both the dimer and the trimer used in this work are composed of two compounds. The minor component makes up approximately 9% and 17% of the dimer and trimer standards, respectively. Although having a standard composed of a single compound is more desirable, every piece of information is consistent with the notion that the minor components are simply structural isomers of the major components. These pieces of information include combustion analyses, field desorption mass spectra, and very similar chromatographic retention times (both normal-phase and reversed-phase liquid chromatography). The observed EC/UV detector response ratio determined for the minor component of the trimer is nearly identical to that of the major component. Although the EC/UV ratio determined for the minor component of the dimer is somewhat different from that of the major component, this is not viewed as compelling evidence that the minor component is not an isomer. The difference could easily be explained by the difficulty of determining an accurate detector response ratio for the minor component of two substantially merged peaks. It also should be pointed out that structural isomers were expected to be minor products in the syntheses. There are three possible structural isomers of the dimer and four of the trimer. The structures shown in Figure 1 represent the isomers that are expected to be the major components. The presence of small amounts of structural isomers in these standards should have had minimal influence on the results of this study.

Examination of UV Absorbance

The monomer, dimer, and trimer each possess two terminal MOPP-derivatized isocyanate groups. For accurate quantification of these compounds by means of MDHS 25, it must be assumed that they give the same molar electrochemical response. If so, the UV responses (at 242 nm) of the dimer and trimer must be within 33% of the UV response of the monomer for MDHS 25 to recognize them as derivatized isocyanate species. This is based on an EC/UV ratio window of 0.75–1.5 times the EC/UV ratio of the

TABLE I. UV Spectrophotometer Absorbance Data

Compound	Absorbance[A] 5.0 μM	10.0 μM	20.0 μM	Molar Absorptivity (thousands)[B]
But/MOPP	—	0.077	0.157	7.83 ± 0.05
TDI/BEC	0.093	0.183	—	18.34 ± 0.11
TDI/BBU	0.123	0.240	—	24.14 ±0.27
Monomer	0.220	0.435	—	43.57 ± 0.16
Dimer	0.294	0.581	—	58.26 ± 0.23
Trimer	0.417	0.825	—	82.64 ± 0.33

[A] Absorbance at 242 nm

[B] Slope of least-squares regression line ± standard error of slope

monomer. The relative UV responses can be predicted by measuring the molar absorptivities of the three compounds at 242 nm.

The absorbance at 242 nm for the six test compounds at two concentration levels along with their molar absorptivities are shown in Table I. Molar absorptivities were calculated as the slope of the plot of spectrophotometer response vs. concentration. Based on the molar absorptivities shown in Table I, the dimer and trimer give 34% and 90% greater UV response, respectively, than the monomer. This means that neither the dimer nor the trimer would be recognized as derivatized isocyanate species based on their EC/UV ratios, assuming they give EC detector responses equivalent to that of the monomer. The trimer would fall well outside of the window.

The significance of these findings depends on the extent to which they are indicative of a more general problem with MDHS 25. In other words, are the UV responses of these model compounds exceptions to a rule that is generally followed, or are other TDI urethane oligomers and prepolymers likely to exhibit similar excesses in UV response? If the excess exhibited by the model compounds is predictable, then the extent to which other TDI-derived species exhibit this excess might also be predicted reasonably well based on their structures. The UV response of a particular species will be quite predictable if it is essentially the sum of the UV responses of the individual isolated chromophores that comprise that species. In the case of TDI urethane oligomers possessing MOPP-derivatized terminal isocyanate groups, the UV response at 242 nm is expected to be very nearly the sum of the responses of the TDI phenyl ring and the MOPP phenyl ring.

To test the hypothesis that the UV response is additive, three compounds were chosen to represent the chromophores that comprise the MOPP-derivatized urethane oligomers. The MOPP urea of n-butyl isocyanate (But/MOPP) was chosen to represent the MOPP phenyl ring chromophore. The bis(ethyl carbamate) of 2,4-TDI (TDI/BEC) and the bis(n-butyl urea) of 2,4-TDI (TDI/BBU) were chosen to represent the urethane-bound and urea-bound TDI phenyl ring chromophores, respectively. Table II shows the six compounds examined along with the component chromophores by which they are represented in the model. Note that both the dimer and trimer actually possess two TDI rings that are half urethane-bound and half urea-bound. The dimer and trimer are treated by the model as if they each possessed one urethane-bound TDI phenyl ring and one urea-bound TDI phenyl ring. Summation of the molar absorptivities of the component chromophores generates predicted molar absorptivities of the monomer, dimer, and trimer. The validity of the model is indicated by the extent to which the predicted values agree with the observed values. The average difference between the predicted and observed values is only 5.4%.

The success of the model clearly demonstrates that the UV absorbances of the monomer, dimer, and trimer can be viewed as simply the sum of the absorbances of their constituent chromophores. It also indicates that the molar absorptivities of the constituents do not vary substantially from compound to compound. Therefore, it is possible to determine the portion of UV absorbance attributable to the TDI phenyl rings and the portion attributable to the MOPP phenyl rings. In the monomer, only about 39% of the UV absorbance at 242 nm is attributable to the MOPP-derivatized isocyanate groups. Assuming the EC response is directly proportional to the number of MOPP-derivatized isocyanate groups, only compounds that possess two MOPP-derivatized isocyanate groups per TDI unit (like the monomer) can be expected to have the same EC/UV ratio as the monomer. All compounds that are formed from TDI molecules by reaction of a portion of the available isocyanate groups (e.g., urethane oligomers and prepolymers) will necessarily possess fewer than two isocyanate groups per TDI unit. Such compounds are not expected to be accurately recognized as derivatized isocyanate species based on comparison of their EC/UV ratios with that of the monomer.

Examination of HPLC/UV/EC Analyses

The UV and EC detector response data for the monomer, dimer, trimer, and TDI/BEC are shown in Table III. As in the

TABLE II. Comparison of the Observed Molar Absorptivities of the Monomer, Dimer, and Trimer with the Values Predicted by Summing the Molar Absorptivities of their Constituent Chromophores

Compound	Number of Constituent Chromophores: MOPP	TDI urethane	TDI urea	Molar absorptivity: Observed (O) (thousands)[A]	Predict. (P) (thousands)	(O-P)/O × 100
But/MOPP	1	0	0	7.83		
TDI/BEC	0	1	0	18.34		
TDI/BBU	0	0	1	24.14		
Monomer	2	0	1	43.57	39.81	8.6%
Dimer	2	1	1	58.26	58.16	0.2%
Trimer	2	2	1	82.64	76.50	7.4%

[A] Data from Table I

TABLE III. UV and EC HPLC Detector Response Data[A]

Compound	UV Detector (thousands)[B]	EC Detector (thousands)[C]	EC/UV Detector Ratio
TDI/BEC	17.6 ± 1.4	14.5 ± 3.0	0.80 ± 0.10
Monomer	36.5 ± 3.1	95.2 ± 10.1	2.59 ± 0.06
Dimer	46.2 ± 3.2	112.8 ± 9.1	2.44 ± 0.04
Trimer	57.8 ± 4.5	141.1 ± 12.8	2.44 ± 0.05

[A] All values are averages of 16 runs ± 95% confidence intervals
[B] Arbitrary detector response units; UV detector set at 242 nm
[C] Arbitrary detector response units; EC detector set at 0.80 volts

UV spectrophotometer results, the UV detector response increases from monomer to dimer to trimer. This increase would be expected to cause the EC/UV ratios of the dimer and trimer to deviate substantially from that of the monomer. But this is not observed. The EC/UV ratios of the dimer and trimer are very nearly the same as that of the monomer. This is because the EC detector response also increases from monomer to dimer to trimer, at roughly the same rate as the increase in UV response. This increase is not likely to be as predictable as the increase in UV response. But it is consistent with the fact that TDI/BEC, which is structurally similar to the urethane backbone of the dimer and trimer, exhibits a significant EC response. As a result of the UV and EC responses increasing at roughly the same rate, both the dimer and trimer are fortuitously identified by MDHS 25 as species containing derivatized isocyanate groups. But because the EC response is not proportional to the number of derivatized isocyanate groups, quantification based on the EC response overestimates the amount of derivatized isocyanate group in the dimer and trimer. It would appear inevitable that isocyanate species possessing an "excess" of UV-absorbing groups will be either not identified as isocyanates by MDHS 25 or, if identified, not correctly quantified.

Although the UV detector response increases from monomer to dimer to trimer, it does not appear to increase at as great a rate as the UV spectrophotometer response. This observation is based on the ratio of responses of the dimer and trimer to the response of the monomer, as shown in Table IV. Whereas the UV spectrophotometer trimer/monomer ratio is 1.90, the corresponding UV detector ratio is only 1.58. The difference is somewhat less in the case of the dimer, and is actually reversed in the case of TDI/BEC. It is likely that the differences in responses of the diode array spectrophotometer and the variable-wavelength UV detector are due, at least in part, to differences in optical characteristics, such as bandwidth.

Comparison with Another Evaluation of MDHS 25

In their evaluation of MDHS 25, Bagon et al.[12] investigated prepolymers of HDI, MDI, and TDI. The isocyanate group content of these products was established by titration. Known amounts of each product were derivatized with MOPP and analyzed by HPLC/UV/EC. Summation of the EC responses of all the peaks in the chromatogram having the appropriate EC/UV ratios enabled an estimation of the recovery.

MDHS 25 would be expected to perform relatively well when dealing with the HDI and MDI prepolymers, at least with respect to the problem of excess UV absorbance. The HDI prepolymers, being aliphatic, contain no chromophore to compete with the MOPP group. Therefore, it is expected that the UV response of these derivatized prepolymers would be directly proportional to the number of derivatized isocyanate groups. The average EC/UV ratio of the HDI prepolymer peaks was found by Bagon et al. to be 1.29 times that of the monomer. This may indicate an EC contribution in the prepolymer molecules from a source other than the methoxyphenyl group of MOPP. The average recovery found for the HDI prepolymer samples was 99%.

The MDI prepolymers examined by Bagon et al. are aromatic but, like the MDI monomer, all possess one isocyanate group per MDI phenyl ring. Therefore, even if the MDI phenyl ring is responsible for a large portion of the UV absorbance, the UV response per isocyanate group in the MDI prepolymers is expected to be nearly the same as in the monomer. The EC/UV ratio of the only nonmonomeric MDI peak observed by Bagon et al. was 1.07 times that of the monomer. This means that the MOPP groups are likely to be the only contributors to the observed EC response. The average recovery found for the MDI prepolymer samples was 94%.

The TDI prepolymer used in their evaluation was Desmodur L. Based on the idealized structure of Desmodur L given by Purnell and Walker,[6] components of this prepolymer are expected typically to possess one isocyanate group per TDI unit. Since the TDI monomer possesses two isocyanate groups per TDI unit, the prepolymer would have a relative excess UV absorbance per isocyanate group. This excess would be expected to be similar to that observed in the urethane dimer used in the present study. But the reported EC/UV ratios for the components are actually slightly greater than that of the monomer. It is likely that the EC response per isocyanate group was elevated as in the current authors' dimer, resulting in an EC/UV ratio close to that of the monomer. This would result in a quantification by EC that is too high, i.e., a recovery greater than 100%. The average recovery found for the TDI prepolymer samples was 127%, with a median recovery of 119%. By comparison, the EC response of the

TABLE IV. Ratios of UV and EC Responses of the Test Compounds to those of the Monomer

Compound	UV Spectrophotometer[A]	UV Detector[B]	EC Detector[C]	EC/UV Detector Ratio
TDI/BEC	0.42	0.48	0.15	0.31
Dimer	1.34	1.26	1.19	0.94
Trimer	1.90	1.58	1.48	0.94

[A] Absorbance at 242 nm
[B] UV detector set at 242 nm
[C] EC detector set at 0.80 volts

urethane dimer in the present study was also 119% of that expected based on the number of MOPP-derivatized isocyanate groups present.

Use of Dual Detectors in Total Isocyanate Determination

The use of the detector response ratio technique to identify isocyanates for which analytical standards are not available is a very sound approach. Its introduction into the field of isocyanate analysis in MDHS 25 was clearly an advancement that enabled pursuit of total isocyanate determination. The primary weakness of MDHS 25 is that too small a portion of the detector response for some derivatized isocyanate species is attributable to the MOPP-derivatized isocyanate group. The authors' laboratory is currently investigating derivatizing reagents that yield derivatized isocyanate species whose detector responses are more proportional to the number of derivatized isocyanate groups. Based on results reported by Wu et al.,[13] the use of tryptamine as a derivatizing reagent and fluorescence/electrochemical dual detection would appear to be an advance in the accurate identification and quantification of isocyanate species for which no standards are available. The fluorescence and electrochemical detectors are of similar sensitivities, and the detector responses for a range of derivatized isocyanate species are nearly proportional to the number of derivatized isocyanate groups.

CONCLUSIONS

It has been shown in this study that the UV responses of 2,4-TDI/ethylene glycol urethane oligomers possessing terminal MOPP-derivatized isocyanate groups are readily predicted by summation of the UV responses of their constituent chromophores. Because the UV responses proved to be additive, it could be determined that the MOPP-derivatized isocyanate moiety contributes only a small portion of the total UV response of these species. As a result, the UV response is not directly proportional to the number of derivatized isocyanate groups present. This means that the EC/UV response ratios for these species cannot be expected to be similar to that of the MOPP-derivatized TDI monomer and, therefore, cannot be used with confidence to identify these species as derivatized isocyanates.

This study also found that the EC detector responses for these urethane-bound isocyanates are not proportional to the number of derivatized isocyanate groups. Therefore, quantification of such species using EC detector response is not expected to be accurate.

In the particular case of these model compounds, the responses per derivatized isocyanate group for both the UV and EC detectors increased at nearly the same rate in going from monomer to dimer to trimer. Therefore, the EC/UV ratio is nearly the same for the three compounds, and they were recognized fortuitously by MDHS 25 as derivatized isocyanates. However, quantification of the dimer and trimer based on the EC response of the monomer is biased high. It would appear inevitable that excess UV response exhibited by derivatized oligomeric isocyanate species will result in either incorrect identification or inaccurate quantification.

REFERENCES

1. **Musk, A.W., J.M. Peters, and D.H. Wegman:** Isocyanates and respiratory disease: current status. *Am. J. Ind. Med. 13*:331–349 (1988).
2. **National Institute for Occupational Safety and Health (NIOSH):** *Criteria for a Recommended Standard: Occupational Exposure to Diisocyanates.* [DHEW (NIOSH) Publication No. 78–215] Cincinnati, Ohio: NIOSH, 1978.
3. **National Institute for Occupational Safety and Health (NIOSH):** *Recommendations for Occupational Safety and Health: Compendium of Policy Documents and Statements.* [DHHS (NIOSH) Publication No. 92–100] Cincinnati, Ohio: NIOSH, 1992.
4. **Silk, S.J. and H.L. Hardy:** Control limits for isocyanates. *Ann. Occup. Hyg. 27(4)*:333–339 (1983).
5. **Health and Safety Executive:** *MDHS 25, Methods for the Determination of Hazardous Substances: Organic Isocyanates in Air.* London: Health and Safety Executive/Occupational Safety and Hygiene Laboratory, 1987.
6. **Purnell, C.J. and R.F. Walker:** Methods for the determination of atmospheric organic isocyanates: a review. *Analyst 110*:893–905 (1985).
7. **Dharmarajan, V., R.D. Lingg, K.S. Booth, and D.R. Hackathorn:** Recent developments in the sampling and analysis of isocyanates in air. In *Sampling and Calibration for Atmospheric Measurements*, edited by J.K. Taylor. [ASTM Special Technical Publication No. 957] Philadelphia: American Society for Testing and Materials, 1987. pp. 190–202.
8. **National Institute for Occupational Safety and Health (NIOSH):** Method 5521: Isocyanates. In *NIOSH Manual of Analytical Methods*, 3rd ed, vol. 2, edited by P.M. Eller. [DHHS (NIOSH) Publication No. 84–100] Cincinnati, Ohio: NIOSH, 1989.
9. **Key-Schwartz, R.J.:** Analytical problems encountered with NIOSH Method 5521 for total isocyanates. *Am. Ind. Hyg. Assoc. J. 56*:474–479 (1995).
10. **Baldwin, M.A. and F.W. McLafferty:** Direct chemical ionization of relatively involatile samples. Application to underivatized oligopeptides. *Org. Mass Spectrom. 7*:1353–1356 (1973).
11. **Prókai, L.:** *Field Desorption Mass Spectrometry.* New York: Marcel Dekker, 1990. Chap. 2.
12. **Bagon, D.A., C.J. Warwick, and R.H. Brown:** Evaluation of total isocyanate-in-air method using 1-(2-methoxyphenyl)piperazine and HPLC. *Am. Ind. Hyg. Assoc. J. 45*:39–43 (1984).
13. **Wu, W.S., R.E. Stoyanoff, R.S. Szklar, and V.S. Gaind:** Application of tryptamine as a derivatizing agent for the determination of airborne isocyanates: part 3. Evaluation of total isocyanates analysis by high-performance liquid chromatography with fluorescence and amperometric detection. *Analyst 115*:801–807 (1990).